Safety in Mines Research Advisory Committee

PROJECT REPORT

A MANUAL FOR BEST PRACTICE FOR EMERGENCY RESPONSE PROCEDURES

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Research Agency: Turgis Technology (Pty) Ltd.

Project No. COL 605
Date: February 2000

Executive Summary

This project was designed to have the following outputs:

- Recommendations for best practices to deal with coal mine emergencies, with emphasis on inrushes, fires and explosions.
- Provide a document from which training staff can formulate and check training manuals and practices.
- A checklist to assist management to review their policies, standards and practices.
- A review of the Department of Minerals and Energy guidelines relevant to emergencies in collieries.

The project reviews and discusses the various topics that could constitute an emergency situation in a colliery. The actions that should be undertaken to prevent such emergencies occurring and if the emergency does occur, how to deal with it, are also covered.

The authors drew on research that is particularly relevant to South African coal mining conditions, upon personal experience and on the opinions of a wide variety of persons with technical and professional expertise in the coal mining industry. International best practice was also reviewed, and included in the work as appropriate.

In the interests of ensuring ease of reference, this report is presented in the following four parts, each of which is presented as a stand-alone document:

Part 1 Causes and prevention of inrushes, fires, explosions and other emergencies.

Part 2 The management of inrushes, fires, explosions and other emergencies.

Part 3 A review of the Department of Minerals and Energy guidelines relevant to inrushes, fires, explosions and other emergencies.

Part 4 A checklist of best practice requirements for the prevention and management of inrushes, fires, explosions and other emergencies.

A bibliography of relevant publications is also given.

The conclusion reached is that legislation, guidelines and many of the existing codes of practice are satisfactory, but where problems occur is in ensuring that they are implemented, that actions required are carried out diligently and that training information is retained.

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A MANUAL FOR BEST PRACTICE FOR EMERGENCY RESPONSE PROCEDURES

PART 1

CAUSES AND PREVENTION OF INRUSHES, FIRES, EXPLOSIONS AND OTHER EMERGENCIES

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1 Introduction

South Africa is the fifth-largest coal producer in the world and the third-largest exporter. In 1998 some 240 million sales tons were produced[1]. These sales amounted to R18 bn of which exports accounted for R10 bn in foreign exchange. The coal industry is vital to the South African economy in terms of employment, foreign earnings, power supply, chemical by-products, fuel, heating, industrial manufacturing and supply industries.

During 1998 approximately 55 per cent of production came from underground workings. The mining methods comprised bord-and-pillar, stooping, rib-pillar, shortwall and longwall mining. The majority of these underground mines are highly mechanised using electrically driven machines to extract the coal.

Although the fatality and reportable injury rates (per 1000 employed) have shown a downward trend from the 1950's to the present day, this trend is marred by incidents of disasters in which large numbers of lives are lost. These disasters are usually associated with flammable gas or coal dust explosions, fires, inrushes of water or mud, or major roof collapses. These catastrophes are unacceptable but are a real consequence of underground coal mining operations.

The promulgation of the Mine Health and Safety Act (29/1996) after the Leon Commission of Enquiry into health and safety has had a marked impact on the minerals industry in South Africa, taking it into a more enlightened period of responsibility towards workforce health and safety. The new Act made health and safety the joint responsibility of the employer, the employee and the State. It requires employers to identify hazards, minimise related risks and prepare codes of practice. Equipment manufacturers and suppliers are now responsible for the safety of their equipment. Health and safety training has become essential for the employees to assume the responsibility for the identification and minimisation of hazards. These concepts embody the principles of co-responsibility and the elements of self-regulation determined largely by workplace risk assessment and management *done in conjunction with the mine Health and Safety Committee*, without which emergency response preparedness and procedures are meaningless.

This manual was complied by extensive review of and extraction from technical and research papers, legislation, Department of Minerals and Energy (DME) guidelines, existing Codes of Practice (CoP) and mine standards and procedures. Interviews were conducted with Mine Managers, Ventilation Managers, other senior officials, managers of the Mines Rescue Services and members of the Department of Minerals and Energy.

An extensive review of documents covering the major disasters in South African Coal mines was undertaken at the Department of Mineral and Energy. Where constructive conclusions could be drawn the findings are built into the text as recommendations for better practice. Specific reference to these occurrences are not made.

Additional reference material for those involved in the management of emergency situations and drawing up Codes of Practice is given. An extensive Bibliography of relevant publications is provided. Users will find this to be a source of a large amount of detailed information.

This document is not intended to be prescriptive but to act as a guide and an aide memoire to users. A comprehensive checklist is given in Part 4 to assist users to implementing Best Practice techniques.

In order for any emergency or potential emergency to be managed successfully, the hazard and risk must first be identified and assessed. Once that has been done and carefully considered, written procedures must be put in place. These should be in the form of Codes of Practice.

All Codes of Practice and procedures require regular review and it is recommended that this be undertaken annually or when some circumstance on the mine changes. It is also essential that the old versions be withdrawn. Many instances have been observed in the mining industry where conflicting and out of date CoPs and procedures are in use on the mine. This should be rectified as soon as possible, wherever it occurs. It is recommended that a control mechanism for the administration of CoPs and mine standards be implemented to administer the issue, review and recall of these documents, incorporating a proper Risk Management System.

The document can also be used by training staff to check the contents of their training manuals to ensure that all aspects of Emergency preparedness are covered. It is also imperative that proper Hazard Identification and Risk Assessments be done on each individual operation to identify and list the significant emergency risks that could be encountered on the operation and strategies have to then be formulated for each and every possible event. This hazard identification and risk assessment process cannot be stressed enough and this document is designed to assist in this process, but each individual operation is unique and all the hazards and risks can only be identified by qualified individuals on the operation.

As a general principle, it must always be borne in mind that:

Any system, no matter how well it is engineered, is ultimately dependent upon human reliability to actually work.

2 Introduction of hazardous substances into the mining environment

The intention is to prevent hazardous substances from being introduced to the mine, particularly unknowingly. This requires a formal procedure to be in place.

Before any material, substance, chemical or other article is allowed into the mine (even on a trial basis) a risk assessment should be done to ascertain the degree of risk it poses *under the circumstance of use* in or on the mine. Note this includes workshops, stores, processing and loading facilities etc.

This risk assessment should be carried out by, or at least in conjunction with, the mine's ventilation department. The fire risk, toxicity and reactivity of the substance, in the circumstance of use, must be assessed. This must be formally documented and kept on record.

3 Flammable gas explosions

3.1 Introduction to flammable gas explosions

Of all the risks in underground coal mining, the most catastrophic and feared is a coal dust explosion. They are capable of completely destroying an underground mine and such events invariably result in a large loss in life.

Coal dust explosions are usually initiated by a localised explosion of flammable gas. There are exceptions such as the explosion of electrical equipment or the free detonation of explosives.

The obvious first line of defence is good ventilation practice to dilute the flammable gas, together with practices to eliminate the sources of ignition for the flammable gas.

Over the last 18 years there have been 81 reported explosions in South African collieries. These explosions have resulted in 232 deaths and 137 injuries(2).

Injuries and fatalities from South African coal mine explosions 1980 - 1998		
Year	**Injured**	**Killed**
1980	2	0
1981	18	12
1982	20	12
1983	16	69
1984	0	6
1985	7	34
1986	9	0
1987	11	35
1988	7	0
1989	4	1
1990	13	0
1991	9	2
1992	2	7
1993	1	53
1994	4	0
1995	0	0
1996	8	1
1997	6	0
1998	0	0
Total	**137**	**232**

A summary of injury and fatality data from 1980 to 1998 is presented in the following table. It is apparent, from these data that considerable improvement has taken place, particularly with respect to the number of fatalities.

3.2 Flammable gas

3.2.1 Sources of flammable gas

Methane is the major constituent of the flammable gases associated with coal. However other highly flammable gases (hydrogen and various hydrocarbons such as ethylene, ethane, butane, pentane etc.) can occur depending upon the constituents, temperatures and pressures involved during its formation. The flammable gas content of any coal can be determined, as well as the rate at which it is released when the coal is exposed during the mining operation.

It is essential that all coal mines carry out tests on their various coal seams to determine the gas content and gas release rate.

Flammable gas is emitted from all coal to a greater or lesser extent during the mining operations in a colliery. Peak flammable gas emissions at the immediate working face increase as a mining machine cuts into solid coal. The emissions then drop to some background value as the machine backs away. Peak concentrations are often several times higher than the average.

In practice, if a working face is not adequately ventilated, these peaks may exceed the lower explosive limit even when the average concentration is satisfactory.

It must also be remembered that when flammable gas is detected in air, even well below the explosive limit, it has somewhere between the source and its point of detection, passed through the explosive range.

For any flammable gas explosion to occur the following must exist:

- **Gas must be present in sufficient quantity**
- **It must have oxygen**
- **It must have a source of ignition**

If any one of the above criteria is not met an explosion cannot occur.

To prevent a flammable gas explosion from taking place:

- **Detect presence of the gas**
- **Dilute below explosive range**
- **Prevent a source of ignition**

Once a gas has been diluted below its lower explosive limit it cannot settle out.

In terms of statutory requirements no persons may work or remain in an area if the atmosphere contains 1,4 percent flammable gas and the electricity supply, with the exception of that controlling the ventilation appliances, should be remotely isolated.

Flammable gas can occur in a colliery, either as a sudden inrush or a slow build up.

3.2.2 Sudden inrushes of flammable gas

Sudden inrushes of flammable gas are caused mainly by geological features but can also be caused by goafing, when pillar extraction or longwall mining is practised, or as a result of the failure of walls in sealed off areas. Flammable gas usually builds up against impermeable geological features especially dykes.

