

SIMRAC

Final Project Report

Title: DEVELOPMENT OF ACTIVE GUIDANCE SYSTEMS TO
OVERCOME PROBLEMS OF DISORIENTATION AND LOW
VISIBILITY FOLLOWING SEVERE EXPLOSIONS

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Post Explosion Rescue Systems

SYNOPSIS

The objective of this research project was to review methods of overcoming the disorientation of underground mine workers following an explosion or severe fire.

Traditional voice communication systems and both active and passive guidance systems have been reviewed. Visits to overseas research establishments, contact with equipment manufacturers in both South Africa and Australia, reviews of the literature and discussions with members of the local coal mining community have all helped in formulating this report. Close liaison with other research groups at Miningtek who have SIMRAC funding for similar work has also helped to focus this project on important issues.

The results of this project indicate that different strategies may be required for fires and explosions. For example, passive guidance systems such as directionally marked rope or the use of conveyor structure would assist in low visibility associated with a fire, while following a severe explosion the integrity of such systems could not be guaranteed. At present, there is no ideal system available but one commercial system (MOSES) continues to be developed to meet most of the requirements. Further work on directional radio guidance systems is also recommended to provide an alternative system.

The research was completed on time and within the approved budget.

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1. INTRODUCTION

Fires and explosions have unfortunately been a fact of life since the earliest days of coal mining. While much has been achieved in reducing the frequency and severity of these events it seems impossible to totally eliminate the loss of life and injury associated with them. Provision must therefore always be made for rescue and recovery following an incident.

Over many years brave individuals and highly trained rescue teams have risked their lives in rescue attempts. For these people the most harrowing experience is to recover the bodies of those not immediately killed in the explosion who made desperate but unsuccessful attempts to escape the aftermath. In order to assist these people the concept of self-rescuers, whether body worn or in a cache and whether self-contained or filter type, was developed. As part of this strategy we also have refuge bays equipped for the long term support of survivors. However, recent events in our mining industry have indicated that even those who don their self-rescuers may well be so disoriented by smoke, dust and damage to the infrastructure that they fail to escape either to a refuge bay or a safe part of the mine.

The ability to guide oneself to a known location depends at present on the person's senses i.e.

- touch
- sight
- hearing
- taste
- smell

Of these only the first three are sufficiently well developed to provide a sense of direction under most conditions. Following either a fire or an explosion sight is severely restricted or non-existent due to low visibility, while an explosion may also either temporarily or permanently cause deafness.

It is against this background that communication and guidance systems must be developed and judged.

2. EXPLOSIONS IN COLLIERIES

2.1 South African Statistics

The causes of underground fires in South African collieries during the period 1970 to 1990¹ are shown in Figure 1. The spontaneous combustion of coal was found to be the major cause of fires, being responsible for more than a third of the 254 fires reported during this period. Electrical systems caused approximately thirty per cent of the underground fires, with flammable gases being responsible for just over 21 per cent.

CAUSES OF FIRES IN S.A. COLLIERIES

1970 - 1990

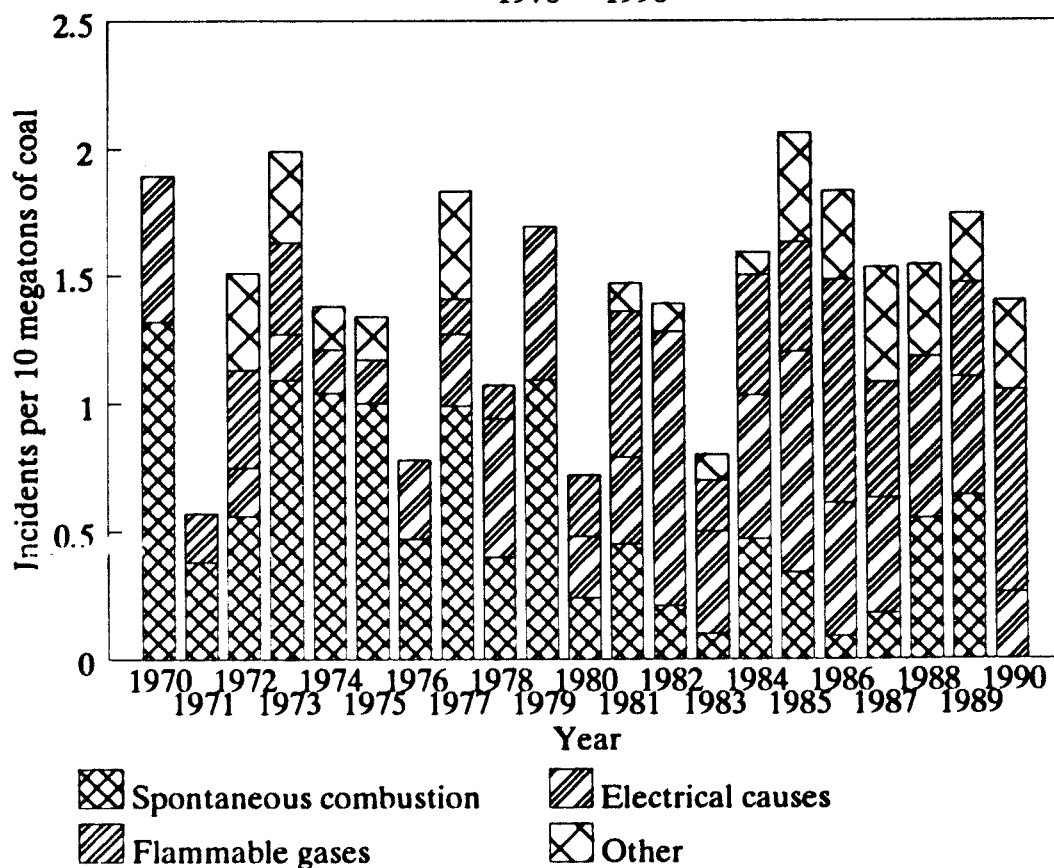


Figure 1
Causes of reported underground fires in South African collieries.

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The frequency of reported ignitions and explosions for the period 1982 to 1993² is shown in Figure 2. There was an average of 3.8 ignitions and 1.5 explosions per year over the twelve year period. Four people were injured in incidents involving ignitions and there were no fatalities. If one looks at explosions, on the other hand, there were 93 injuries and 218 deaths.

