MINE EMERGENCY PREPAREDNESS

System to Assist Self-Escape

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INTRODUCTION:

Underground coal mining accounts for some 65% of world hard coal production has made a major contribution to the economic development of every country in which mining has taken place. However, there has been a significant associated cost in terms of mining accidents, social problems and high mortality rates.

The largest proportion of fatalities underground has historically been attributed to falls of ground although through recent advances in technology of roof control have enabled dramatic improvements in this area.

Underground fires and explosions of firedamp and coal dust represent the other major hazards and associated incidents continue to generate anxieties in both mine workers and the public at large.

In some cases there is evidence of adverse trends in ignitions and explosions although their severity is much reduced due to improved environmental and monitoring standards.

RECENT INCIDENTS IN UNDERGROUND COAL MINES

YEAR	NAME OF MINE	INCIDENT	NO. OF FATALITIES
1992	Westray, Canada	Explosion	26
1992	South Mountain No. 3, USA	Explosion	8
1993	Bilsthorpe, UK	Fall	3
1993	Middelbuit, SA	Explosion	53
1994	Moura No. 2, Australia	Explosion	11
1994	Koornfontein, SA	Fire	16
1998	Skochinsky, Ukraine	Explosion	63
1999		Explosion	

"In the critical minutes following an incident, the safety of the underground workers is largely influenced by their own actions."

To maximise post-disaster survival there must be effective systems of self-escape, primarily involving irrespirable atmosphere life support, supported by an effective programme of training and incident rehearsal.

The subject of self-escape should be examined from all perspectives.

Serious fire incidence rates have reduced substantially as more effective mine inspection and monitoring systems have been introduced. Since major incidents now have a relatively low frequency this raises questions over the response capability of individuals in a serious incident. Identifying these questions towards mine emergency preparedness strategy and training needs including the following.

- Is it possible to provide effective training to respond to emergencies?
- Must the training be hands on instruction possibly supported by mobilisation exercise or realistic simulation?
- Is it practicable to provide training, which emulates the stresses and breathing limitations of using self-contained self-rescuers in an emergency evacuation situation?
- Is the current standard of evacuation training given to workers to precondition them for a real escape actually effective?

- Can this type of training really simulate the effects of airways choked with potentially lethal combustion products?
- Are the systems to assist self-escape appropriate and will they actually be used?

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These questions of worker self-escape response in emergency situations are not straightforward. One overriding fact is that the probability of survival after a major incident is influenced greatly by the delivery of relevant and repeated training particularly if this is delivered in a realistic setting.

The Inquiry into the 1994 accident at Moura No. 2 Colliery included in its findings that mine escape and rescue options for persons in underground coal mines were in need of review.

Several task groups representing various industry stakeholders were subsequently assembled. Task Group No. 4 was allotted the task of developing guidelines in response to Recommendations 9 and 10 of the Wardens Report.

These recommendations were as follows:

Recommendation 9

".... It is recommended that a representative industry working party, containing appropriate expertise, be convened by the Chief Inspector of Coal Mines and that group be charged with the development of guidelines for the Industry covering life support for escape."

Recommendation 10

"…. It is recommended that the Chief Inspector of Coal Mines set up a working party, comprising persons with appropriate knowledge and experience, to examine and report on a range of issues relating to emergency escape facilities.

The group should investigate means whereby persons in any part of a mine, who are subject to disorientation or severe visibility, are able to find their way out of the mine. Consideration should also be given by the group to the potential role for motorised transport in emergency escape arrangements."

The specific objectives for Task Group No. 4 were:

- To recommend guidelines to the Chief Inspector of Coal Mines (QLD) on self rescue escape.
- To present a report to the Chief Inspector of Coal Mines (QLD) addressing issues identified in Recommendations 9 and 10 of the Moura No. 2 Warden's Report.