Flammable gas migrates within the coal seam and as the roof and floor normally consist of an impervious material such as sandstone or shale, it remains within the coal seam. When the seam is intersected by a dyke or some other geological feature this acts as a dam wall for the migrating flammable gas and so causes a build up well in excess of the quantities normally contained in the seam. This, together with the fact that the coal in the vicinity of a dyke is normally burnt and de-volatilised, leads to more interstitial space which can contain flammable gas.

From a practical point of view it is extremely important to have a detailed geological plan, which is updated regularly and from which projections can be made. The mining staff can then be warned of geological features ahead of advancing faces. If a colliery is prone to sudden outbursts of flammable gas which are associated with geological features it is recommended that a drilling programme be instituted to drain the flammable gas before mining takes place.

The drilling programme, which should be laid out in consultation with the geological staff, can be done from surface or underground depending on the circumstances. If the depth to the coal seam is relatively shallow and there are no major obstacles to drilling from surface, then this would be the preferred method of flammable gas drainage.

On surface there are no complications in disposing of the high concentrations of flammable gas that would issue from the borehole as it is discharged to the atmosphere. The disadvantage of drilling from surface is that the length of the borehole in the coal seam is relatively short, and depending on the porosity of the coal, a number of holes have to be drilled to ensure adequate drainage.

The alternative method of flammable gas drainage is to drill horizontal holes from underground. The disadvantage of this method is that the high concentrations of flammable gas that inevitably issue from the hole are released into the underground workings. Extreme care has to be taken when drilling is being done and ventilation conditions have to be adequate to deal with any sudden outburst of flammable gas. Once the hole has been completed and gas is issuing from it, it is normally prudent to pipe it directly into a return airway, which has an adequate flow of air to ensure its dilution to below the legal limit.

Sudden inrushes of flammable gas can also occur as a result of failure of walls surrounding sealed off areas. Once an area has been mined out and all equipment removed, including all straining wire and steel, the area is normally sealed off using suitable seals as described in the mine's Code of Practice. Flammable gas levels in these sealed off areas then steadily increase, pass through the explosive range, and then reach levels that can be as high as 80% flammable gas before they stabilise.

Obviously if one of these seals fails then the entire quantity of flammable gas contained in the originally sealed area is available to be released into the mines ventilation system. For this reason, it is imperative to have regular inspections of all seals and the results of these inspections recorded. All sealed areas need to be identified and shown on an underground plan of the colliery with all seals uniquely numbered and demarcated on the plan.

3.2.3 Slow build up of flammable gas

The slow build up of flammable gas in a mine or part of a mine is normally because of poor or no ventilation.

No ventilation is obviously the situation that occurs when an area is sealed as discussed above. In operating areas no ventilation can be the result of the failure of the main fan or fans, failure of ventilation controls or major restrictions in airways.

If the main fans fail, the regulations require that an alarm sound and everybody be withdrawn from the mine. Failure of ventilation controls can occur accidentally or because of poor planning.

Most sections are ventilated by creating an intake airway using brick walls or other suitable seals between pillars, with the fresh air being brought in down the travelling and belt roads to the face and then returning behind the walls into the return airway.

If, for some reason, one of these walls is not in place then the air, which always takes the line of least resistance, will short circuit via the opening and in consequence, will not reach the face. For this reason, it is imperative that miner and his staff check the ventilation walls or seals on their way into the section at the start of the shift. A check that the ventilation at the face is adequate and has not changed since the end of their last shift should also be carried out.

Inadequate ventilation can occur due to poor air utilisation and availability, poor planning resulting in bad mining layouts, restrictions in airways and failure of or lack of ventilation controls. Increased production requirements such as starting a new section from an old one and on a more localised basis, advancing a face too far without adequate auxiliary ventilation, also cause severe ventilation problems.

Instructions given to start a new section may require ventilation walls to be breached so that mining can be started. This can lead to the failure of all ventilation in the old section and if it is still operating, flammable gas levels can rapidly build up with disastrous consequences. (A case reported in the files of the Department of Minerals and Energy where walls were breached to start a new section, led to an explosion in the old section with a resulting loss of life.) For this reason, it should be a requirement as well as good mining practice to have all planning and sequencing involving the starting of new sections approved by the responsible ventilation personnel.

3.3 Sources of ignition

Friction is the principal cause of ignition and can be classified into four types(3):

1. Pick on rock, caused by cutting tools during mining.
2. Rock on rock, as occurs in roof falls.
3. Steel on rock.
4. Metal on metal.

The majority of ignitions are caused by mechanical miner picks striking rock during the coal cutting process and is exacerbated by worn picks rubbing against the rock leaving a high temperature smear of hot material that is sufficient to ignite flammable gas.
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South African coal tends to be hard and mining machinery has to be powerful with between 30 and 40 kW per pick and high drum speeds of around 3 m/s to achieve the required mining rate.

Picks should be examined at the start of every shift and at intervals, as required, during the shift. The water spray system to cool the picks and suppress dust must be correctly functioning with the nozzles clear and pointing in the right direction, with water available in sufficient quantity and pressure.

The system whereby the water spray is directed immediately behind the pick’s cutting path provides the best and quickest cooling (pick path spraying).

Rock against rock contact can occur during roof collapse or barring down. With rock of the correct properties, a single impact can ignite flammable gas.

The impact of steel against rock is well known to be able to ignite flammable gas. This can be caused by as little energy as a pinch bar being used to “sound” rock.

Best practice would be to sample rock in the vicinity of coal seams for quartz content. In the United Kingdom rock containing less than 20 per cent quartz is considered as “probably not a hazard” and rock containing 40 per cent quartz is “definitely a hazard”. The Australians have proposed a five point scale for categorising the ignition potential of their rocks. The situation does not appear to have been investigated for local rock formations.

Metal on metal frictional ignitions can come about through friction building up enough heat and sparking caused by impact / sliding action. Rusty steel, high silicon steel, magnesium alloys and aluminium alloys are particularly prone to sparking.

Particular care should be taken with equipment having light alloy casings or external components, which usually contain magnesium.

Where mechanical miners are used, a risk assessment should be carried out to assess the risk of a flammable gas ignition and should include:

- Gas content of the coal.
- Gas release rate of the coal.
- Quartz content of the adjacent rock.
- Presence of pyrites or other intrusions.
- Presence of burnt coal.
- Ventilation available.
- Method of ventilating the working face.
- Mining method.
- Type of machine and maintenance standards.
- Training and experience of the crew.

Where the risk of a flammable gas ignition is significant, then a machine mounted active suppression system or pick path spraying should be fitted to the mechanical miner.

Electricity is discussed under the section on electrical equipment and its use.

Explosives cause a small but significant number of ignitions. The latest developments in permitted explosives have reduced the risk significantly. Ignitions arising from explosives are normally due to poor blasting technique, mudblasts and open explosions.

Contraband is fully covered in terms of the Regulations

3.4 Ventilation systems

3.4.1 Ventilation system requirements

A ventilation system that is properly designed and effectively implemented is the first line of defence against any flammable gas explosion. There must always be a factor of safety designed into any ventilation system, based on the risk posed by the flammable gas.

To achieve this, a mine should have an adequate number of technically competent ventilation practitioners to give professional recommendations to the mine's senior management and to carry out monitoring and auditing.

In terms of the Regulations, the Manager is required to have in place a formal Code of Practice for ventilating the mine.

In addition to the requirements specified in the regulations, it is recommended that the code have clear and concise definitions of all terms not carrying a clear universally accepted meaning. In particular flammable gas action levels and what is meant by the term "atmosphere" or "general atmosphere" or "general body of the air" and how this term is to be used in the context of the CoP. (e.g. the term "atmosphere" shall mean any point 150 millimetres from the place of issue of flammable gas, measured in any direction).

Standards should be specified for:

- Primary ventilation.
- Auxiliary ventilation.
- Ventilation appliances and equipment (including seals, walls, barricades etc.).
- Mining sequence.
- Minimum air quantities.
- Provision of extra ventilating air if required.
- Action levels for all pollutants (incl. flammable gas).
- Specifications for ventilation management during the shift.
- Pre-use checks and documentation of all ventilation equipment in a section.

Methods of ventilating active headings and working faces must be clearly specified along with all equipment and their relative positions. All duties and responsibilities must be clearly defined.

Whilst statute specifies the maximum allowable concentration of flammable gas in the air as 1,4 percent any ventilation system must be designed for a much lower level. Thus, the maximum allowable concentration would only be reached if there were a serious breakdown in the ventilation system.

There should be formal ventilation planning methodology and documentation, which must be scrutinised and signed by the various responsible persons before any ventilation layouts, or changes to layouts are carried out.

It is well known that one of the most dangerous times with respect to accidents involving flammable gas is during ventilation changeovers, equipment changes, starting up or closing down sections. It is most important that any layout or change include detailed sequencing and makes provision for all necessary precautions.

3.4.2 Methods of ventilation

SIMRAC Report Col 205 "Reduce explosion risks and improve safety and health conditions by better ventilation practices in mechanical miner headings." Persons who are involved in the drawing up of ventilation standards should peruse this report. A brief summary of the relevant points are:

- The use of air jet fans:

There are important variables that influence the behaviour of the airflow in a bord and pillar heading when jet fans are used. A number of rules are given to ensure that correct airflow patterns prevail.

- Controlled recirculation of air.

The practice, as used overseas is discussed and the main conclusions are: The intake air volume should be determined by the flammable gas release rate. Recirculation reduces the risk of ignitions by better mixing of the air and that a force / exhaust overlap ventilation system proved to be superior as it addresses both the flammable gas and dust issues.

- On board air moving systems:

Actual underground tests were carried out and the conclusions are that a normal sprayfan system can only effectively ventilate a heading 6m - 10m from the last through road. When combined with an on-board scrubber this distance can be increased up to 20 m. It is also important that the sprayfan action is concentrated below the boom as methane tends to accumulate there and dust is made during the downward shearing.

This report also discusses roadheader ventilation and higher capacity onboard scrubbers.