IGNITIONS AND EXPLOSIONS IN S.A. COLLIERIES 1982 - 1993

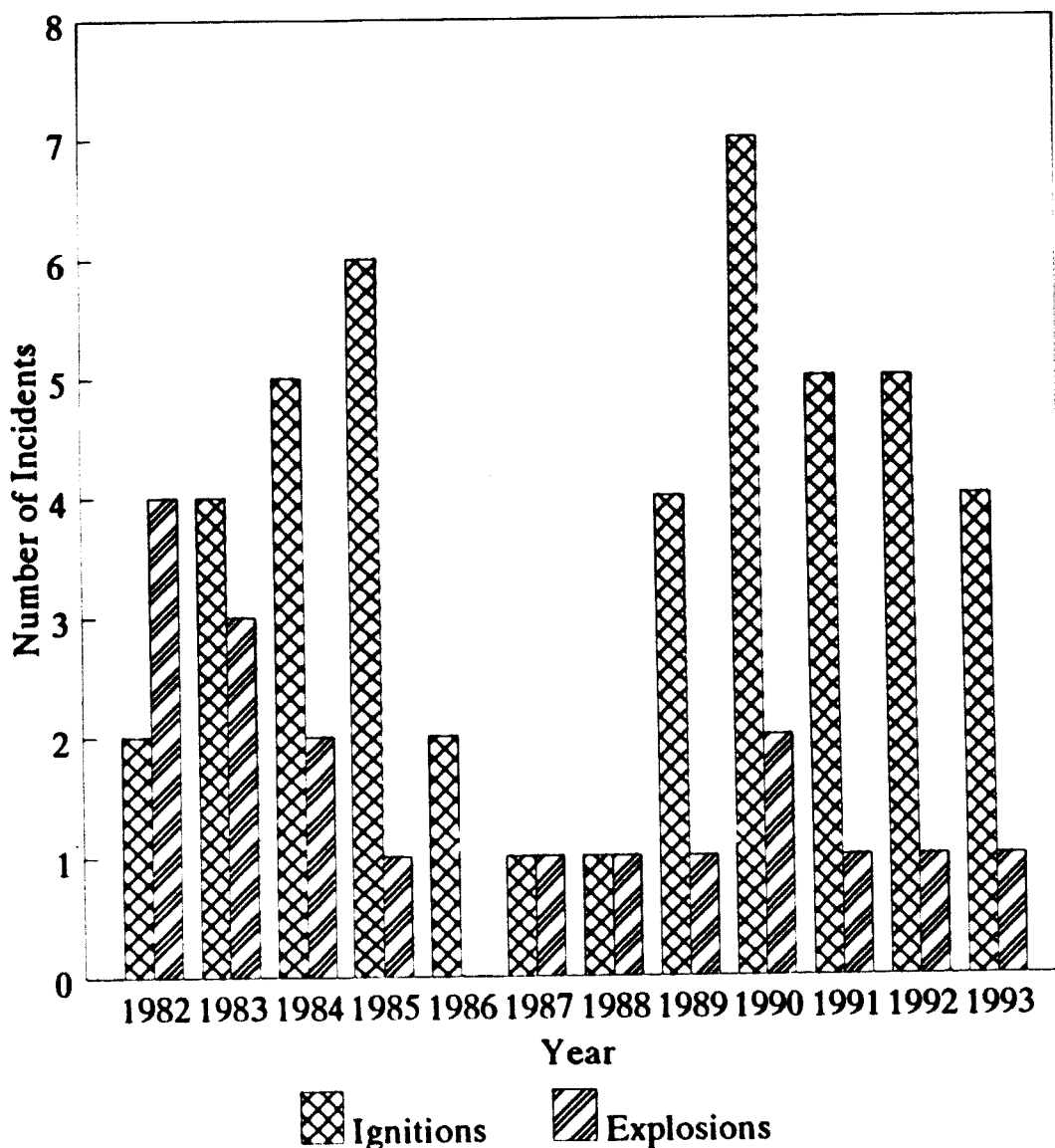


Figure 2
Ignitions and explosions in South African collieries.

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Figure 3 shows the average number of injuries and deaths per explosion over this period. Major incidents are shown to have occurred in 1983 (Hlobane), 1985 (Middelbult), 1987 (Ermelo) and 1993 (Middelbult). These four incidents make up 22 per cent of the total number of explosions that occurred, yet account for 28 per cent of the injuries and 87.2 per cent of the fatalities.

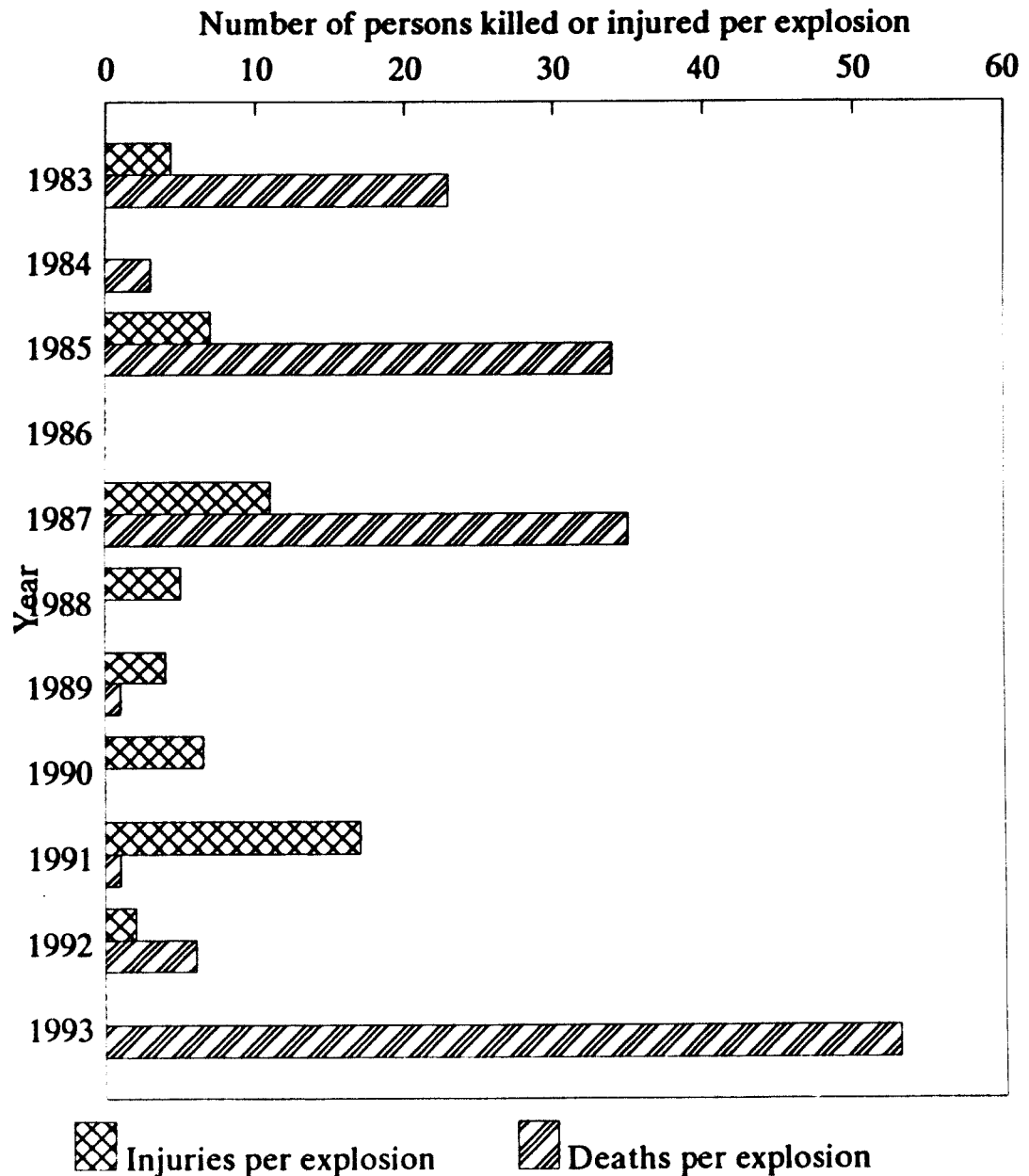


Figure 3
Injuries and fatalities in methane and coal dust explosions, 1982 – 1993.

