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AC B4207B CN 622.8684 TAS 1998 DA 1998 TI Report on the development of explosion AU Humphreys, D R (David) CB Safety in Mines Testing and Research AC B4207C CN 622.8684 TAS 1998 DA 1996

TI Task Group 5: Moura Implementation AU McCracken, J (John) CB McCracken Consulting Services

# SEALS AND VENTILATION STRUCTURES

# INTRODUCTION.

As a result of the Warden's Inquiry into the circumstances surrounding the explosion that occurred at Moura No.2 mine in August 1994, a number of recommendations were made and acted upon by various Task Groups. In all 25 recommendations were made by the Warden's Inquiry and five Task Groups were established to concentrate and act on particular aspects of the recommendations. Task Group 5 was required to report in two areas being:

(a) The requirement for the purchase and use of mine inertisation equipment; and

(b) the development of appropriate standards of construction of mine seals.

A separate report covering the results of the inertisation investigations has been issued by the Task Group.

This report will present the results of Task Group 5's considerations for the development of explosion resistance standards for mine ventilation structure, which have formed the basis for an approved standard for ventilation control devices issued by the Chief Inspector of Coal Mines.

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SIMTARS Report : Development of Explosion Resistance Rating

TG 5 Moura Implementation Program [McCracken Consulting]

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# TERMS OF REFERENCE

The terms of reference supplied to the Task Group for the review of mine seal standards were that:

The task group should review world wide practice in the design of mine seals. The review should establish design criteria which are practicable and achievable in Queensland mines. Various methods for determining the suitability of construction materials should also be identified. Any evidence of failures in explosion resistant seals installed in mines should be investigated and any modes of failure be specifically covered by the design process. As a minimum, the design criteria must establish:

- (a) worldwide practice in Australia and designing of mine seals: current design options available.
- (b) effects of volume of sealed area (if any);
- (c) time of erection; - strength of materials relating to time
- (d) engineering standards for dimensions/design of seals for various width and height of roadways;
- (e) standards for attachment of seals to floor roof and sides;
- (f) standard method for preventing water build up behind a seal; and
- (9) recommend installation standards which might include stone dust or inert gas barriers immediately inside of a sealed area

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# TASK GROUP STRATEGY

To address the issues raised in the consideration of standards of construction for mine seals, the Task Group carried out a number of investigations and gathered information from a number of sources. The main areas of investigation carried out by the Task Group were:

(a) Conduct a Hazop (Hazard and Operability) study of the requirement for explosion resistant ventilation structures in a coal mine.

(b) Gather data on the effects of explosion overpressures on human physiology and damage to structures.

(c) Presentations from various manufacturers on the construction and performance characteristics of proposed explosion resistance structures, particularly seals.

(d) Review of the likely pressures developed by underground coal mine explosions.

(e) Maintain a watching brief on overseas testing of various types of seal construction undertaken by suppliers.

(f) Assessment of overseas practices during visit to examine application of the Gag inertisation equipment to Australian mining for relevant practical design parameters for ventilation control devices in areas of an underground mine.

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# HAZARD AND OPERABILITY (HAZOP) STUDY

The first major task undertaken by the Task Group was a Hazard and Operability (Hazop) study to assess the requirement for explosion resistance ratings for various underground ventilation structures. The rational behind this approach was that the design of explosion resistant ventilation structures should be based on a balanced risk management strategy rather than historical practices. The HAZOP study was facilitated by Dr John Mc Cracken, McCracken Consulting, and a copy of his report is attached in Appendix 1.

The main conclusion drawn as a result of the Hazop study was that, if it was considered that there was a requirement for seals used adjacent to goaf areas to be explosion resistance, it was also necessary to specify explosion resistance ratings for other ventilation structures. In conducting the Hazop study, the Task Group recognised that there were many situations in which an overpressure could occur, including face ignitions with limited volumes of fuel, goaf ignitions with much larger fuel volumes and windblast due to large goaf falls. This gave rise to the requirement for the Task Group to develop explosion resistance ratings for a range of ventilation structures, not just goaf seals, and to provide protection against windblast. Each type of ventilation structure would require a separate explosion/overpressure resistance rating depending upon the explosion pressures likely to be encountered or the level of human survivability of an explosion.