With regard to existing practice it was determined that:

- *"for persons underground at the time of a major incident escape options are limited and there is no consistent strategy in place for rescue of mineworkers across the industry."*

- *"filter self rescuers have a limited application in mine emergencies."*

- *"knowledge of conditions underground after an incident is insufficient for accurate assessment of the mine environment."*

The diversity of mine configurations and potential emergency scenarios led the Task Group to conclude that:

- The primary need is to enhance the capabilities of underground persons to effect their own rescue – **"self escape"**. This is to be achieved by the provision of facilities in mines, training of mineworkers, and management and development of generic and mine specific escape strategies.

After analysing the current situation and options to improve practices in various aspects of self-escape recommendations and guide quite specific, whilst others require more investigation, and industry input before specific recommendations could be made. The major conclusions and recommendations of the Task Group are summarised as follows:

- Provision of new escape and rescue systems will be of limited value unless the people in danger or participating in rescue can make the appropriate decisions when confronted with an emergency situation. Planning, preparation and training for such emergencies is essential to improving their chances of survival.

- Every underground mine should develop a Self Escape Management Plan as part of a Safety Management Plan to provide all persons underground with capability to reach a place of safety, recognising the difficult environmental conditions following an incident. Training initiatives in the form of new generic training resources and training guidelines should be developed to support the use of these plans.

Escape routes, alternative routes and facilities are to be planned, developed and equipped as part of Self Escape Management Plans. An oxygen-based escape system is required with the following attributes:

- All persons to wear self contained self rescuers
- Replacement SCSR caches are to be provided at suitably located changeover stations
- Use of refuge chambers where appropriate
- Provision of communication capabilities post incident

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Specific recommendations aimed at improving capabilities in these areas have been made. These recommendations promoted the Task Group's proposed vision for response to incidents at mines in the future:

> *All persons underground at the time of an incident shall be trained, equipped and able to make an escape to the surface, or place of safety, if physically capable. Monitoring, communications systems and other new rescue technology will provide surface personnel with capability to safely deploy aided rescue measures to rescue those unable to self-escape.*

The issue of providing realistic training with self-contained self-rescuers (SCSR) is noted. Most mine operators regard the opening up and activation of SCSR's to provide realistic exposure to these devices as being prohibitively expensive. This is compounded if a realistic environment is required involving the use of smoke heat and humidity.

There are different models developed of mine escape in order to estimate survival odds under certain conditions (US Bureau of Mines, Kovak and others 1990). One important aspect is the use of measurement data from donning trials. The profiles of donning proficiency in a five level classification (failing, poor, marginal, adequate and perfect).

During evaluation test at several minesites a large variance between the mines was identified where around 30 per cent of subjects failed critical steps, i.e. those necessary to isolate their lungs from the environment.

Technologies and systems to enhance self-escape from mines are with one or more of the following:

- **Basic respiratory protection systems**
  - Self rescuers (belt worn)
  - Refuge emergency bases
  - Self rescuers (long duration)

- **Robust communication systems**
  - Emergency notification
  - Request for help
  - Location and status of workers
  - To give direction and guidance

- **The availability of effective guidance systems**
  - Overcome problems of disorientation
  - Low visibility
  - Guidance to a place of safety

- **Availability of transport systems**
  - To exit the mine
  - To refuge/emergency bases (more expeditiously)

Basic respiratory protection systems

During the 1900-nineteen hundreds, fire and explosions have resulted in a number of fatalities mainly due to asphyxiation or poisoning by toxic gases. In the past 10 years strategies have been developed to prevent those who survive an initial incident from succumbing to the environmental conditions created.

The mining regulations of many countries set out a clear legal requirement for effective systems of self rescue (escape) from mines in the event of an emergency. The regulations consider the requirements for appropriate self-rescue apparatus.

Self-Rescuers:

Filter Self Rescuers:

The filter self-rescuer's basic function is to protect the wearer, from the effects of carbon monoxide. It is a once only use device, which serves the purpose of basic respiratory protection should a situation arise where the main toxic gas is carbon monoxide. It is however less able to sustain life as the oxygen content of the atmosphere reduces, and its effectiveness is decreased by the presence of atmospheric moisture.