2.2 Major Colliery Explosions

In the Hlobane explosion of 12 September 1983, sixty eight miners were killed and eight were injured. The source of the ignition was found to be a silicon controlled rectifier panel of a battery driven scooptram³. A conductor had been caught between the flanges of the flameproof enclosure of the control panel during a repair operation, and the resulting gap allowed the propagation of a flame. The explosion took place shortly after work commenced on the Monday morning. It is believed that methane accumulated in the section during the weekend, after mining operations in another section had disrupted the ventilation on the Saturday. A low pressure system (storm) which had passed over the colliery on the Sunday is also suspected of contributing to the release of methane from the coal seam.

The Middelbult explosion of 12 August 1985 occurred close to a bord and pillar section while workers were constructing an air crossing². It is believed that methane emanated from a borehole that was intersected during normal mining operations, and accumulated in the roof cavity that was created for the air crossing. It is suspected that the ignition occurred as a result of blasting operations in the roof. Thirty four miners were killed and another seven were injured.

The explosion of 9 April 1987 at Ermelo Mine Services occurred after a new section was opened on the opposite side of the main development to the section it was replacing². The redirection of ventilation from the old section to the new section is believed to have allowed methane layering to occur in the old section. Whilst the ignition source was not determined, the explosion is believed to have taken place while the old area was being inspected and one miner was waiting at a transformer in the old section. Thirty five miners were killed and eleven were injured. Four of the fatalities were as a result of carbon monoxide poisoning.

Fifty three people were killed in the Middelbult explosion of 13 May 1993. This case is still sub-judice.

3. TRADITIONAL UNDERGROUND MINE COMMUNICATION SYSTEMS

Communication between personnel engaged in rescue operations and mining activities is extremely important. As mines have become larger and more mechanised, the need has arisen for faster, more reliable, and more mobile communication systems. Even though the technology associated with underground communications has advanced rapidly in recent years, problems still arise with new communications systems which result in communication delays and breakdowns.

In choosing or specifying a communication system for use underground it is important to consider the purpose for which the equipment is to be used, the environment, and the resources available to maintain the system. Lambert⁴ suggested that the following factors be considered when selecting a voice communication system :

- Whether fixed, mobile or portable operation is required ;
- Whether used for production or occasional use;
- The number of personnel using one channel;
- The deployment of personnel;
- The duration of service between battery charging, in the case of portable units;
- The ability of the mine to test and maintain the equipment or the quality of back-up service offered by the supplier;
- The range over which communication is required;
- Acoustic and electromagnetic noise;
- Moisture, dust, dirt and corrosion;
- Availability of conductive materials other than a dedicated cable in the region of communication;
- Dimensions and geology of the haulage and stope through which the communication is required; and
- Cost and reliability.

The factors listed above were identified in an investigation of gold mine communication systems. For underground coal mines the following factor should be appended to this list :

- Adherence to intrinsic safety standards for coal mines.

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The following commercially available communications systems have been identified as being traditional communication systems, and will be discussed in this section of the report :

- mine telephones,
- leaky feeder radiating system,
- medium frequency induction system, and
- low frequency warning or pager system.

3.1 Telephones and intercoms

Telephones first appeared in underground mines in the early 1900's, and are now field-proven, reliable and the most widely used of all mine communication systems. In South Africa, early magneto telephones and manual switchboards have largely been replaced by Private Automatic Exchanges (PAX's), which do not need a switch-board operator. The extensions of these PAX systems do not have access to the South African Post Office Network and the mine usually has a Private Automatic Branch Exchange (PABX) for this function.

In an average sized gold mine a 200 to 500 extension PAX is typically installed at each shaft head. An additional 100 to 200 extension PAX is installed underground at the sub-shaft head. A 200 to 500 pair cable is used in the main shaft, and a 100 to 200 pair cable is installed in the sub-shafts. Extensions are provided wherever required (such as at the shaft station on each level, at stores, dams, pumphouses, sub-stations, workshops, first-aid posts, control centres and even stope waiting places). In 1986, amendments to the Mines and Works Act made it compulsory to provide verbal communication to each Refuge Bay. Most managers have chosen telephones to fulfil this role.

'Intercoms' and 'loudspeaking-telephones' are systems where communication is provided between fixed points only (eg. on an incline shaft), using a single pair of wires to connect them. A loud alarm signal or amplified voice signal is used to call the other extensions. A typical mine telephone is shown in Figure 4.

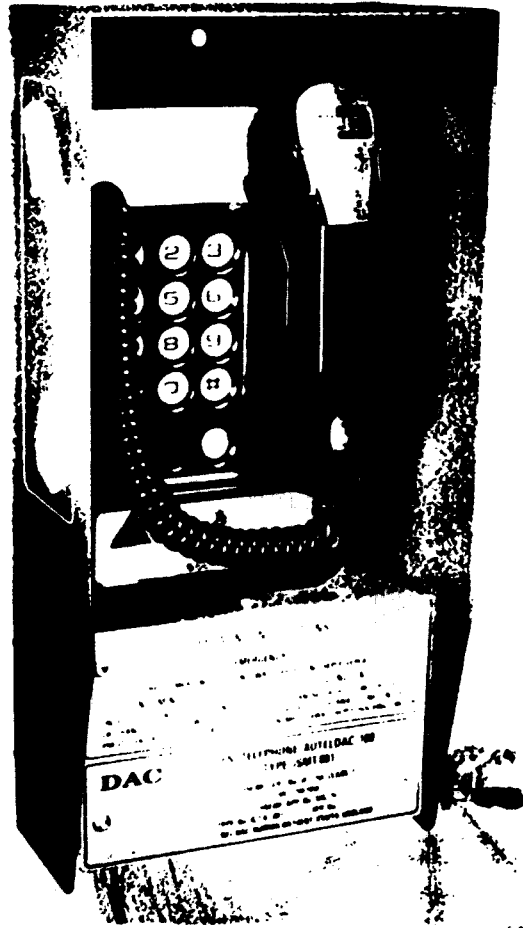


Figure 4
Typical mine telephone.

3.2 Radio Systems

Successes in the application of radio systems to underground mining operations have been limited by advances in "wireless" technology. Two-way radio systems ("walkie-talkies") operating in the high frequency (HF) and very high frequency (VHF) bands, have greater flexibility and wider coverage than telephones but are limited by the inability of HF radio waves to turn corners or penetrate rock. The communication distance was found to be about 200 metres.