This is illustrated by the following examples:

Ventilation stoppings were required only to have a rating up to the threshold pressure so that in the event of an explosion, persons could survive.

Goaf seals were required to prevent propagation of flame and pressure to the outbye areas of the mine and therefore would require a rating based on expected explosion pressures in a sealed area.

It was also considered that it was not the role of the Task group to specify the actual design details of ventilation structures, but rather to develop the design criteria to be met. These included an overpressure rating, fire ratings and long-term structural stability requirements to ensure integrity of function. It was considered a management/ manufacturers' requirement to develop appropriate designs and construction methods to satisfy the criteria established by the Task Group.

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# MINE EXPLOSION PRESSURES AND SURVIVABILITY

During the investigations by the Task Group a number of references to damage and injury rates in relation to explosion pressures were examined. Many of these are appended to the Hazop study report (Appendix 1 to this report). The effect of blast overpressure depends on a number of factors including the peak overpressure, the rate of pressure rise and the duration of the positive pressure phase. It was noted that the level of damage and probability of injury and fatality was affected by the nature of the explosion source. The damaging effect of a given overpressure is greater if the rate of pressure rise is rapid. Damage also increases with the duration of the explosion up to several hundred milliseconds.

Input was also sort on likely mine explosion pressures and Dr Peter Golledge of SIMTARS made a presentation to the Task Group. Dr Golledge indicated that estimating the likely the magnitude of explosion pressures developed in an underground coal mine was complicated by many factors. These included the volume of fuel involved, the nature of the fuel i.e. methane or coal dust and its concentration, the nature of the ignition source, the degree of confinement and the development of turbulence. Experimentally all these factors had a major effect on the explosion pressures observed and made it impossible to express an opinion on the possible limits to explosion pressure in an underground coal mine.

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# PRESENTATIONS BY SEAL MANUFACTURERS

During the tenure of the Task Group a number of presentations were made by manufacturers who were in the process of designing and testing a variety of different seal types. Manufacturers who made presentations were:

(a) DAWS pumpable stopping

(b) Tecrete

(c)Tecseal

(d) Wilson Mining Services - who were appointed the Australian agents for marketing of the MICON 550 system of mine seals. These seals consist of two dry block walls infilled with a mix of aggregate and polyurethane foam. In tests at the USBM Lake Lynn facility, these seals are reported to have withstood repeated explosions of 20 psi. Stronger seals can be constructed by increasing the core thickness. For example, in a 2.4 metre (8 ft) high opening a seal constructed with a core of 0.41 m (16 inches) would provide a 140 kPa (20 psi) rating. A core of 0.5 m would provide a rating of 350 kPa (50 psi).

(e) Bliss Fox - who were in the process of developing a fast installation seal which would have an explosion resistance rating of 310 to 380 kPa (45 to 55 psi). At the time of their presentation the design of this type of seal was subject to a patent application and the members of the Task Group were required to sign a confidentiality agreement.

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# **OVERSEAS TESTING OF TECRETE SEALS**

During the tenure of the Task Group, Tecrete conducted a series of tests at the USBM Lake Lynn Experimental Mine at the request of BHP Coal to investigate the explosion resistance properties of various types of Tecrete seals. Task Group member Mike Downs ensured that the Task Group was kept informed of the test results.

A major objective of the tests was to develop a seal able to withstand an explosion of 150 kPa (20 psi) within 24 hours of construction and built to dimensions typical of Australian mines. Seal designs tested were based on the Meshblock construction system which consists of wire mesh blocks interlinked and tied to the roof ribs and floor by roof bolts. A grout mix is pumped into the Meshblocks and allowed to cure before a spray coat of grout is used as a final sealer.

Reports of the testing indicated various seals survived explosion pressures varying from 35 kPa (5 psi) to 525 kPa (75 psi). Peak pressure in some blasts exceeded 700 kPa (100 psi). All seal designs are reported to have demonstrated excellent blast resistance at their designed ratings.

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# WORLDWIDE PRACTICES

A review of overseas standards and practices was provided to the Task Group by David Humphreys, Principal Engineer, SIMTARS. His report is attached in Appendix 2. From this it is clear that there is a substantial difference between explosion resistance ratings for seals in the US and those used in the UK and Europe.