- Other systems discussed are:

The Aero Safe Jet System which consists of sprays ejecting high pressure water and air creating massive turbulence to combat methane build up.
However, this system does have a disadvantage in that dust is blown past the scrubber and towards the driver.

The use of air curtains, but it is concluded that it is suitable for dust control only, as it is not effective as a method of controlling flammable gas.

The conclusion reached in perusing research documents and interviewing relevant persons is that the best method of ventilating a heading is the use of a fan and ducting that is robust, cannot be easily damaged and is simple to install. This can be a force system, an exhaust system or a combination of both.

4 Detection systems

4.1 Introduction to detection systems

Detection systems can be broken down into hand held instruments, detection systems on continuous miners and telemetric systems.

4.2 Hand held instruments

4.2.1 Flammable gas measuring instruments

These are in two categories and are subject to the requirements of
SABS 1515:

(1) Range 0 percent - 5 percent CH_4

These are the commonly used instruments for routine gas detection. They are often referred to as “methanometers”. These instruments must be able to be presented to the gas source and no means of aspiration or bringing the gas to the instrument may be used. These instruments give a reading of the gas concentration. They may also give an audible or visible warning.

(2) Range 0 percent - 100 percent CH_4

These tend to be specialised instruments, generally used by the ventilation department for investigative purposes. They may also give an audible or visible warning. There is no restriction on how the gas may be sampled.

4.2.2 Flammable gas warning devices

This is hand held or worn on the body. It gives an audible and visual warning when a pre-set concentration of flammable gas is detected.

4.2.3 Carbon monoxide instruments

These can be either measuring instruments or warning instruments (or both). They are either hand held or (more commonly) body worn. They can be set to give an audible and or visual alarm at a pre-set gas concentration. Most have the facility to give a second alarm at a higher concentration. The current commonly used levels are 100 ppm and 400 ppm, although these may be reduced by proposed legislation.

4.2.4 Other hand held instruments

There are a variety of instruments, other than those mentioned above, available to cover a range of gases. These instruments tend to be specialised in nature and are used, as required, by the ventilation department on a mine.

4.2.5 Problems associated with hand held instruments

Numerous problems have been identified in the mining industry with the use of these instruments and these problems can be easily addressed. These problems could, conceivably, have major repercussions for the mine in case of a serious fire or flammable gas incident.

The common problem areas are:

- Inadequate staffing of the lamproom with respect to numbers and competence of the staff.
- Inadequate supervision of the lamproom by a properly trained person.
- Inadequate record keeping, checking, maintenance and calibration of the instruments.
- Poor design of lamprooms making the collection and user checking of the instruments an unnecessarily long process.
- Failure of the user to carry out his pre-use check.
- Failure of the user to report problems with instruments.
- Confusion over the concentrations of the test gases used in calibration and pre-use checks.
- Test gas past its expiry date.
- Failure of the user to carry out proper gas testing procedures.

It is also a requirement of the DME guideline that users are issued their individual instruments and that a detailed history of each instrument is kept up to date.

All maintenance and calibration must be done strictly in accordance with the Original Equipment Manufacturer's (OEM) procedures for the instrument.

In particular, calibration must be done regularly, the pre-use check, and a means of verifying that these have been done, should be in place.

The issuing and maintenance of both flammable gas and carbon monoxide instruments must be the subject of the CoP for lamprooms.

Regular independent audits of the lamproom to ensure that standards are maintained are considered essential.

4.3 Instruments on mechanical miners

The position of sampling head will depend on the make and type of machine, however, the position must be the best compromise between optimum sampling position and sensor vulnerability. The fitting of a second head as an alternative sampling point and as a back up is good practice.

The operation of flammable gas detectors on continuous miners (and other machines) should be part of a Code of Practice or other formal procedure.
All installation, maintenance, replacement, calibration, testing and operation must be carried out as per the OEM specification.

At the start of every shift and at any other time as required, the instrument(s) must be tested by a suitably qualified and certificated person.

The alarm and machine trip levels must be set as determined by the manager in consultation with the ventilation manager but in any case, the trip level must not exceed 1,4 percent flammable gas as specified by statute.

The instrument should be interlocked with the cutting drum to prevent it operating in flammable gas levels above 1,4 percent or such lower level as may be determined by the manager.

The operator of the continuous miner or other machine fitted with on board flammable gas detection equipment must be trained and certified as being competent in using and understanding the information given by the system.

4.4 Telemetry systems

These are fixed installations sending signals to a centralised facility.

The positions of the detector heads should be determined by the Ventilation Manager or the responsible Ventilation Officer for the area concerned.

This equipment must be installed, maintained, calibrated and tested as per the OEM specification. Persons who are to maintain such equipment should be trained and certified as competent by the OEM.

The position of each detector head should be plotted on a plan and indications of the origin of the air that it is monitoring should be given. A history of each head with a “typical” graph of the normal read out, for comparison purposes, should be available.

Persons who are required to monitor the displays from telemetry heads should be properly trained with the assistance of the OEM.

All persons who are required to interpret data from these heads should be trained and certified competent by the OEM.

A procedure should be in place detailing action to be taken and persons to be notified in the event that any head gives abnormal readings.

4.5 Training

One of the most critical aspects of gas detection is the training of the users of the instrument.

A methodical training programme, drawn up in conjunction with the instrument supplier, is necessary. This programme should not only inform users how to operate the instrument at the level that he or she is required to use it but also give an understanding of why he or she must carry out the tests, or carry the instrument at all times. When the user emerges from the training centre, he or she should be competent in gas testing and certified as being such.

Training in the use of the instruments is important, but the training should be broad enough to ensure that the users know how to react in the event of gas being detected and training should extend to ensure that all users are competent to deal with any emergency which may arise.

Users of gas testing instruments can be checked on the job for competency by the supervisor when he or she passes out of the training centre. In addition, the user should be independently tested on the job at irregular intervals. Those who’s ability is in doubt must be immediately sent for retraining.

By having independent testing the mine has a means of quality assurance for practical flammable and noxious gas testing in place.

All supervisors must check on the diligence of gas testing by their subordinates, while on the job, as failure to test or to test incorrectly is a very common cause of flammable gas incidents.

Complacency about flammable gas testing is probably the most common contributing factor to gas explosions.

5 Barometric pressure changes

The mine must install barometric pressure monitoring equipment that measures and records continuously the fluctuations in ambient surface barometric pressure.

There should be in place a procedure or CoP to cater for the monitoring and interpretation of the data obtained.

The mine should investigate the influence of barometric pressure fluctuations and the rate of these fluctuations underground and establish any changes in flammable gas emissions resulting therefrom.

This information will enable the Ventilation Department to establish alarm levels and develop a strategy to minimise the risk for these events.

6 Coal dust explosions

Apart from coal, dusts of virtually all combustible substances including flour, grain, sugar, aluminium and sulphides can explode. The criteria for an explosion to occur relate to particle size, concentration, ignition sensitivity, oxygen availability and ignition source.

6.1 Mechanism of a coal dust explosion.

Most coal dust explosions occur following a flammable gas explosion. The shock wave from the initial gas explosion disperses coal dust into the air. Provided the individual coal dust particles are spaced far enough apart to have enough oxygen and close enough for the heat produced by one burning particle to initiate the combustion of the next, an explosion can occur and if it does so it will continue until it is stopped by some mechanism or it runs out of fuel.

It is generally accepted that for coal dust to be dispersed into the air, the particle size should be smaller than 240 microns (i.e. that which will pass through a 60 mesh sieve). The minimum concentration of coal dust in the air to propagate an explosion is around 50 g/m^3 and the most explosive concentration occurs in the 150-350 g/m^3 region.

With a detonation, the flame front or shock wave, travel together at speeds of approximately 1000m/s.

6.2 Prevention of coal dust explosions

The Manager is required by law to have in place a Code of Practice for the Prevention of Coal Dust Explosions.

The Department of Minerals and Energy have issued a “Guideline for the Compilation of a Mandatory Code of Practice for the Prevention of Coal Dust Explosions in Underground Coal Mines.” This comprehensive document, drawn up on a tripartite basis, by appropriate technically qualified people, addresses all the relevant parameters in detail. The practices recommended are very suitable for local mining conditions.

These include:

- Minimum stone dusting requirements
- Design, installation and maintenance of stone dust barriers.
- Sealing of abandoned areas.
- General inertisation of coal dust.

It is not intended to duplicate this document in this report.

7 Fires

7.1 Introduction to colliery fires

The historical data for all South African collieries shows that 92 per cent of underground fires are caused by spontaneous combustion, electricity, gas ignitions or welding and flamecutting in that order. Spontaneous combustion accounting for 60 per cent of the total.

7.2 Spontaneous combustion

7.2.1 The mechanism of spontaneous combustion

Spontaneous combustion is a spontaneous exothermic reaction of coal and oxygen under ambient conditions. Whilst the exact process has not been fully determined, it is generally agreed that it takes place in four overlapping stages and can be very briefly described thus:

Oxygen is adsorbed onto the surface of the coal. This is followed by decomposition and an increase in temperature. Carbon Monoxide is the main gas released. Exothermic reactions then take place, increase temperatures to around 150°C to 230°C. Carbon Dioxide is given off. As the temperature continues to rise, combustion of coal begins.

Not only can this occur underground during the mining process, but also more commonly, spontaneously combustion occurs in discard dumps, tips and stockpiles, as well as in silos and ship's holds.

If the quantity of air flowing over a coal surface is very small, then the rate of oxidisation is low and the state of equilibrium is reached whereby heat generation is limited by the availability of oxygen. This is the ideal condition in high resistance air paths, such as goafs in longwall workings, and in sealed areas.

If the air quantity is large, then the heat is dissipated as quickly as it is generated and this cooling effect may be adequate to prevent any significant rise in temperature. This is probably the condition that occurs in almost all the low resistance air paths in roadways.