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Nevertheless filter self-rescuers have given many years of reliable service to the mining industry worldwide and are generally well understood and trusted by the workforce. There are a number of filter self-rescuers available, all function on the same basic principles although the designed duration of protection varies.

Self Contained Self Rescuers:

In the past five years self-contained self-rescuers SCSR's have been introduced into underground coal mines in rapidly increasing numbers.

There are generally two types available: chemical oxygen and compressed oxygen.

While some countries grant their own approvals in accordance with domestic legislation, there are three major approval standards that embrace requirements for SCSR's

- EN401 – Specifically designed for SCSR's in Europe and features both laboratory and practical performance testing
- MSHA/NIOSH U.S.A. This testing based around man wearing tests with some bench testing
- GME South African Government Mining Engineer Approval

SCSR's units are typically rated from 30, 45, 60, or 90 minutes, the time being determined according to the length of time that the unit supplies adequate breathing air to the wearer during a prescribed requirement of physical activity.

The selection of self-rescuers should take into account advantages and disadvantages, some of those being:-

- Preference for apparatus that has a self-starting mechanism for an initial supply of oxygen.
- Weight
- Ease of donning
- Level of protection (duration, quality of oxygen supplied)

- Size and ergonomics
- Availability of training models
- Robustness of the case (etc)

There has been extensive testing of different manufacturers SCSR's under a variety of controlled conditions in order that duration and reliability can be confirmed.

Tests carried out on some units, which achieved 60 minutes nominal duration approval with NIOSH achieved only 40-50 minutes nominal duration approval when tested to EN401 standards.

This also happened during man-wearing tests carried out utilising volunteers in a number of underground conditions with different SCSR's all approved under BSEN401. Some individuals wearing a 30 minute nominal duration SCSR under relatively good conditions were provided with as little as 17 minutes protection. Others were able to obtain oxygen for as long as 45 minutes.

This is an important consideration for cache station change over procedures. Two different procedures are taught:

1. **On reaching a changeover station, the SCSR is to be immediately changed for a fresh unit, regardless of how long it has been worn.**
2. **Alternately, the unit being worn should be left on, while carrying the fresh unit, until it starts to run out of oxygen.**

The second technique appears to have certain defects.

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Most studies highlight the extreme range of respiratory characteristics of individuals and this should be taken into consideration when a particular SCSR is being considered for a particular escape scenario.

Effect of personnal related factors on duration of chemical oxygen self-rescuers are within the following:-

- Body mass index - an indicator of fat levels – most important factor that influences oxygen consumption.
- Age – mechanical disadvantage for older workers.
- Fitness – fitter people require less oxygen.
- Anxiety – an anxious person will have an increased pulse rate and rapid shallow breathing
- Heat and humidity – people who work in hot and humid atmospheres will experience an increase in pulse rate, but noting that acclimatisation is a factor.

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Research has found that based on current industry profile (weight, age, fitness) 95% would achieve 60% of the rated duration of the SCSR.

As a general rule all SCSRs place increased levels of stress on wearers. Regular and realistic training is essential to ensure that all wearers are familiar with the apparatus, its donning procedures and breathing resistance in order that the maximum benefit is obtained from the SCSR in terms of duration during emergencies. Again it is important to note that training SCSRs are not true replicants of the live units. Startup feels different, there is no taste in the trainers, breathing resistance varies, etc.

In addition to those SCSR's that are of adequate size and weight to be carried comfortably whilst working, there are available larger, longer duration SCSR's.

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For these systems a nominal life span of 90 minutes is available, and the chemical oxygen unit is the most common form of long duration SCSRs.

Cache strategies:

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One of the central aspects to the development of an effective escape strategy is to have a well conceived basis for determining the achievable travelling distances for each SCSR to be used at the mine. Some factors to consider include:

- Mine conditions that may be encountered, gradients, road surface, obstructions, etc

- Mine site trial to determine realistic travelling distances and cache spacing
- Fitness capability of workers.
- Reassessing and updating as the mine situation changes.
- ***Plan for the worst case.***

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Research and experience has found that: -

- In good conditions (good visibility and being able to travel standing upright) the following applies: -
  - 60 min SCSR on average person can travel 2.5 km.
  - 30 min SCSR on average person can travel 1.25 km.
- Poor visibility reduces travel distances by 60% of that travelled in good visibility.