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A number of different radio-based approaches have since been developed, each providing a specific area of superior performance but also presenting characteristic disadvantages. The primary options are :

- "leaky feeder" radiating cable systems,
- medium frequency inductive systems, and
- ultra low frequency warning or paging systems.

3.2.1 Leaky feeder systems

Leaky feeder systems depend on a specially manufactured, heavy duty co-axial cable, with a controlled radio frequency (RF) leakage characteristic, installed along roadways throughout a mine. Portable VHF radios are able to receive these radio signals in the immediate vicinity of the leaky feeder antenna. One can understand the principle by considering a situation where water is fed from a bucket into a hosepipe, which has holes drilled into it along its entire length. The water will "leak out" in small amounts along the hosepipe.

The NEI DAC leaky feeder system will be described in this report. Other commercially available systems include Tunnel Radio's FD4, and EL - Equip's LF4 radio systems⁵.

The DAC radio highway consists of a base station and a leaky feeder co-axial cable. The base station is the heart of the system. It serves to convert audio (speech) or data signals to radio frequency (RF), for transmission via the leaky feeder cable, and vice versa. It is intrinsically safe and has a flameproof power supply (12 volts DC). The simplest "talk-through-mode" configuration requires one radio transmitter module and one receiver module. Up to four leaky feeder cables can be distributed from this unit and seven base stations can be linked together.

As RF signals are radiated along the whole length of the leaky feeder cable, their level naturally falls with their distance from the base unit. This is compensated for by installing totally enclosed two-way repeater amplifiers in line with the leaky feeder cable, at 500 m intervals, to provide a signal level increase of 16 dB per amplifier unit. They therefore boost the return RF signals from mobile transceivers and the outgoing base station signals simultaneously. They draw just 12 mA of 12 volts DC from the operating power provided on the leaky feeder cable. Intrinsic Safety certification requirements allow up to 15 repeaters to be used on the leaky feeder cable before additional

DC power is needed.

Complex "Christmas tree" configurations of leaky feeder cable layout are achieved by using passive splitter units fitted in-line with the leaky feeder cable. These small "single-input, dual output" units are installed wherever a roadway splits. An unlimited number of these can be installed as they draw no operating power, but each incurs a RF loss of 3 dB. In practice, this is readily compensated for by reducing the distance to the next repeater by 100 m. Each spur must be terminated by a standard terminating unit, to prevent standing waves.

Coverage of up to 25 km of roadway can be achieved, with the furthest point being not more than 15 km from the base. The leaky feeder cable is 15 mm in diameter and comprises a stout durable co-axial cable with air spaced core and a deliberately loose braid conductor (Fig. 5). The cable is suspended from the apex of the tunnel roof with plastic clips.

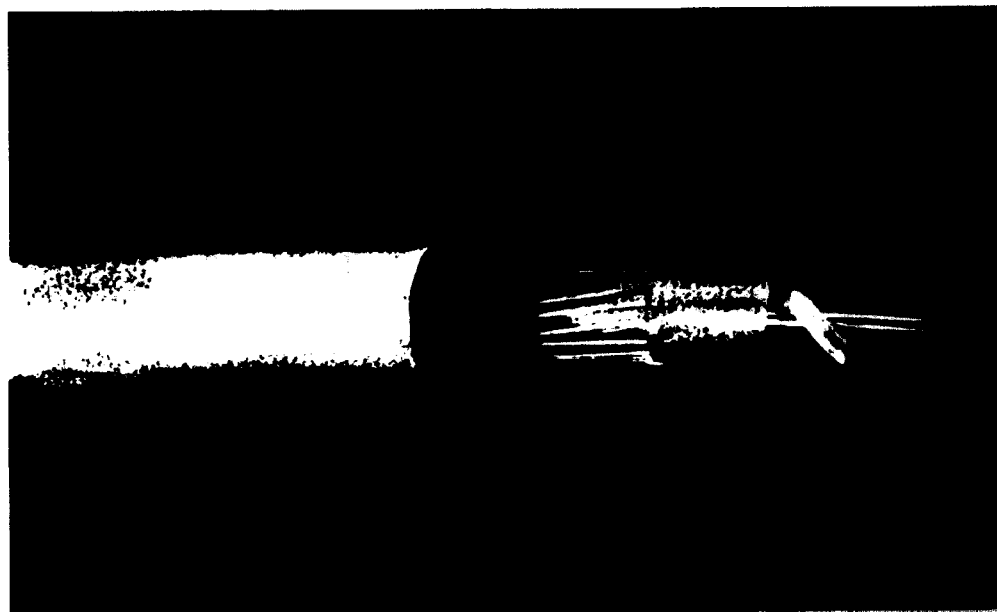


Figure 5
Typical leaky feeder co-axial cable.

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The pocket sized two-way personal radios are rugged, simple to use, VHF radios. they are powered by detachable, rechargeable nickel cadmium batteries, giving a long duty cycle. Other options include a loudspeaker and microphone unit designed to clip on to a lapel, and a keypad enabling telephone calls to be made directly from the personal radio. Rugged two-way radio units are available for installation in underground vehicles.

In order for two portable radios to communicate with one another in the simplest operating mode ("talk through mode"), two radio frequencies are employed. One frequency (F1) is used for mobile station transmission (with the base station receiving), while the other frequency (F2) is used for base station transmission (with the mobile station receiving). When a mobile station transmits, the leaky feeder cable picks up "F1" and the repeaters send the signals along the cable to the base station's receiver. Here it is detected and demodulated to produce audio signals which are then sent out on the base station transmitter and also retransmitted at "F2". The leaky feeder cable then radiates the transmission (at its new frequency), assisted by the repeaters to the mobile radios, so that wherever these radios are in the mine, they receive the speech from the first mobile radio cleanly and clearly.

The cost of a basic leaky feeder system is shown in Table 1.

Table 1
Cost of a basic leaky feeder system.

ITEM	COST (Rands)
Base Station	
4 channels	40000
Antenna	
5 km leaky feeder with boosters @ R 15,50 per m	77500
Terminating Units	
@ R 400 per unit	2000
Portable Radios	
@ R 2500 per radio	75000
Total Cost (incl VAT)	221730

3.2.2 Medium frequency inductive systems

Medium frequency (MF) radio systems have been used for several years in South African mines with good results. MF radio waves do not suffer the severe corner losses that are characteristic of HF and VHF waves, and can travel through solid rock for several hundred meters under favourable conditions.

In 1946 the Chamber of Mines recognised the need for underground through-the-rock radio communications for PROTO rescue teams, and commissioned the CSIR to investigate the propagation of radio waves through quartzite rock. The attenuation of the electromagnetic waves by the surrounding geological materials was found to be so high as to limit the maximum communication distance to about 800 m at an optimum frequency of 350 kHz. It was concluded that a portable transceiver with an RF power of 10 W, weighing four and a half kilograms, could be built. It was calculated that two such transceivers could accommodate a system loss of 140 dB (Figure 6).