Other factors affecting the susceptibility of a coal deposit to spontaneous combustion are seam factors, geological factors and mining practices.

7.2.2 Practical measures to prevent spontaneous combustion

It is important to recognise that there is a wide variation in both the temperatures at which gases appear and the volumes generated at a given temperature when comparing different coals. This limits the general applicability of information derived from one specific coal, there is no substitute for obtaining detailed knowledge on a specific coal on any particular colliery.

Testing of coals to indicate their propensity to spontaneous combustion has a long and varied history because of the complex nature of coal and the many methods, by which it is mined, transported and stored. Nevertheless, it is important that the propensity to spontaneous combustion of coal be determined. There are many methods by which this can be done and there are various universities and research organisations in a position to carry out this work.

However, in addition to the inherent nature of coal to spontaneously combust, the situation in a mine may be much more complex and less controllable than conditions modelled in a laboratory.

Bord and pillar workings:
Spontaneous combustion usually starts in piles of broken coal from roof falls, spillage or pillars that have fractured. Unmined top coal can also be affected.

The solution here is good housekeeping and vigilance.

Pillar extraction:
The nature of pillar extraction means that it is difficult to ensure that no broken coal is left lying in the goaf. Ventilation of pillar extraction is a problem as low airflow, conducive to spontaneous combustion can occur. In mines where spontaneous combustion is a problem vigilance is required when extracting pillars, especially when snooks are left in the goaf. Again, good housekeeping is required.

Longwalls:
Retreating longwalls could have a pressure differential over the goaf depending on the presence of a gas bleeder road through the goaf. Seals can be built in the gate roads behind the face.

Advancing longwalls will have a pressure differential over the goaf and sealing must be undertaken.

Worked out areas:
Worked out areas tend to deteriorate. Falls of ground and pillar scaling take place. There are only really two alternatives, keep fully ventilated and inspected or seal off completely. A poorly ventilated and essentially abandoned area increases the risk of spontaneous combustion and a build up of flammable gases.

Monitoring:
Potential sites of spontaneous combustion including tips, dumps and silos should be monitored.

Given the accuracy and sensitivity of modern gas monitoring systems and the existence of carbon dioxide in normal air, the most appropriate gas indicator of the onset of heating is carbon monoxide. At higher temperatures significant quantities of methane, hydrogen, ethane and ethylene can be evolved. At these higher temperatures, it is possible for sufficient quantities of these gasses to be evolved to generate an explosive atmosphere. Monitoring air velocity is important as low velocities are conducive to spontaneous combustion.

The installation of a continuous monitoring system and following the trends in carbon monoxide, flammable gas and temperature levels is therefore a prerequisite for maintaining control of spontaneous combustion.

In addition, smell is a good indicator of spontaneous combustion.

7.3 Electrical ignitions

7.3.1 Introduction to electrical ignitions

Electrical ignitions can be categorised as those causing:

- An ignition of explosive gases or dusts, usually methane and coal dust in the case of coal mines;

- An ignition of flammable material, e.g. coal or combustible electrical materials, such as transformer oil or cable insulation.

The electrical ignition prevention methodology for each of the above categories differs and will be described separately.

7.3.2 Ignition of flammable material

The current drawn to provide power to electrical equipment causes a rise in the temperature of the current carrying parts of the equipment. The rating of electrical equipment is dependent on the maximum temperature that the insulation can withstand without damage and the equilibrium between the heat caused by the flow of current and the degree of cooling of the equipment at that temperature. This point is emphasised since overheating of electrical equipment can occur due to poor cooling as well as overloading. Normal electrical overload devices are incapable of detecting poor cooling.

Thus, electrical equipment can overheat due to:

- Overload; or
- Inadequate cooling.

The two sources of inadequate cooling most frequently encountered in mining are:

- Placing equipment in an location which is poorly ventilated; and
- Equipment being covered by a heavy layer of dust or material.

7.3.3 Types of overload

Two forms of overload are possible. The most frequent form of overload occurs when a machine or device is operated at a load in excess of that for which it is designed. This is the form of overload that is normally referred to as an overload by electrical personnel.

A particularly severe form of overload takes place when a fault between two or more phases occurs. This type of fault is known as a phase fault or short circuit. In this event the currents flowing in the supply to the fault can be as much as 10 000 times the designed maximum current for the system. Such high currents cause equipment to heat up rapidly, and in addition cause release of energy at the site of the fault that is equivalent to a substantial explosive charge.

Numerous cases of flameproof enclosures totally disintegrating due to an electrical short circuit have occurred in South African coal mines. Such an event may result in the ignition of flammable gas or dust or severe injury to persons in the vicinity.

7.3.3.1 Prevention of overloading

Two types of electrical relays are provided to protect against each of these circumstances, so-called overload relays for the less severe case and relays known as overcurrent relays for the severe case. In the former, the relay usually has a delay built in, which takes cognisance of the slower heating effect of a normal overload. The latter relay is instantaneous in action and attempts to trip the supply in the shortest possible time.

These safety devices are frequently abused in mining operations. Unlike the abuse of mechanical equipment, electrical abuse is unlikely to manifest itself during normal operations. The abuse of these devices is usually only evident when they are required to operate in an emergency and fail to do so.

7.3.3.2 Abuse of protection relays

The most frequently encountered forms of abuse are the following:

- Overload relays set to the maximum setting or set far too high for the cables or machines being supplied with power.
- Overcurrent relays on the primary side of a transformer being set too high for a fault between the transformer secondary terminals and the first secondary circuit breaker.
- Failure to connect the overcurrent back tripping facility from gate end boxes to the circuit breaker feeding the gate end boxes when the contactors in the gate end boxes are not designed to break a phase fault.
- Failure to set the overloads on the circuit breaker feeding a bank of gate end boxes to the designed rating of the cable or gate end box busbars, whichever is the lesser.
- Feeding a small machine such as an electrical fan or a pump off a gate end box with overloads set for high power machines such as continuous miners or shuttle cars.
- Increasing the setting of overload or overcurrent relays if a trip out occurs without determining the reason for the trip out.
- Assuming that the rating of electrical equipment has a built in safety margin.

7.3.4 Inadequate cooling

Inadequate cooling can result in electrical equipment overheating if it is operated at or near the rating of the equipment.

The overheating can result in an immediate ignition of material such as coal or coal dust if the heat rise is sufficiently high. A less obvious effect of overheating is the deterioration of insulation that will only be apparent at a later stage. This deterioration will invariably lead to a phase fault at some later stage.

The most frequently encountered causes of overheating in coal mines are:

- The lack of adequate ventilation over electrical equipment. This occurs in substations that have been closed up to comply with the regulations, without a form of ventilation being applied.

- Transformers and banks of gate end boxes placed in dead ends and other locations where ventilation is negligible.
- Equipment being covered by material. In most cases this applies to cables which are laid or have fallen onto the floor and are covered by coal or other materials. If the coal is wet the condition is not serious, but the heat from the cable might dry the coal leading to worse cooling and a far greater risk of ignition.
- Dead turns of trailing cable on shuttle car reeling drums. This usually occurs when a shuttle car is operating close to the gate end box and a substantial proportion of the cable is left on the drum at all times.
- Equipment covered by a layer of coal or stone dust. In the case of coal dust, apart from interfering with the cooling of the equipment, the coal dust can be raised to a temperature at which it will start to smoulder.

7.4 Ignition of potentially explosive gases and dusts

7.4.1 Nomenclature for explosion protected electrical equipment

The methodology for preventing electrical ignitions of gases and dusts is fairly well known and extensively applied in the hazardous locations in coal mines. The measures consist of the various explosion prevention techniques such as:

- Flameproof apparatus, also known as **Ex 'd'** apparatus;
- Intrinsically Safe apparatus, also designated **Ex 'i'** apparatus;
- Various other lesser known prevention techniques such as Increased Safety (**Ex 'e'**), Encapsulation (**Ex 'm'**), Purged and Pressurised (**Ex 'p'**) apparatus.

The primary safety measure is to ensure that explosion protected apparatus is installed and maintained in a safe condition. Reference to SABS 086 Part 2 – "The Installation, Inspection and Maintenance of Equipment used in Explosive Atmospheres on Mines" is recommended in this regard.

In addition to explosion prevention techniques, the legal requirement to isolate all electrical supplies, other than certain Intrinsically Safe (**Ex'i'**) as discussed below, in the presence of flammable gas is a further action to prevent such ignitions.

Of importance in the planning of emergency procedures to deal with flammable gas concentrations in excess of 1,4 percent, is the directive from the Department of Minerals and Energy with the requirement that only Intrinsically Safe apparatus classified as **Ex 'ia**' may remain energised in this event. This implies that any flammable gas detecting instrument, whether hand held or fixed, air flow meters and any other electrically operated equipment must satisfy the requirements for **Ex 'ia'** apparatus. Presently a certain amount of this type of apparatus is either purely classified as **Ex 'i'** or is classified as **Ex 'ib'**. This apparatus may not be used if the presence of flammable gas has been detected.

The Approval Authority reports and Test Certificates must be examined to determine whether the apparatus complies with the above requirement.

The Department of Minerals and Energy is currently considering the introduction of a period of grace during which mines may phase out existing non-compliant apparatus.

Explanation on the Classification of Intrinsically Safe (**Ex 'i'**) Apparatus

In the past all Intrinsically Safe apparatus was designed, built and subjected to identical test procedures. Subsequently, two classifications for Intrinsically Safe apparatus were introduced, namely **Ex ‘ia’** and **Ex ‘ib’**. In the case of the former, extra safety standards were introduced into the design of the equipment and the specified test procedure is more stringent than for **Ex ‘ib’** apparatus. The Chief Inspector of the Department of Minerals and Energy followed international practice by directing that only **Ex ‘ia’** apparatus may remain energised in the presence of flammable gas.