In poor conditions 95% will achieve 1 km with a 60 min SCSR and 500 m. with a 30 minute SCSR

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The first cached SCSR units should be located within the distance achievable by 95% of the workforce using belt worn apparatus.

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Open Circuit Compressed Air:

Open Circuit Compressed Air Breathing Apparatus (OCCABA) supplies air to the wearer from a cylinder of compressed air. The exhaled air escapes through an exhalation valve in a facemask to the external atmosphere.

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While having a number of obvious advantages including cool breathing air, low resistance to breathing and full face mask, CABA has the considerable disadvantages of being heavy, of relatively short duration and a high maintenance and testing requirement. These units under live man testing have also shown a wide variation of duration.

<u>Refuge/Emergency bases:</u>

The concept of refuge/emergency bases is widely accepted, particularly in metalliferous and other mines. There use in coal mines is becoming more common. The ideal site is one having a borehole to surface through which air, water and food can be passed to the mineworkers inside. However drilling boreholes to considerable depth may preclude this option.

An early type of refuge was the result of mineworkers barricading themselves in a development heading and opening the compressed air supply. There are numerous other similar and successful examples of survival this way, even when compressed air was not available. This underlines the importance of basic awareness training for mineworkers in understanding the science of mine gases, so they are able to assess the effects of irrespirable atmospheres and to implement counter measures to the danger.

When considering mine emergency preparedness and response requirements it is imperative that due consideration is given to those factors that could severely affect an individual's ability to find a way to a place of safety out of the mine or even out of a working district (section). When wearing a self-rescuer of any type, reduced physical performance should be anticipated and the ultimate distance covered may well be a function of the physiology and psychology of the wearer rather than the performance of the self-rescuer.

In those mines where there are long distances to a place of safety a self escape plan should not be based solely on the use of self rescuers and consideration should be given to the introduction of refuge/emergency bases.

Refuge stations have been part of the underground mining scene for many years particularly in non-coal mines; there are two main types in use with varying designs and capacities - permanent and moveable.

<u>Permanent refuges</u>

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Permanent types are normally large in design and of substantial construction. Such systems are normally installed in larger minesites in main roadways. Refuge stations of this type are normally an emergency assembly point for the workers but they also have other uses., (eg lunchroom (crib), first aid centre, communications, (phone, radio, computer), and change over base for self-rescuers)

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Moveable Refuge/Emergency Bases:

The design of moveable refuge/emergency bases must be practical to suit rapidly moving workplaces, yet must retain the basic elements necessary to sustain life for significant periods of time following a fire or explosion. These moveable emergency bases can also be used to enable mineworkers to exchange SCSR's before continuing outbye to a place of safety or waiting to be rescued whilst wearing SCSR's.

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Moveable Emergency base should be compact in design with capability of:

- Oxygen generation
- Carbon dioxide (CO^2) removal
- Climate control (humidity and moisture removal)
- Communication systems
- First aid
- Self sufficient power supply
- Potable water
- Chemical toilet
- Mobile and can be relocated easily

One system has been tested by the manufacturers at outside temperatures of 25^{o}c and 40^{o}c.

During the test the internal temperature of the system when occupied by 12 workers for a period of 24 hours never exceed 30^{o}c and relative humidity remained below 70%. The system maintained a positive pressure to prevent ingress of toxic gases.