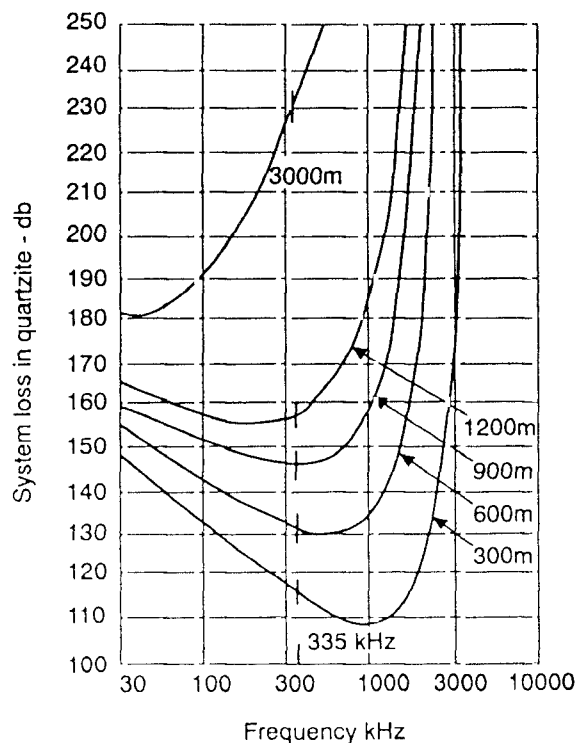


Figure 6
Optimum communication frequency of about 350 kHz for a range of 800 m.

The Chamber of Mines Research Organization (COMRO) embarked on a practical research and development programme which evolved various prototypes. The early 1970's saw COMRO's handheld prototypes being used successfully. Grinaker Electronics (GRINEL) was then commissioned to continue developmental research and begin the commercial production of MF radios. GRINEL completed its development programme in 1977, and production commenced in 1978. By 1981 most of the rescue teams of the gold mines were equipped with these MF radio systems. In 1988 GRINEL introduced a second-generation radio, known as the SC 1000, which is widely used in mining operations. A third-generation radio the SC 2000 has now been developed and will be available in the near future.

A general description of the medium frequency inductive radio system can commence with the findings of Leek and others, in 1947, which indicated that a significant improvement in radio transmission along a mine tunnel was obtained if an insulated wire was provided in the tunnel to propagate the radio signal⁶. The conductor and the surrounding rock could be thought of as a large co-axial cable, or transmission line, for the propagation of radio signals along fairly large distances. If one end of an insulated conductor, suspended along a length of a mine tunnel, is connected to the output of a radio transmitter, an induction field will be generated between the conductor and the surrounding rock. The antenna of a radio receiver placed within this field will receive the signal from the transmitter. Direct electrical contact between the receiver and conductor is not necessary. Conversely, if a transmitter with a suitable antenna is operated with the induction field of the transmission line, a signal will be induced into the line and will propagate along its length to a receiver at the end of the line, or at some other point in the induction fields. Two-way communication between the fixed station and a portable radio, or between one portable radio and another within the tunnel, is therefore possible.

A description of a typical medium frequency inductive system is as follows : A remote control unit (RCU) is installed in a control room on surface and connected, via a pair of telephone lines down the shaft, to a radio base station to provide effective two-way communication. The base station consists of an SC 1000 radio transceiver, housed in a steel cabinet, and is able to interface in two directions (to the RCU or to the antenna system). The antenna is employed in all areas where radio coverage is required. The type of antenna system is dependant on the type of coverage which is required in an installation.

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There are two main types of antenna :

- (a) Long Wire Antenna (LWA) – which is normally insulated 2,5 mm² or thicker copper wire (blasting wire will suffice). The LWA is installed about 200 mm from the haulage roof and extends from the base station for distance of up to 12 km. It is connected via a matching unit to the base station radio and terminated at every tail–end with a terminating unit. Splitters can be used to T–off into crosscuts. It is a cheap, easily installed antenna, but is also easily stolen.
- (b) Distributed Antenna System (DAS) – is RG 213 coaxial cable, which is installed in main haulages. The cable is thick, and a steel armoured version is also available. The cable can be installed in an existing cable tray in a haulage. It is therefore more rugged, more expensive and difficult to install than LWA, but is far less vulnerable to theft.

In conjunction with the DAS antenna, passive radiators are installed every 500 m to "induce" a signal into the cables, rock or nearby pipes. These are connected to the antenna by means of quadrature couplers which then give a flat signal response over the entire antenna system. This means that the signal from a portable radio at the base station will be the same as from a portable radio 10 km away. DAS/LWA splitters can be used to extend the antenna system into crosscuts and stopes by using long wire.

The SC 1000 and 2000 radios are rugged, lightweight (3,3 kg and 1 kg respectively) and user friendly, with all functions of the radio being done automatically (eg. audio and squelch settings). A keypad can be included and improved ergonomics ensure balanced radio weight distribution. The speaker and microphone are located in line with the ear and mouth of the operator, ensuring effective operation in high noise environments.

Two types of clip–on Nicad battery packs are available. These packs can be replaced underground, since they are intrinsically safe. Five–way and ten–way chargers are available, and a spare battery is recommended for each radio.

The *Vehicle Radio* version of the SC1000 is housed in a compact steel enclosure which is mounted on shockmounts (rubber buffers) to dampen vehicle vibrations. The radio has a potted, built–in ferrite antenna and a charger, to allow use of the vehicle power source. The unit also houses a hose–proof (resistant to being sprayed on by water) microphone, speaker,

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control buttons and, if required, a call keypad.

The PROTO rescue system is built into a compact portable station. During rescue operations the portable station is carried to a fresh-air base and a pair of wires is extended from the portable station to the nearest available pair of telephone wires. The control room on surface can then link up to the rescue bay station via a RCU, providing instant two-way communications. In addition to this, a temporary loop antenna is erected in the area of the fresh air base, to the existing pipe work or cables, enabling all rescue team members wearing a portable SC 1000 to have a direct line of communication with each other and back to the surface.

The MF radio system can also be used to dispatch backfill to stope paddocks or socks. A pager system similar to the Personal Emergency Device (PED), described later, can also be integrated into the existing MF system.

Table 2.
Cost of a basic medium frequency system.

ITEM		COST (Rands)	
Base Station	Single frequency	11200	
	Repeater Station		19900
Antenna	5 km DAS @ R3,00 / m)	15000	15000
	5 km LWA @ R 1,00 / m)	5000	5000
Remote Control Unit		4800	4800
10 DAS Radiators	500 m apart	11000	11000
30 Portable Radios	R 5800 per SC3000 radio	174000	174000
Charger	10 batteries per charger	10500	10500
Spare Batteries	1 per radio @ R 935	28050	28050
Commissioning	2 technicians @ R 1500	3000	3000
Total Cost (incl VAT)		299307	309225

Voice communications is possible as follows, portable radio to base and back, open system, selective call (closed system) and dual tone multi frequency (DTMF) with telephone interface. Communication between two portable radios is dependant on the infrastructure and typically extends over a distance of 800 m.

A single frequency system has the advantages that it operates on one frequency, is cheaper than the repeater system, and the mine does the installation. The main disadvantage of this system is the distance over which communications can be made between two portable radios, which is about 500 to 800 m (line-of-sight). The repeater system offers better clarity and an increased communication distance, but is more costly and complex to install.