Older apparatus may have been tested and certified to the original **Ex ‘i’** classification. Newer **Ex ‘ib’** apparatus is normally cheaper than **Ex ‘ia’** apparatus but must be isolated if flammable gas is detected.

7.4.2 Some misconceptions about explosion protected equipment

These misconceptions are noted in SABS 086 Part 2, but are repeated for the sake of completeness of this document.

7.4.2.1 Coal dust explosions in substations or in electrical equipment

It is frequently stated that coal dust explosions can only be initiated by a flammable gas explosion. This is possibly due to the fact that the coal dust explosions demonstrated at Kloppersbos are initiated by flammable gas.

Layers of coal dust on equipment in a substation can result in a short circuit that has sufficient energy to raise the dust into a cloud. Since a short circuit generates extremely high levels of energy, the coal dust, if not passivated with stone dust, can explode. In addition, a short circuit in a cable, air-cooled transformer or switchgear in the hazardous locations in a coal mine may similarly raise clouds of non-passivated coal dust.

The energy released during a short circuit fault, supplemented by the energy in a coal dust explosion may result in total destruction of the flameproof transformer or switchgear.

7.4.2.2 Ability of flameproof enclosures to withstand internal electrical faults

As stated above, electrical phase faults (short circuits) release energy that is far in excess of that released by an ignition of flammable gas inside the enclosure. In most cases, severe damage to the enclosure will result. The explosion can cause the enclosure flame paths to open up and could cause injury to persons or the ignition of flammable gas, if present. In some cases, covers have blown off the enclosures or the enclosures have exploded when short circuits have occurred within the enclosure.

7.4.2.3 Pilot wire systems

Because the supply to a pilot wire system is intrinsically safe, the system itself is assumed to be intrinsically safe. This is not the case since the currents in the adjacent power cores in a cable can induce voltages that are far higher than can be tolerated in an intrinsically safe system.

Therefore, any devices used with pilot wire systems must be flameproof or certified by a test authority as encapsulated for use in hazardous locations. (Note - Normal encapsulation intended to make equipment water proof does not comply. The encapsulated apparatus must be certified for use in the presence of methane or coal dust.) This applies particularly to remote switches such as float switches for pump starting.

7.4.2.4 Battery operated machines and welding of battery posts

A popular misconception is that all batteries are intrinsically safe. This is certainly not the case. Most batteries used for starter motors and all batteries used for traction are not intrinsically safe.

Loose connections between cells in a battery will generate sufficient heat to ignite flammable gas or coal dust, or for that matter other flammable material in contact with the terminal. The battery posts on battery operated equipment should be inspected before the machine is put into use on each shift. If any sign of overheating or melting of a post is detected, the machine should be withdrawn from service until the problem is eliminated.

As a further result of the misunderstanding of intrinsic safety, the traction batteries are often used to provide power to repair welded battery posts. A carbon electrode is used to melt lead on or onto the damaged post. This practice is dangerous in a hazardous area since the arc temperature is well above the ignition temperature of flammable gases.

7.5 Ignitions due to mechanical equipment

As with electrical equipment, mechanical equipment can cause ignitions of explosive gases and coal dust or other flammable material. Similarly, the preventative techniques differ for the two cases.

The primary cause of ignitions of flammable material arises from friction in the mechanical context. The two major machinery types where such conditions arise are:

7.5.1 Mobile mining machinery

In the case of mining machinery, binding brakes on shuttle cars, load haul dumpers (LHD's) or battery scoops are fairly frequently encountered. Due to the power of the drives of these machines a binding brake will rapidly heat up to a temperature where the brake drum or disc can be seen to be glowing. At temperatures well below this point, the temperature can still be high enough to cause ignitions. Although a glowing brake drum or disc is obvious, cases have been noted where the operator ignored the problem and continued to operate the machine. One mine fire in an overseas colliery was reportedly attributed to an overheated brake.

Apart from the brakes on mobile machines, any situation where rubbing of moving parts occurs can result in overheating. This can be due to collapsed or damaged bearings causing a drive shaft to rub on a casing.

7.5.2 Conveyors

Conveyor fires are a relatively frequent occurrence in both surface and underground applications. In the case of underground conveyors, particularly those near the face, the conveyors are operating in an environment more conducive to conveyor fires.

Conveyor fires typically arise as a result of:

- The drive pulley slipping due to inadequate belt tension on the return side of the drive pulley or due to overloading of the belt;
- Conveyor belts rubbing on steelwork due to a misaligned belt;
- Idlers or pulleys not rotating due to spillage or bearing collapse.

The most rapid cause of a fire is a stalled conveyor. The use of belt slip interlocks is strongly advocated to prevent such an occurrence. Belt slip interlocks, if used, will usually alert staff immediately of the problem, and if a fire occurs, it can be rapidly extinguished. These interlocks should be routinely tested.

Friction may cause a component or part of the conveyor structure to overheat to the extent that spillage may be ignited. The disastrous Kings Cross Station fire in the UK was caused by frictional heating.

A more insidious cause of conveyor fires is a build up of heat due to friction in some component part of the conveyor. At the end of shift when the conveyor is stopped, the heat may be sufficient to initiate a slow fire that is not immediately detected. Such a fire can spread from the belting material to the coal on the belt. Alternatively coal dust or spillage may be ignited without the belting being involved in the initiation of the fire. The use of flame retardant conveyor belting does not guarantee that such a fire will not occur.

Idlers or pulleys that are covered with spillage can also result in a fire that can remain undetected for some time. The heat of friction can result in the spillage being dried to a point where it is easily ignited. As the fire spreads, other spillage in the vicinity dries and contributes to the spread of the fire.

7.5.3 Frictional flammable gas and coal dust ignitions

The ignition of flammable gas by picks on continuous miners and coal cutters is well known and preventive measures are well documented.

7.5.4 Diesel machinery

Likewise the ignition of potentially hazardous gases and dusts by diesel powered machines is also well documented.

In both the above cases adherence to correct operating and maintenance procedures will control the risk of ignitions from these from these sources.

Non-flameproof Diesel Powered Machines

Non-flameproof diesel powered machines are permitted to be used in the non-hazardous locations in coal mines provided certain conditions are met. Adherence to these conditions will obviate ignitions under normal circumstances.

A real danger exists in the event of an emergency that may result in dangerous levels of flammable gas or coal dust in the atmosphere in the vicinity of the incident. Under these circumstances, it is likely that non-flameproofed vehicles may be used to carry out emergency evacuations or transport rescue teams to the site of the incident. The non-flameproofed diesel vehicle could be extremely dangerous if used in a hazardous location under these circumstances.

7.6 Miscellaneous causes of fires

7.6.1 Welding and flamecutting

Whilst fires caused by welding and flame cutting are comparatively few in number, they still occur.

In a fiery mine all cutting, welding, grinding and similar operations must take place in a workshop approved by the DME. The regulations (15.10) are very specific about the requirements for these workshops. A system of storage, issuing and record keeping must be put in place and audited. Only persons appointed in writing should be permitted to use such equipment.

Only under special circumstances with adequate controls and gas testing may any such work be done outside an established workshop.

Obviously adequate fire fighting equipment must be immediately available, particularly an adequate supply of water. Flash back arrestors must be fitted to oxyacetylene equipment. All oils, paints, grease, and other flammable fluids must be stored securely, away from flame cutting, heating and grinding operations. Good housekeeping is essential, and all rubbish, oily rags, accumulations of grease etc. must be removed before any flame cutting or welding is carried out.

A Code of Practice of other procedure should cater for welding, flame cutting and other “hot work” as well as photography, video and audio recording and use of other electrical equipment and instrumentation.

7.6.2 Blasting

An ignition or explosion of flammable gas or a coal dust by explosives is often due to blown out shots which is a function of the blasting technique used (type of delay fuse) or when inadequate tamping of the shot hole occurs. Mud blasts are also a cause.

Prevention is by ensuring correct blasting procedures and stone dusting right up to the face when it is anticipated that blown out shots may occur, particularly when blasting through geological discontinuities.

7.6.3 Diesel filling stations and oil/grease stores

Regulations 10.25 cover the use of diesel equipment underground, including refuelling and must, of course, be fully complied with.

The transporting and storage of large quantities of diesel fuel underground necessitates careful consideration. A tank of diesel is a major fire hazard. Preferably, all refuelling stations and storage areas should ventilate into the return airway and be able to be sealed off in case of a fire. They should be constructed so that the tank(s) cannot be damaged or ruptured by the vehicles being refuelled. Bund walls with sand or gravel that can cope with the entire volume of the tank plus a 20 percent margin of safety should be installed.

Drip trays and a means of metering fuel volumes should be available. Water sprays covering the entire refuelling station should be installed with the activation valve situated on the intake side.

Water sprays provide cooling, particularly of the tank itself. An adequate number of 9 kg fire extinguishers must be provided also downstream of the airflow.

All refuelling stations and oil stores should be commissioned by the responsible engineer and the ventilation department. Their condition should be regularly checked and logged by an accountable person.

7.6.4 Rubber tyre stores

Rubber tyres are flammable, produce vast amounts of dense black smoke and are very difficult to extinguish.

Unless there are good reasons, rubber tyres should not be stored underground. If underground storage is considered an absolute necessity then the minimum number of tyres should be kept in the stores.

The best method of storing these tyres is under water. If this is not an option, then the tyre store should ventilate directly into the return airway and a spray system should be positioned above the tyres.

Old tyres should not be left lying around underground "in transit" but removed immediately out of the mine.

Once a rubber tyre is well alight, the only way to extinguish it is by water, assuming that one can approach it through the dense smoke and heat. The tyre by this time is so hot, that it simply re-ignites if fire extinguishers are used.

7.6.5 Compressors

Good housekeeping, maintenance and checking on high temperature trip out circuits will ensure safe compressor operation. This must be allocated to a qualified and accountable individual.