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Robust communications systems

The requirements placed on post-emergency communications support technology, are severe and pose a number of fundamental questions:

- What form of communications will survive an explosion, fire, ground fall on inundation, where there are likely to be intermittent breaks in cables, and yet offer a range sufficient to bridge fire zones, areas of ground falls and better still offer a range of several kilometres?
- How will local conditions affect the function and scope for deploying emergency communications technology?
- Can the equipment be designed such that no action or minimum action is required to activate and deploy the system?
- Can the equipment be designed to communicate through the strata or through the overburden?
- Is it possible to reliably broadcast a mine-wide emergency warning?
- Can an independent communications system be deployed which functions in underground environments, offers a range of kilometres and does not rely on existing communications or cable infrastructure in the mine if this is damaged?

In the event of an emergency, workers will need to be notified, management and rescuers will need to know how many workers are in danger, where they are located and how extensive is the emergency and associated damages.

Communication is vital.

A number of past incidents have highlighted the lack of robustness of telephones in emergency situations; unprotected telephone communication cables have been destroyed. This potential for unprotected cables surviving damage, can be improved by strategic positioning and protection of cables during installation.

Mechanically robust intrinsically safe telephone designs are now widely available but the question of cable integrity remains an issue. The increased use of leaky feeder communications in mines is providing an additional flexible means of communication and rugged intrinsically safe handsets of substantial construction suitable for the underground environment are also available. By having two independent systems contributes to a higher level of communications integrity and availability during a mine emergency. However, there are recorded incidents in every country where major disasters have led to the failure of conventional communications systems.

In view of these and other limitations, work has been undertaken in a number of countries to develop and examine the application of high integrity communications systems designed specifically to meet a number of severe incident scenarios.

The following situations would benefit from high integrity communications being present:

- To broadcast a mine-wide early warning in the event of an emergency
- To provide communications from permanent and moveable emergency bases
- To provide communications to workers trapped by falls of ground, fire or inundations
- To provide communications between the incident control centre and fresh air base (s)
- The fresh air base (s) and rescue team (s)
- To provide data communications from environmental monitors at locations in the mine affected by the emergency

Essentially, the limitations on being able to provide effective early warning are related to limitations in underground communication systems.

Even with an extensive underground telephone system and a leaky feeder radio system in place there are many locations and situations underground where workers cannot be contacted directly. Building on the pioneering work of the United States Bureau of Mines and its research programme to understand, the science of through-the-earth propagation (Parkinson 1973) several systems have been developed to provide mine-wide through-the overburden communications. These communication systems are essentially surface to subsurface wide area broadcast systems.

The commercial systems available include.

- PED System - Mine Site Technologies (Pty) Ltd, New South Wales
- Canary System – VLF Magnetic Systems Inc. Ontario, Canada
- Com System, Telemagnetic Signalling Systems Inc. Ontario, Canada.

The key to successful deployment of the equipment is the use of an appropriately sized surface loop antenna with a high transmitter power. This is a potential weakness in these systems, in that surface access is required to install a loop, which may need to be up to 12 to 15km in circumference. In general range depends on antenna size and disposition, depth, strata conductivity, local electromagnetic noise and the influence of mine conductors.

It is evident after an incident has occurred information, to the location of workers and communication with the workers is essential. The first response phase of the incident is critical in terms of information. Management must be able to determine how they can gather accurate data and information on conditions, location and status of the workers.

Locating personnel and establishing effective communications in tandem with comprehensive emergency preparedness planning are essential elements if an incident is to be managed efficiently.

The availability of effective guidance systems:

At large mines having extensive lengths of open roadways or complex ventilation networks, it is essential that emergency procedures are planned in advance, smaller mines may have relatively simple underground layouts with less extensive distances, however and recognising that certain locations would require particular attention in all cases:

- Long length, single-entry headings
- Longwall coal face districts
- Roadways having hot and humid conditions and/or steep gradients
- Extensive room and pillar operations

A number of incidents have been recorded internationally where, in severe conditions workers have been unable to locate refuge/emergency bases or escape routes in spite of them being in the proximity of the workplace.

Following a fire, explosion, and large scale ground fall or outburst low visibility conditions are generated and the following becomes critical:

- Behaviour during exposure to a major incident is associated with disorientation, loss of direction and possible delays in donning respiratory protection.
- These elements create uncertainty, confusion and possible panic reactions increasing risk to evacuees.