3.2.3 Ultra low frequency warning or paging systems

In 1981, the US Bureau of Mines began investigations into the use of "through-the-earth" transmission as a means to alert miners of the need to evacuate the mine⁷. This research was being undertaken to replace the use of stench gas in metal mines. Although this project did not lead to the commercial availability of a ULF system, it was determined that ULF transmissions could be the basis of an effective "through-the-earth" communication system.

In July 1986 a disastrous mine fire at Moura Colliery in Queensland, Australia, caused government funds to be made available for research in the field of underground warning systems. The vehicle through which the funding was channeled was the National Energy Research, Development and Demonstration Council (NERDDC). Project Number 1075 resulted in the PED communication system.

PED, the Personal Emergency Device, is the first successful paging system which can transmit messages through-the-earth, from the surface to miners underground. This is important in emergency conditions where alternative communication systems, based on hard wiring and aerials, can be rendered inoperable through fire, explosion or rock falls. The system is based upon the transmission of ultra low frequency electromagnetic waves.

The PED system consists of an above ground transmitter, loop aerial and personal computer (PC) for message generation. The PED receiver has been integrated with the existing cap lamp battery, from where it derives its power. The surface configuration, i.e number and location of transmitters and aerials, depends on the individual site requirements.

Messages are created on the PC, which is interfaced to the transmitter. The transmitter radiates its signal through a loop antenna, installed on surface,

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which can be 1,5 to 2,0 km in length (max 7,0 km). The signal can be propagated through the strata for up to 1 km in depth and laterally for a 1 to 2 km radius. The miner's lamp flashes for a ten second period to alert the miner that there is an incoming message and the decoded message is displayed on the liquid crystal display (LCD) of the PED. Messages of up to 32 characters long can be displayed for one minute, then the back light will extinguish, leaving the "NO MESSAGE" display.



Figure 7
A miner reviews his PED after receiving a message.

The AUTOPED is a vehicle mounted receiver. A large display on the dashboard provides specific messages to the operator. The unit can store up to five individual messages that may be recalled when the driver returns to his vehicle. The vehicle's horn could be wired to alert the driver of an incoming message should he leave his vehicle.

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CONTROLPED remotely controls devices and equipment including pumps and fans without the requirement of hard wiring to surface. It can send commands to 540 individual destinations, above and beyond the 962 destinations available to PED and AUTOPED receivers. The suppliers of the PED system claim that it could be used to activate stench gas containers, strobe lights or sirens which would tell the miners to make use of their self rescuers. Via a RS 232 interfacing link, the PED system can monitor the mine and, for example, a high methane presence in an area could result in all sub-stations in the area being isolated. Booster fans could then be switched on and all personnel could be notified to evacuate the area. It is also claimed that the cost of the system can be justified against safety benefits and advantages, better-productivity and personnel utilisation, and guaranteed signal coverage with negligible maintenance costs.

Table 3
Cost of a basic PED system

ITEM	COST (Rands)
Transmission System	124125
Transmitter	94000
Modular cord	10625
Lightning protection	5000
Antenna safety unit	6000
Commissioning	8500
Software and Receivers	131500
Pedcall software	14500
Ped receivers (30 @ R 1900 per unit)	57000
Autoped receivers (10 @ R 5500 per unit)	55000
Antenna (5 km @ R 1000 per km)	5000
Total Cost (incl VAT)	255625

3.3 Comparison

For many years the telephone and, later, intercoms and loud-speaking telephone systems were the only underground voice communication systems in South African mines. Telephone systems are easy to install, relatively cheap (approximately R 300 per telephone) and everyone knows how to use them. On the negative side, a break in the telephone line means a breakdown in communications. They are also restricted to fixed points unless small portable units are available which can be carried by mine personnel and plugged into jacks coupled to the telephone network. Unattended phones are also vulnerable to vandalism.

Radio communications became a viable option with the successful implementation of Grinaker's medium frequency inductive radio system. This system became an integral part of mine rescue operations performed by PROTO rescue brigadesmen. The radio was then adapted for mine wide communications and maintained a large market share over the last thirteen years, with sanctions and embargoes keeping other radio systems out of the market. The system has been employed in a number of different applications, such as use in shafts, main haulageways, drives, crosscuts, travelling ways, stopes, development ends, raise boring, rescue and now backfill operations.

The main advantage of the MF radio system is that it has a lower capital cost than the leaky feeder system. For a thirty radio system, it costs approximately R 224 700 for a repeater system, whereas a leaky feeder system costs approximately R 230 730. Communications are not restricted to line-of-sight, but the communication distance from the antenna is dependant on four factors :

- height of the tunnel,
- humidity,
- conductivity/nature of the rock strata , and
- power in the antenna conductor (which is limited due to intrinsic safety standards).

Two types of antenna can be selected (Long wire antenna – LWA or Distributed antenna system – DAS), giving one the flexibility to provide mine wide coverage at a reduced cost. The LWA costs only R 1,00/m and DAS only R 5,20/m (which includes a radiator every 500 m), compared to R 15,50/m for a

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leaky feeder antenna (which includes a booster every 500 m). The main disadvantages are that the transmitting and receiving frequencies of 426 kHz and 510 kHz respectively, fall in the MF band which experiences much electrically radiated noise. This degrades the performance of the MF radio system.

At low frequencies (20 kHz to 1 000 kHz) signal attenuation is low. Antenna efficiency is also low, but through-the-rock propagation does occur. It is necessary, however, for the MF antenna to be larger than an antenna for a VHF or UHF system (because the wavelength is larger). This has resulted in the development of a bandolier-type loop antenna for portable MF radios.

MF radios are relatively expensive. The SC 1 000 costs R 7 500,00 per radio and the SC 2 000 costs R 5 800,00 per radio, while the leaky feeder VHF "walkie-talkie" radios cost only R 2 500,00 per radio. Besides being more expensive, some mines view the MF bandolier antenna as being "bulky" and uncomfortable, since most miners are already laden with a cap lamp, self rescuer, methanometer, notebook pouch and first-aid pouch. The new SC 2 000 was been redesigned to address this problem and now weighs 1 kg instead of 3,3 kg. The cost of ownership has, on some mines, been very high and so the new SC 2 000 has been redesigned to encompass one motherboard, reducing maintenance on the radio.

With the disappearance of sanctions the market has opened up to an alternative radio system i.e leaky feeder (LF) with its associated VHF "walkie-talkie" type radios. Its main advantages are that it operates in the HF or VHF range so voice quality is good, the radios are cheaper than MF radios, they are easy to use and the cost of ownership is lower. Unfortunately, the capital cost is high. Once mining expands geographically (after the initial installation of the system) the LF cable must be extended to wherever communication is needed (at R 15,50/m). Also, skilled technicians are needed to maintain the system. An advantage of installing the expensive LF cable is that it can become an information highway, enabling telemetric reporting and control of vehicle health monitoring systems, fans, pumps, and video systems. At Finsch diamond mine, LF is used to transmit data from a surface control room to all its underground vehicles and vice versa⁸.