7.6.6 Plastics

All plastics used in mines should be subject to a risk assessment. Factors to consider are:
- Ease of ignition
- Toxicity
- Flame spread
- Ability to support combustion
- Quantity used
- Storage conditions and quantities
- Circumstance of use

It must be borne in mind that small scale laboratory tests do not reflect the situation when large quantities of a particular material are used underground.

The CSIR Division of Building Technology (Fire Engineering Section) are able to carry out full scale tests on materials used in the mining (and other) industries.

Plastic pipes.

When HDPE pipes are used underground, firebreaks should be installed at regular intervals. These could be 5 m to 6 m long lengths of metal or UPVC pipe.

A single HDPE pipe is not a major fire hazard, however the risk increases with multiple pipes in bundles and increases even more when the pipes are angled or are vertical.

7.6.7 Surface Fires

Numerous instances of veld fires damaging mine property or being "carried" underground have been recorded. All flammable material (vegetation etc.) should be cleared away from mine entries and collapsed shallow workings (particularly the more remote ones) to create a fire break. This should be done in the appropriate season and should be inspected and logged regularly.

7.7 Code of Practice

A Code of Practice should be in place to cater for the requirements for siting, selection, installation, operation and maintenance of all electrical and mechanical equipment, workshops and all stores. It should also cover accountability to individuals for ensuring the requirements for fire preparedness in the various working sections are complied with.

7.7.1 General fire prevention measures

All electrical equipment must be installed in an area that is totally free from flammable gas. The area should be kept clean of coal dust, flammable material and any general rubbish. Where appropriate it should be securely fenced off.

Electrical equipment should be installed so as it can be ventilated directly into the return airway, or when this is not possible be equipped with doors that can be closed in the event of a fire so that the smoke an fumes do not contaminate the intake air. This is particularly important when oil filled equipment is used.

Installations, particularly sub-stations and transformers should, where appropriate, be installed in especially constructed areas (i.e. with bunds and walls). It is preferable that only dry (oil free) transformers and switchgear should be purchased for use underground.

Fire fighting equipment, of the type and quantity that is appropriate to the hazard must be provided, installed correctly and maintained at all relevant electrical and mechanical installations, on mobile equipment and other places as necessary. A good and readily available supply of water is necessary at all places where rubber tyred mobile equipment operates or travels. Any point on the route should be able to be quickly reached with a hose.

Only flame retardant cables and adequate cable jointing materials should be used underground. Cables should be suspended and protected from damage. Where numbers of cables run together, adequate fire breaks should be provided at least every 100 m.

In terms of Regulation 11.1.2.(b). A Code of Practice is required for the organisation of fire prevention, fire fighting and fire drill.

Legal appointments under Regulation 11.1.2.(c). are intended to cover all fire fighting appliances on the mine and not, as is often thought, only the equipment allocated for the

Rescue Brigade. This would therefore entail several appointments. It is suggested that the Shift Boss or equivalent be appointed for his section.

7.7.2 Fire detection

Depending on how the shifts on the mine are operated a Fire Patrol can operate either daily or over weekends and public holidays. Legally one must have a means to detect fires or spontaneous heating, if the interval between shifts is 6 hours or more.

Best practice is to be able to detect, and so be able to fight, a fire as soon as possible. The ideal is a suitable balance between the human nose and an electronic system.

To date, an “electronic nose” that detects trace odours is not commercially available in this country for fire detection, although developments are in progress overseas on this type of device. An incipient fire starts to give off odours before it gives of the quantities of gas that are currently needed to trigger detector systems. It is quite possible, that in the future, electronic fire detection systems will be odour sensitive.

Underground mining personnel should be taught at initial and refresher training to recognise the smell of smouldering coal.

All persons who are involved in the detection, monitoring and/or the interpretation of data from electronic fire detection systems should be fully trained.

The placing of electronic detector heads requires a detailed knowledge of the airflow pattern of the mine and a suitable balance between smoke and carbon monoxide detector heads. Current indications are that smoke heads tend to pick up burning coal and conveyor belting quicker than CO heads but one should not be used to the exclusion of the other.

Products of combustion and heat sensitive heads are also available.
Placement of heads.

- Conveyor belts
- Intake airways
- Inbye workings
- Return airways

The tube bundle system, which is able to draw gas samples to a place where they can be analysed (usually surface), has largely been replaced by modern electronics.

Personal CO monitors must be regarded as part of the overall fire detection strategy of the mine with personnel being taught to report any unexplained and/or abnormal CO levels immediately.

As with all equipment, fire detection equipment is only as good as its care and maintenance.

Chemical Detector Tubes
They are very useful for giving an “order of magnitude” indication of the problem but due to the nature of the information display, differences in sampling pumps and pumping technique as well as cross sensitivity, moisture levels etc. they should not be used as “absolute” readings. Under laboratory conditions, the tolerance is ± 25 per cent.

7.7.3 Action in case of a fire

The first course of action is, obviously, to fight the fire immediately on detection if this can be safely done. Generally speaking, if an underground fire cannot be brought under control in the first two or three hours then sealing or inertisation will be the only option.

Even if a fire is being successfully fought, it is still prudent to evacuate all non-essential personnel from the area that is affected or could potentially be affected.

The techniques of conventional fire fighting are well known and need not be elaborated on. The Mines Rescue Services not only train the Rescue Brigadesmen but keep up to date with all the latest firefighting techniques and should be consulted for fire preparedness and fire fighting advice.

The various graphical methods and ratios (Fire Indicators) have been devised to assist in monitoring the state of a fire (Coward triangle, USBM diagram, Graham’s Index, Willet's Index etc.)

These Fire Indicators and layouts for pressure balancing seals are given in the appendices to SIMRAC REPORT COL 031

Accurate gas analysis is now available by means of the MOGAL (Mobile Gas Analysis Laboratory) and the Mines Rescue Services Gas Chromatograph.

Good sampling techniques are essential for any fire monitoring. Of particular importance is to get a representative and uncontaminated sample. This can be particularly problematical when there are low pressure differences over the seals and barometric pressure changes can result in contaminated samples. A technical paper by Fauconnier and Beukes listed in the bibliography discusses this in detail. Another technique that can be used when Rescue Brigadesmen are in the area with breathing apparatus, is to take a plastic 2 litre carbonated soft drink bottle full of water, proceed to the sampling site, empty the bottle and reseal it. The water will be replaced with a sample of the air/gas that is required to be analysed.

The technique of inertisation also merits a mention, which although occasionally used, is perhaps not as popular here as it is in Europe.

The methods commonly available for inertisation are Nitrogen Injection and the jet engine inert gas generator. Both methods have not only been successfully used to extinguish fires, but to prevent sealed off areas from entering the explosive range or taking sealed off areas out of the explosive range. A technical paper by Walters listed in the bibliography discusses this topic in some depth.

The mine should have a Code of Practice or procedure in place that covers fire preparedness, fire prevention and fire fighting. Responsibilities should be clearly stated in this document.

SIMRAC Project COL 031 – “Review of Practices for the Prevention, Detection and Control of Underground Fires in Coal Mines” discusses these topics in detail. It is recommended that all coal mines should have a copy of this document.

7.8 Training

All mine personnel should be trained in the actions required of them in case of a fire. The primary actions should be:

- Raise the alarm – Report the fire, giving concise details to the appropriate location.
- Attempt, if possible to fight the fire, if this can be done do safely.
- Evacuate all non-essential personnel and if the fire cannot be safely fought, evacuate everyone.

8 Avoidance of hazards caused by lightning

8.1 Hazards

Underground: Premature detonation of explosives.
Ignition of flammable gas in abandoned and accessible areas.

Surface: Premature detonation of explosives.
Injury to persons working on mobile electrically powered equipment and tall metal structures.
General: Injury to persons or damage due to inadequate bonding and earthing at surface refuelling bays, main fans, electrical substations etc.

It should be noted that an electrical storm could exist in "clear sky" conditions.

8.2 Avoidance measures

The following avoidance measures should be introduced:

- Adequate bonding and earthing of metal work and electrical power supplies.
- Removal of metal, except roof support, longer than 300 mm.
  and metal equipment from areas to be sealed.
- Scheduling sealing operations out of the lightning season.
- Removal of bore hole casings and sealing of bore holes.
- Electrical storm warning system.
- Use of “Stat-Safe” detonators.

In order to assist Managers to carry out a risk assessment, details are given in SABS publication SABS 03-1985 indicating the potential for lightning strikes in various geographic areas of the country.

This risk assessment should also take into account depth of workings, the likelihood of explosive atmospheres in abandoned areas as well as water aquifers and soil resistivity.

8.3 Siting and operation of an electrical storm warning system

Electrical storm warning systems should be placed at suitable strategic points to ensure adequate warning of an approaching electrical storm from a distance of 20 km. Such system must be able to sound an alarm should a storm pass within 10 km. This system should be monitored at all times when production or maintenance is in progress on either surface or underground at the mine.

The system should be regularly tested and the tests recorded. All persons who are required to monitor the system and / or to interpret the results should be appointed in writing and fully trained and certified competent.

8.4 Storm warning procedures

All actions, alarms, persons notified etc. should be recorded on a standard form as part of the Lightning Hazard Avoidance Procedure or CoP.

When a lightning strike is detected at a distance of 20 km, all necessary persons or their alternates/deputies designated by the Manager should be informed. If shot holes are charged up and ready to be fired then the firing should take place. If this cannot be done then before abandoning an already charged or partially charged system, all wires from the remote side of the detonators should be connected together to prevent a circuit forming. These wires should be insulated or kept away from the floor, roof or sides. All shot firing activities should cease until an "all clear" is issued.

When a lightning strike is detected at 10 km, the storm evacuation procedure should commence. Persons should be withdrawn to a safe place where they cannot be injured by premature detonation of explosive. All work on electrically powered mobile equipment and tall metal structures should cease.