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This has led to a number of research projects directed specifically at overcoming problems of disorientation and low visibility (SIMRAC 1995) (UKHSE 1997). South Africa studies (Kielblock and Von Rensburg 1987) suggest that maximum workplace to refuge/emergency base distances should not exceed 1500m in high seam workings and that this distance may need to be halved in low seam operations. These distances assume good visibility.
It was also concluded that the average speed of travel in zero visibility conditions maybe only 25 per cent of that possible when visibility is normal.

These findings raise questions regarding how workers wearing SCSR's of limited duration should be guided to a refuge/emergency base or other places of safety under conditions of nil visibility and what should be assumed concerning the maximum travelling distances in particular mine conditions.

Any guidance system, which permits a substantial increase in speed of travel, and clearly defines the final location of refuge/emergency base or place of safety offers an extended time of safety to these facilities.

The work to develop and evaluate effective guidance systems is important to permit the operating rating of SCSR's to be considered to a wide range of evacuation scenarios. However systems to enhance self-escape must be understood by all workers, as part of mine emergency preparedness training the assignment of designated escape routes is a critical part of any self-escape strategy.

A number of approaches to emergency guidance systems ranging from the use of ropes to sophisticated navigation beacons have been proposed. Guide ropes have the merit of low costs however the direction of travel and the physical integrity of the guide rope remain in question after an explosion.

In an effort to provide a more effective and general-purpose means of guidance, active electronic guidance systems have been developed which employ visible and audible signals to guide personnel during an emergency.

Typical is the system under development by the UK Health and Safety Executive (UK HSE 1998). This will employ high intensity green and red LED's in each beacon together with an acoustic sound. The system would start at the working face and terminate each section at the refuge or similar place of safety.

When the worker is travelling in the correct direction during the emergency evacuation a sequence of green lights is observed whilst red lights are observed, this is an unsafe direction. The system will be intrinsically safe certified when development and trails are completed.

A problem with roof mounted units is that they may be obscured in thick smoke which tends to rise. The audio effect can suffer in that same smoke from the "foghorn" effect.

The utility of installed lifelines has been tested under simulated conditions (SIMRAC 1995b). The results showed that on average subjects wearing SCSR's and operating in nil visibility conditions move at approximately 75 per cent of normal walking speed when aided by a lifeline, the corresponding was less than 40 per cent when using only the existing structures in the area.

In Summary:

Rather than starting anew – we must build on the strengths we have already developed.

Miners must be trained and re-trained in the fundamentals of the mine emergency escape plan, and required competency levels of understanding.

Underground Worker:

Self rescuer training and retraining on short and long duration units must continue to establish and reinforce levels of confidence and competence.

In particular the change over of SCSRs in hostile atmosphere is critical. This cannot be rehearsed too often.

Continue with the discussion and introduction of the refuge/mobile emergency base. System which allows:-

- Short distance to travel from the workplace,
- Meeting point
- Communication centre
- Self-rescuer exchange, long duration
- First aid station
- CABA storage
- Fresh air supply etc

In short a "temporary place of safety". Because of the nature of coal mine emergencies it becomes critical to have a system of communications that will enable the workers who arrive at the refuge/mobile emergency base to decide or be told whether they are "safe" or they must move on. If the group of workers are "safe" the emergency control team on surface can concentrate on the other emergency zones in the mine where assistance is required immediately.

Effective guidance systems are a relatively new area of research, but with the development and evaluation of this concept the concern of losing the way to a place of safety and disorientation in limited visibility should be controlled, especially if training and retraining is conducted in a near to reality scenario as possible.

Communications and guidance systems need to be robust, following a fire or explosion. Visibility may be severely restricted leaving the escaping workers to guide themselves to safety by touch and hearing. It is against this scenario that the adequacy of guidance systems should be judged.

We have not yet reached best practice. Simulations repeatedly show areas for improvement. We all know the costs in this area are high.

The alternates are far worse.

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