The PED (Personal Emergency Device) has proven to be a reliable one-way through-the-earth communication system. It uses ultra low frequency electromagnetic waves, through the earth, to flash a message on a pager located

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on the miners cap lamp battery pack. People can be contacted regardless of their location, and can be notified of any imminent dangers. One of its main disadvantages is that it has been successfully implemented in small scale mines in Australia but has achieved limited success at a trial site in West Driefontein Gold Mine. This was due to the following reasons :

- Resentment at having to carry the heavier PED unit,
- Management viewed as trying to "control" PED carriers, and
- PED carriers not appreciative of all PED's benefits.

Personnel also prefer the telephone system.

Advantages and disadvantages of the four underground communication systems dealt with in this section are shown in Table 4, overleaf.

Table 4
Advantages and disadvantages of traditional underground communication systems.

<p><u>Telephones</u></p>	<p>Advantages</p>	<p>Disadvantages</p>
<ol style="list-style-type: none"> 1 Relatively cheap and reliable. 2 Easy to use. 3 Their operation is understood by everyone. 4 They don't require skilled maintenance. 	<ol style="list-style-type: none"> 1 Dependant on the electrical continuity of the line. 2 Prone to failure due to bad joints, moisture, corrosion, and damage from falls of ground. 3 Person must be near or at the called extension which is restricted to a fixed point. 4 Unattended phones are vulnerable to vandalism. 	
<p><u>Leaky feeder system</u></p>	<p>Advantages</p>	<p>Disadvantages</p>
<ol style="list-style-type: none"> 1 Offers mine wide coverage, and is intrinsically safe. 2 Two way radios are relatively cheap, easily available and easy to use. 3 LF base station interfaces with other speech networks. 4 The portable radio antennas are small and efficient, therefore giving good voice quality and minimal interference. 5 Many overseas installations in coal, copper, lead and zinc mines. 6 Low cost of ownership. 	<ol style="list-style-type: none"> 1 Communication is restricted to line-of-sight or around one corner (Each mine does vary i.e site specific). 2 LF systems are relatively expensive to install, as the cable must be strung throughout the mine, to wherever the communications is required. 3 Repeater amplifiers must also be installed at intervals to compensate for signal loss in the coaxial cable. 4 Technicians must be employed to install and maintain a LF system. 	

Table 4 continued overleaf

Table 4 continued

Medium frequency inductive system

Advantages

- 1 Communications not restricted to the proximity of the cable; for longer ranges it is not dependant on an unbroken cable and portable radios can be deployed anywhere.
- 2 Many local installations, standard radio system for mine rescue.

Disadvantages

- 1 Considerable proportion of the electrically radiated noise underground is in the MF band which degrades the performance of MF communication systems.
- 2 The antennas have to be larger than VHF radio antennas and are usually bandolier type loop antennas.
- 3 When the signal deteriorates, the loop antennas have to be orientated in the correct direction.
- 4 SC 1000 is a modular radio encompassing a motherboard and eight module slots, which have needed more maintenance. This has resulted in a high cost of ownership. (The SC 2000 has been totally modified to eradicate this problem).

PED system

Advantages

- 1 It contacts persons underground regardless of their location.
- 2 It contacts people privately or in groups of people.
- 3 It assists management to deploy machinery and personnel immediately in response to breakdowns, wherever they may be.
- 4 Immediate co-ordination of supplies and spares to production areas.
- 5 No underground aerial networks to be installed and maintained.
- 6 PED still operates during emergencies eg. fires and explosions.
- 7 Remote control of equipment underground.
- 8 PED is reliable and robust and intrinsically safe.
- 9 No skilled labour needed to maintain the system.
- 10 It generally has a short payback period and low maintenance costs. (approximately 1 % of Capital Cost).

Disadvantages

- 1 One way communication system, person must find a working telephone to respond to a message.
- 2 Trials needed to determine whether the transmitter is "light -ning proof".
- 3 Gold mines will require trials to determine the optimum range of depth of successful transmission of ULF signals. (Might require a second loop antenna underground).
- 4 Trials needed to validate that the PED system will not inadvertently fire off detonators.
- 5 It is viewed as a management tool to "control" the employees carrying PED receivers therefore management teams would have to overcome this "resistance to control" factor.

4. GUIDANCE SYSTEMS

4.1 Passive Systems

Experienced mine workers have a good understanding of the layout of the area of the mine where they work, together with the location, size and shape of equipment. Recent tests conducted by Miningtek have shown that once blindfolded personnel locate themselves and are able to touch a structure such as a conveyor belt, electric cable etc. they can move quite confidently and quickly to a rescue chamber.

Following a mine fire and with zero visibility, personnel can move along conveyor belts or along "lifelines". Lifelines of various design have been tried and must be located to lead survivors towards fresh air or a rescue chamber. It is imperative that the person moves in the correct direction and the best known system involves rope with raised conical shaped surfaces. Moving in the correct direction results in the hand moving along a smooth surface, while in the wrong direction the hand comes up against the blunt or bottom surface of each cone, making it very difficult to slide along the guide. These lifelines can lead all the way to the main air intakes, to a refuge bay, or to the section conveyor.

However, recent experience in a local mine has shown how disoriented people can become if they are not aware of where they intersect the conveyor system and they can easily move in the wrong (inbye) direction.

The main objection to the use of passive guidance systems is that in the event of a severe explosion any such devices are likely to be destroyed. Since the conveyor road has the highest concentration of fine coal dust, damage in that roadway is usually the greatest and with damaged and distorted conveyor structure obstructing it, travelling through it in low visibility would be impossible. Passive systems guiding survivors to the conveyor structure are, therefore, not considered suitable.

The use of passive guideropes in the travelling roads is a possibility but practical considerations such as movement of men and equipment during normal operation of the section make this a difficult proposition. Again there would be no guarantee that any rope or cable would remain intact following the explosion.

In summary, it can be said that passive guidance systems have some use in low visibility following a fire but in the event of an explosion there is a significant risk that large sections of the system could be destroyed.

4.2 Active Systems

4.2.1 MOSES

The Mainsfail Operated Evacuation System (MOSES) was designed to guide personnel from the workplace underground to a safe area, such as a refuge bay, in conditions of low visibility. This is accomplished by a series of small, roof-mounted units, spaced at intervals of 50 m, which emit both an audible and visual signal in a cyclic routine. The cycle commences at the working face and terminates at the refuge bay. The duration of the cycle is preset at a control unit situated in the refuge bay. Each of the units of the MOSES system is powered from a 220 V supply, as well as being supplied with internal backup batteries capable of sustaining operation for up to 18 hours. The system can operate up to a maximum distance of 4 km from the control point, and can be triggered manually or by any of a variety of environmental sensors.