When the storm has passed beyond 10 km, a notification should be issued permitting all work other than shot firing. Shot firing may be carried out once the storm has passed beyond 20 km.

There should be in place a document detailing action to be taken, emergency services to be summoned and persons to be called out, in response to an incident caused by a lightening strike.

9 Inrushes of mud, water, noxious gas or flammable gas

9.1 Causes

Holing into abandoned workings or surface accumulations.

9.2 Prevention

In all cases the provisions of The Mine Health and Safety Act, Regulations 7.10.1 to 7.10.9 inclusive – “Working near water or gas: Precautions” must be adhered to.

9.2.1 Mining of new areas

The Manager should establish a system to inform the Chief Surveyor and the Ventilation Manager of all new areas to be mined or any deviation from the conventional mining plan.

Before such mining operations commence, a risk assessment must be conducted to analyse the hazards and identify the associated risks. All relevant information (e.g. geographical, topographical) and appropriate plans must be utilised and this information kept. The correctness of all relevant plans must be considered. Should the risk assessment identify other persons who are not in the employ of the mine and may be affected, they must also be consulted. The layout plan should reflect at least the following information:

- Mining layout with dimensions
- Ventilation layout
- Bore hole positions
- Any restrictions to mining
- Significant geological features
- Accumulations of water, mud or gas
- Approval in writing by Manager, Chief Surveyor, Ventilation Manager and any other relevant official allowing the plan to be issued.

9.2.2 Mining towards any mined out area, abandoned workings or surface accumulations of water, mud or gas where the position of which is known with reasonable certainty

Care should be taken when measurements on older plans are given in Imperial units.

Prior to any mining commencing within a specified distance from any mined out area, abandoned working or surface area that could contain accumulations of water, mud or gas, the Manager should conduct a risk assessment and implement at strategy in writing. This should be done in consultation with the Chief Surveyor, Ventilation Manager and any other relevant officials whereby the risks are identified and control measures are put in place to manage the risks. Those officials consulted by the Manager should submit their reports in writing and these documents should be retained.

9.2.3 Mining towards mined out areas or abandoned workings which are accessible

The Manager should consider the written reports of the officials he has appointed to physically examine the area in question and ascertain that:

- The position of such workings is accurately known.

- The area is free from noxious or flammable gases and can be maintained in such condition by means of adequate ventilation.

- Any significant accumulation of water or mud is identified together with its extent and estimated volume and that this is indicated on all relevant plans.

Should an examination of the mined out area or abandoned workings indicate that noxious or flammable gases are present or that any accumulation of water or mud or any other circumstance is such that it could pose a risk, the Manager should implement a strategy in writing, in consultation with the Chief Surveyor, Ventilation Manager and any other relevant officials which shall cover at least:

- The method of mining, including all precautions.

- Any de-watering or de-gassing operations that are to be undertaken together with the equipment, procedures and sequencing of the method to be used.
- All control measures and supervision arrangements required.

9.2.4 Mining towards old mines, abandoned workings or worked out areas where the position is not accurately known and which is not accessible

Attempts must be made to ascertain to a reasonable degree of certainty the position of the abandoned workings and all relevant plans should be scrutinised including those held by the Department of Minerals and Energy and the State Archives where appropriate.

Again, particular care must be taken when measurements on older plans are given in Imperial units.

The Manager should carry out a risk assessment in formal consultation with the Chief Surveyor, Ventilation Manager, any other relevant officials and/or persons or agencies who may be able to provide information or assistance.

All documentation and reports upon which the risk assessment and subsequent strategy is based should be retained.

The Manager should develop and implement a written strategy, in consultation with the Chief Surveyor, Ventilation Manager and any other relevant officials, that takes due cognisance of the risks, and gives detailed instructions with respect to the mining plan, any restrictions and limitations imposed, equipment used, control measures and supervision requirements.

This written strategy should be made available to all relevant officials and miners / artisans who should acknowledge in writing that they understand the contents and will comply with its provisions.

The Manager should ensure that all relevant employees are made aware of the risks of mining in the area and the requirements and controls of the mining strategy.

All survey plans should indicate the area concerned as a high-risk area.

9.2.5 Mining towards surface accumulation of water or mud

The Manager should develop a written strategy in consultation with the Chief Surveyor, Ventilation Manager and any other relevant officials, which addresses the identified risks. This strategy must consider the competence of overlying material the stability of the underground workings, and any bore holes and geological features of significance. The cautionary zone for approaching the accumulation should be indicated on survey plans.

The written strategy should be provided to all relevant officials, miners and artisans who should confirm in writing they understand the contents and will comply with its provisions.

9.3 Response to an incident involving an inrush of water, mud or gas

The mine should have a written procedure in place, detailing action to be taken in the event of an inrush. This document should cover at least the following:

- Action to be taken by persons immediately affected by the inrush, this should be part of the initial and refresher training.
- Establishment of a control and notification of management.
- Summoning adequate rescue personnel.
- Evacuation of persons.
- Establishing the extent of the problem.
- Actions to be taken to manage the problem.

10 Flooding and abnormal weather

(Flow of water into or damage to mine property or workings from an external source i.e. dam collapse, exceptional rainfall, winds etc.)
The Manager should carry out a risk assessment in consultation with the Chief Surveyor, Environmental Manager and other relevant officials as to the likelihood of the mine, both underground and surface workings, the infrastructure including dumps, tips and accommodation being affected by the flow of water from some external source such as nearby dams, rivers in flood, exceptionally heavy rainfall (i.e. I in 100 year rainfall) etc. Based on the result of this risk assessment, appropriate precautionary steps should be put in place to alleviate the potential damage.

Response to an incident of flooding or abnormal weather.
A written document detailing action to be taken and covering:

- Establishment of a control station.
- Rescue procedures.
- Notification of emergency services.
- Alternative emergency accommodation arrangements if required.
- Situation management for the duration of the emergency.

11 Major roof collapses and floods (persons trapped)

Major roof collapses where workers are trapped underground has been well documented in the available literature. Workers can also be trapped by a sudden inrush of water, which will accumulate in a low-lying area of the mine and cut off workers in higher lying areas. For completeness, this section has been included, detailing the equipment that is available in South Africa to deal with such problems.

After the Coalbrook disaster in 1960, when 435 miners were entombed following a major collapse of the workings at the colliery, the South African coal industry took a number of bold steps. Firstly pillar design was investigated and researched, which resulted in the development of a scientific method of pillar design. Secondly the Industry together with Ingersoll Rand of the United States developed a drill rig which could drill a 64 cm hole. This machine was commissioned in 1977 and is housed at the Colliery Training College in Witbank[4].

The drill is run by a team of 7 operators and drivers who have been trained to use the equipment and who are also responsible for its maintenance. This rescue drilling equipment is totally self contained and can drill holes to a depth of 275 metres anywhere in the country as long as access to the site is available on surface. A capsule has also been developed which can be lowered down the hole to hoist out any survivors found in the workings. This capsule, known as the Dahlbusch bomb is flexible to enable it to cope with minor variations in the shaft often encountered in this type of drilling operation. Together with the team which is responsible for drilling the hole, all members of the mines rescue teams are trained by the Mines Rescue Service to operate the capsule. These men are also trained in mine emergency situations, and so, are equipped to be lowered into the underground workings to assist with any rescue.

In addition to the rescue drill, the unit has the ability to quickly drill smaller 15 cm diameter holes, down which a sophisticated underground surveillance probe can be lowered. This probe is equipped with a low light intensity television camera, onboard lighting as well as a two-way audio communication system, all of which can be remotely operated from a control caravan on surface. This probe is an invaluable aid in an emergency, allowing visual and audio observations to be made in otherwise inaccessible workings. These probe holes can also be use to supply trapped miners with ventilation, food and water, while the larger escape hole is being drilled.
In the case of a major collapse or flood the following procedure should be followed. Once it has been ascertained that the situation warrants the use of the rescue drill and that rescue from underground is not possible any other way, the Manager of the Colliery Training College must be notified that the drilling equipment is needed. Thereafter all the steps as laid out in the "Rescue Drilling Procedure Document" must be followed.

Prior to the arrival of the drill, a control room must be established where all the necessary plans and information are made available. The area where the men are likely to be trapped must be indicated on an underground plan, and if possible a geological plan of that area obtained. Thereafter the area should be located on surface and access roads to the site established.

There should be in place a written procedure detailing action to be taken for the rescue of persons using the rescue drill. This should include:
- Establishing a control room.
- Calling on the services of the drill and its crew.
- Provision of services by the mine.
- Allocation of responsibilities for various aspects of the operation.

12 Ground movement, subsidence and sinkholes

The Manager should carry out a risk assessment in consultation with the relevant technically qualified officials and other appropriate parties, if required, to ascertain the risk to the mine, its infrastructure and accommodation and the risk to any third party, of any ground movement, subsidence or sinkhole occurring as a result of the mine’s activities.

The mine should have in place a formal written procedure detailing the action to be taken in the event of ground movement, subsidence or sinkhole occurring.

This should cover:
- Evacuation of persons affected, if required, and preventing access to the area.
- Ascertaining the extent of the problem by consultation with appropriate professionally qualified persons.
- Appropriate action to manage the problem.

13 Collapse or subsidence of any discard dump

The Manager should carry out a risk assessment in consultation with the relevant technically qualified officials and other appropriate parties, if required, to ascertain the risk of a discard dump collapsing or subsiding in any way and particularly if this may affect the safety of persons or damage to property. This could also form part of the Environmental Management Progamme Report (EMPR).

Resulting from this risk assessment appropriate engineering controls should be put into place to ensure the continued safety of persons and property.

Response to an incident of tip collapse.
A formal procedure should be in place as part of the disaster management programme detailing action to be taken in the event of a tip collapse or subsidence.

14 Incident involving pollution or other environmental issues

This should include any incident of spontaneous combustion of any tip or dump.

The Manager should carry out a risk assessment in consultation with the relevant technically qualified officials, and other appropriate parties, if required, to ascertain the risk of the mine causing any incident of pollution or being party to any action that could detrimentally affect the environment.

This risk assessment should be carried out in conjunction with the mine's Environmental Management Report (EMPR) and the Environmental Management Programme (EMP).

Based on this risk assessment, appropriate engineering controls should be put in place to eliminate as far as possible the likelihood of such an incident. Such controls should be formally recorded and appropriate mechanisms put in place to ensure the quality assurance of such controls.

Response to any pollution or environmental incident

A written procedure should be in place detailing action to be taken and covering:

- Ascertaining the extent of the damage.
- Notification of appropriate authorities if necessary.
- Measures to clean up and rehabilitate the area affected.

15 Outbursts

An outburst is a sudden ejection of large quantities of coal (usually in the form of a fine powder) and gas (CH_4 and/or CO_2). This phenomenon is caused by a combination of rock stresses and gas pressure.

Outbursts can perhaps best be described as a "violent mud rush" of dry powdered coal and large quantities of gas being suddenly ejected from the face.

Persons in the vicinity are at immediate and serious risk of being buried and asphyxiated by the coal dust or succumbing to anoxia due to the lack of oxygen in the air. The large quantities of gas that are a constituent of outbursts present a serious hazard to the rest of the mine. This gas can overcome the ventilation system even in intake airways.

Damage caused by outbursts can be severe with machinery and equipment being carried away by the fluid-like coal dust.

As an example, in Germany 9 fatalities occurred and a drilling machine was carried 110 m during an outburst.

Whilst there have been no recorded outbursts in South Africa to date, it is a major problem in the coal mining industry throughout the rest of the world. Most of South Africa's coal is fairly shallow and no outbursts have been recorded at less than 180 m depth. However, coal mining is taking place at greater depths in South Africa and the conditions conducive to outbursts exist in some local collieries. Therefore, it is appropriate to bring this phenomenon to the attention of the industry and in particular Managers of deeper collieries.

Those potentially affected should read the paper by Dr. Kevin Middleton "Outbursts – A Future Problem for South African Collieries" published in the Journal of the Mine Ventilation Society in February 1988.

This paper describes the features associated with outbursts, namely

- Depth of workings
- Seam gas content
- Geological disturbances
- Coal properties
- Permeability mining effects
- It also briefly describes methods of alleviating the above features by describing active and passive techniques that have been used.

Those collieries potentially affected should put in place a procedure that covers:

- Awareness of the possibility of outbursts.
- The immediate and serious threat to life that outbursts pose.
- The hazards, particularly of gas, in affecting rescue of persons and to the mine in general.
- Action plans to deal with outbursts.

16 Major goaf

When stooping is practised in a colliery, which has particularly competent and strong roof, the major goaf which occurs after a number of pillars have already been removed can cause an air-blast which has the potential of injuring people and damaging equipment.

If this is the case on the colliery, a procedure needs to be put in place to make employees aware of the potential hazard. A means of inducing the goaf in the off shift period should be considered and implemented as soon as is feasibly possible when stooping has begun in the section.

Acknowledgements

Mr. D. Bakker, Chief Inspector of Mines, and staff. Dept of Minerals and Energy.
Mr. A. Tatton, Manager Occupational Hygiene, Douglas Colliery.
Mr. D. Rowe, Principal Inspector, Occupational Hygiene, Dept. of Minerals & Energy.
Mr. P.R. Kritzinger, Principal Inspector and staff, Dept. of Minerals & Energy, Witbank.
Mr. C de Klerk and Mr. R Snelson, Mines Rescue Services (Pty) Ltd.
Members of the South African Colliery Managers Association.

References

(1) **Dept. of Minerals Energy** – Minerals – South Africa Statistical Tables. 1980 - 98

(2) **Dept. of Minerals Energy** –Accident Statistics 1980 - 98

(3) **Phillips, HR 1996.**. Identify methods to reduce the risk of explosions and fires caused by frictional ignition. SIMRAC Report COL 226 Pretoria. Department of Minerals and Energy.

(4) **Chamber of Mines of South Africa**. – Rescue Drill Annual Report 1991

Additional material for this report was gathered from perusal of all the publications given in the Bibliography.

Bibliography

The following is a list of books, technical papers and research reports, available locally, which should be consulted by persons involved in the management of any emergency situation and the compilation and implementation of Codes of Practice for Emergency Response.

Environmental Engineering in South African Mines.
The Mine Ventilation Practitioner's Data Book,
Both published by the Mine Ventilation Society.

Fires in Collieries and Gold Mines published by the Chamber of Mines.

Brink D 1997. Importance of good travelling ways during an escape from a stope.
Journal of the Mine Ventilation Society. Vol. 50 No. 2.

Burger AJ 1988. Fire prevention and protection for trackless equipment..
Journal of the Mine Ventilation Society. Vol. 41 No. 10.

de Klerk C 1998. Mine Rescue Services in South Africa in the next millennium.
Journal of the Mine Ventilation Society. Vol. 51 No. 4.

Durant G 1988. The Feasibility of Using Compressed Air Cylinders for Refuge bay Ventilation
Journal of the Mine Ventilation Society. Vol 41 No. 11.

Fauconnier CJ, Beukes JDR. 1978. Some interesting observations about colliery fires and the weather. *Journal of the Mine Ventilation Society.* Vol. 31 No. 4.

Fauconnier CJ, Beukes JDR. 1978. The early detection of spontaneous heatings in collieries and the effect of weather on such heatings. *SACMA proceedings* June 1978.

Fauconnier CJ, Beukes JDR. 1979 Some further thoughts on colliery fires and the weather. *Journal of the Mine Ventilation Society*. Vol. 32 No. 11.

Fauconnier CJ, Beukes JDR. 1980. The determination of optimal gas sampling times and locations for sampling sealed off areas in collieries. *Journal of the Mine Ventilation Society*. Vol. 33 No.10.

Graham N, Eave GG. .1995. Emergency Control Rooms - Structures and Procedures. *Journal of the Mine Ventilation Society.* Vol. 48 No. 4.

Keiblock AJ *et al*. 1989. Functional performance of formal gold and colliery refuge bays. *Journal of the Mine Ventilation Society*. Vol. 42 No. 5.

Maher, S. 1991. *Mining Survey* – Number 1, 1991- The Day the Earth Fell in

Middleton K. 1988. Outbursts - A future problem for South African Collieries.
Journal of the Mine Ventilation Society. Vol. 41 No. 2.

Neething A. 1988. Onefhanlik geventreede toevlugskamer Sigma Steenkoolmyn.
Journal of the Mine Ventilation Society. Vol. 41 No. 5.

Schreiber W 1999. Self contained Self rescuers in the South African mining industry -"life saver or necessary evil". *Journal of the Mine Ventilation Society*. Vol. 52 No. 1

Smith M. 1998. Mine Emergency Preparedness -2000 - A plan for survival.
Journal of the Mine Ventilation Society. Vol. 51 No. 4.

van Zyl *et al*. 1998. Evaluation of a possible method to quantify in heading methane control. *Journal of the Mine Ventilation Society*. Vol. 51 No. 4.

Venter A. *et al*. 1997. An alternative method to supply respirable air in refuge bays of collieries. *Journal of the Mine Ventilation Society.* Vol. 50 No. 4.

Venter A. *et al*. 1999. Portable Refuge Bays -aid or tomb in underground escape strategies. *Journal of the Mine Ventilation Society.* Vol. 52 No. 1.

Walters D.1989. Emergency Control Rooms. *Journal of the Mine Ventilation Society.* Vol. 42 No. 1.

Walters D. 1990. Problems Associated with Fighting Fires on Rubber Tyred Vehicles. *Journal of the Mine Ventilation Society*. Vol. 43 No 5.

Walters D. 1997. Using inert gases to fight mine fires. *Journal of the Mine Ventilation Society*. Vol. 50 No. 2.

South African Mining World. Vol. 4 No. 1. Feb 1985 – Mine Rescue

South African Mining World. Vol. 10 No.11&12. Dec 1991/Jan 1992

United States Bureau of Mines Peak Methane Concentration during Coal Mining USBM RI 7885 1974

Dept. of Minerals and Energy, Witbank: Audit procedure for underground coal mines.

European Union - Directive 1999/92/EC Minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres.

Mines Rescue Service New South Wales Australia. Emergency preparedness and mines rescue guidelines

SIMRAC REPORTS

GEN 101 Practices and procedures to overcome the problems associated with disorientation and low visibility in the aftermath of mine explosions or fires.

COL 010 Assessment of explosion barriers.

COL 030 Reduce methane hazard in collieries. Vol. 01.

COL 031 Prevention detection and control of underground fires in collieries.

COL 115 Assessment of the design of refuge bays in collieries.

COL 116 The suitability of using jet fans to ventilate CM headings.

COL 204 Evaluation of methods for dynamic goaf ventilation and methane drainage to reduce the explosion and fire risk of methane layering.

COL 205 Reduce explosion risks and improve safety and health conditions by better ventilation practices in mechanical miner headings.

COL 226 Identify methods to reduce frictional ignition hazards.

COL 236 Assessment of dispersed barrier systems.

COL 303 Methane prediction in collieries.

COL 316 training guidelines for safe use of electricity to minimise fire hazards.

COL 322 Systems to limit coal dust and methane explosions in collieries.

COL 409 Methane layering in bord and pillar workings.

COL 426 Status of wet head cutting drums for the prevention of frictional ignition.

COL 431 Training aids to assist employees to recognise frictional ignition hazards.

COL 443 Alternative inerting materials for coal mine explosions.

COL 470* (Now COL 622) Seam gas content. (Report not yet available)

COL 501 To test dispersed stone dust barriers for effectiveness in bord and pillar workings.

COL 502 Design, construction and testing of underground seals.

COL 518 Mechanical mine environmental control.