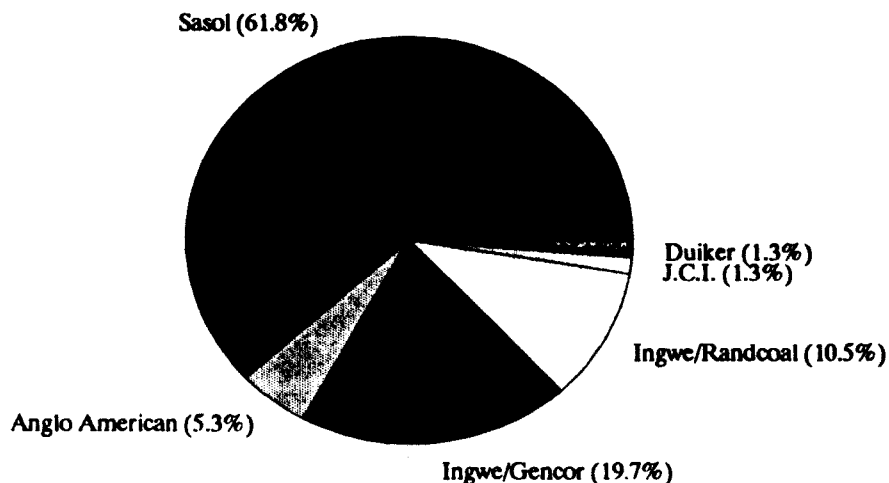


Figure 8.
Company breakdown of the 76 MOSES installation sites.

Post Explosion Rescue Systems

The MOSES system has been developed by Coal Control (PTY) LTD, a company experienced in providing automation and monitoring equipment to the mining industry. Approximately 90 km of evacuation equipment has been installed at 76 sites, on 15 different collieries. The number of sites installed by the different mining groups is shown in Figure 8. A complete list of colliery installation sites is shown in Table 5.

Table 5.
Current MOSES installation sites.

COMPANY	COLLIERY	No. OF SITES
Sasol	Middelbult	11
	Brandspruit	13
	Twisdraai	1
	Bosjesspruit	11
	Sigma	11
Anglo American	Kriel	1
	New Denmark	2
	Goedehoop	1
Ingwe/Gencor	Matla	5
	Gloria	7
	Blinkpan	3
Ingwe/Randcoal	Welverdiend	4
	Van Dyks	4
J.C.I.	South Witbank	1
Duiker	Waterpan	1

Sasol's commitment to the MOSES system seems to have been justified recently when, in Section 35 of the Middlebult Colliery, eight individuals made use of the system to locate a refuge chamber under conditions of zero visibility. The individuals had to don their self-rescuers and are reported as having reservations as to the probability of their having been able to reach safety had the MOSES system not been installed.

Post Explosion Rescue Systems

The first MOSES system was installed after the beginning of this project. The concept was criticised by this project team as being unsatisfactory for incidents involving an explosion, where interconnecting cables may be damaged. Steps have been taken to remedy this deficiency and the first of a new generation of MOSES systems is being installed at Sasol's Bosjesspruit Colliery. The system will be operational by the end of January 1995.

The new MOSES system (MOSES II) can transmit data to a centralised control room on surface to allow the status of the system to be monitored. The system is able to report on both the location and time of occurrence of a cable break. Each unit has now been supplied with an internal battery to allow 14 hours of continuous use in the event of a cable break. The unit is designed to remain synchronised with its address in the system until such time as the data line is restored. Tests have shown that the unit loses approximately two seconds after being operated on battery power for 24 hours. The normal audio signal interval is between 16 and 20 seconds, so there should be no danger of a reversal in the direction indicated by the system as being the escape route.

The maximum number of alarm units that can be installed has been increased from 64 to 240 units, spaced not more than 50 m apart. This enables the installation of a system of 2,4 km in five different directions from a refuge bay. Alternatively, a system can be installed where the total length of all branches connected to a central point does not exceed 12 km, with no branch exceeding 2,4 km. The systems already installed can be upgraded. The cost per kilometre of the original MOSES system is shown in Table 6.

Table 6.

The price per kilometre of the original MOSES system.

ITEM	QUANTITY	TOTAL PRICE
Controller	1	2995
Alarm	32	9440
Cable	1000m	1680
Brackets	168	756
Flasher	1	500
	Total R	15371
Additional alarm (33,3m extension)	R	352

4.2.2 PATHFINDER

The development of the Pathfinder system was proposed by an Australian company, Mine Site Technologies, and Laingsdale Engineering. The system appears to be essentially the same as the first generation MOSES system, and is therefore also vulnerable to cable damage. The Pathfinder system would also employ audio and light signals emanating from beacons, but would utilise a personal direction finder, to assist in determining the direction indicated by the audio and light signals. The proposal to SIMRAC to this system was not successful.

5. RECOMMENDATIONS

As has already been discussed in this report, conditions following a fire or explosion limit the human senses available for guidance to touch, very limited sight and hearing (which may also be limited following an explosion).

Other SIMRAC funded research has indicated that the concept of a single refuge bay supporting a large area of the mine may not be acceptable. The walking range of a man equipped with a self contained self rescuer must be modified to take into account the distance travelled in low visibility. It is likely therefore, that future strategy will involve the use of either mobile rescue bays or more primitive rescue bays cut more frequently into the solid ribside. This is important in designing a guidance system since the required range has an important effect on what is technically possible.

The limitations of a passive system have already been discussed. Active systems can be classified as either roadway mounted or person worn. A good example of roadway mounted equipment is the MOSES system. Since the individual boxes can continue to operate without the joining cables and remain synchronised for prolonged periods, this system has much to recommend it, provided the survivors still retain sufficient powers of hearing to follow the signals.

Although no person-worn guidance system exists, many of the concepts and components for radio controlled direction finding are well established in other environments and industries.

Post Explosion Rescue Systems

The recommendations of this report are, therefore, that development of the MOSES system should be encouraged and that more advanced features such as tagging of individuals should be incorporated into the basic system. Since systems such as MOSES and Pathfinder are commercial propositions the best encouragement for further development is the purchase and deployment of these systems by the mining industry.

At the same time it is recognised that there are circumstances where body worn systems could be a viable alternative and the use of direction finding radio systems in the underground environment should be investigated. This would entail a research rather than a development exercise, and suggestions for future research follow.

6. FUTURE RESEARCH

Recent experience has shown that miners have failed to locate refuge bays under zero visibility conditions following underground fires and explosions – with fatal consequences. A system that would enable miners to locate refuge bays in conditions of zero visibility is of obvious benefit. A roadway mounted system has been developed and has been installed at 76 different sites during 1994 but, as yet, no person worn device has been developed.

This project has led to the proposal of a research initiative to investigate the feasibility of using a radio frequency direction finding technique to locate refuge bays after an underground explosion. The proposal was accepted by SIMRAC, and work commenced in January 1995. The aim of this research project is to establish whether radio frequency direction finding techniques will function adequately under the non-homogeneous and electromagnetically lossy conditions found in a typical coal mine. If so, then a prototype REBLE (REfuge Bay Locating Equipment) system will be developed. The system will be designed so as to allow several REBLE units to operate simultaneously in a colliery. The REBLE system will be of great benefit to mine safety as it will be a person worn active guidance system that will be operable in the event of fires AND explosions.

The project will be completed in September 1996.

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