## **US Practices**

Practice in the US is to construct final seals with an explosion resistance rating of 20 psi (140 kPa) but this is based on the prevention of damage from face ignitions causing the release of gasses retained behind the seals. In conducting a review of the requirement for explosion resistant seals Mitchell (1) considered that the vast majority of explosions occurred in the active working areas of the mine and would be limited in extent by restricted gas volumes and stone dusting . Mitchell (1) states:

"Seldom, however, do pressures 200 feet and more from the origin of an explosion exceed 20 psig unless coal dust accumulations are excessive and the incombustible content of the dust is less than required by law."

In analysing the US philosophy it was clear that the intention of building explosion resistant seals is to prevent passage of pressure and flame from active areas into sealed areas. Stephan (2) concedes that there are circumstances in which a seal constructed to withstand a 20 psi explosion may not be adequate. These circumstances relate primarily to the ignition of an explosive mixture within a sealed area, due to ignition by spontaneous combustion or frictional ignition. Under these circumstances it is recommended that the situation be evaluated on a case-by-case basis.

There did not appear to be any requirements for explosion resistance ratings on any other ventilation control structures in the US.

## UK and European Practices.

The issue of explosion resistant seals has been addressed a number of times in the UK by committee. In 1942 (3), descriptions of various explosion resistant seals were given, some of which had been successfully used to contain explosions within sealed areas after sealing of fires or heatings. Generally, the seals were very long (30 feet or so), but no particular explosion rating was stated.

In 1962 (4), it was assumed that seals should be designed to withstand explosion pressures in the range of 20 to 50 psi (140 to 350 kPa). Construction methods were described again, but these were based on past practice rather than any design methods or tested seals.

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## UK and European Practices (cont.)

In 1985 (5), the design of explosion resistant seals was again reviewed. Explosion resistance rating appears to have been increased to 524 kPa (76 psi) based on observed pressures developed by methane/coal dust explosions. The length of a monolithic gypsum pack was established to resist this pressure was given as :

L = (H+W)/2 + 0.6

Where L = length of seal (m) H = height of seal (m) W= width of seal (m)

It was also acknowledged that

If it were not for the possible risk of explosion, the operation of sealing-off would consist simply of providing a seal designed solely to prevent access of air to the fire and requiring little or no mechanical strength."

There does not appear to be any requirement for explosion resistance ratings on any other ventilation structures other than seals used to control fire and spontaneous combustion.

Very little information has been obtained on the standards for explosion resistant seals in European coal mining operations. West German coal mines are required to comply with a *"Directive for the construction of stoppings"* (6) , which requires the explosion resistant stoppings be capable of withstanding maximum static pressures of 0.5 MPa (5 bar, 75 psi). It would appear that these structures are intended to *"seal off, hermetically, parts of the mine workings,"* to prevent the propagation of *"mechanical, thermal and toxic effects"* to other areas of the mine.

From a search of abstracts, Cybulski *et al* (7), indicate that explosion pressures in sealed off areas had been recorded at more than 30 bar (450 psi). However, conceding the difficulty of building a stopping of such a strength , it is assumed that, in Poland, less strong stoppings of about 5 bar (75 psi) would be sufficient in practice. Again it is considered that explosion resistant seals are required to prevent an explosion from propagating from within a sealed area.

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# DEVELOPMENT OF DESIGN STANDARDS FOR EXPLOSION RESISTANCE OF VENTILATION STRUCTURES

In attempting to develop overall design standards for explosion resistance ratings of ventilation structures, the Task Group decided that the engineering standards should define an explosion resistance for various structures without specifying detailed construction methods. There are a wide range of circumstances that can occur in an underground coal mine which may required explosion resistant structures and many ways of achieving the desired result. The Task Group considered it preferable to recommend a range of design parameters for explosion resistant ventilation structures which would allow manufacturers and operators to select the most appropriate means of construction, rather than to prescribe specific construction techniques.

The Task Group has, therefore, developed a set of criteria for various ventilation structures under a range of circumstances. The Task Group has recognised that it is possible to manage the risks associated with sealing areas in which an explosive atmosphere can form, in a number of different ways.

The recommended explosion resistance ratings developed by the Task Group are shown in Table 1 below. These ratings are based on the task group's assessment of the pressures likely to be developed by underground explosion or windblast, and the survivability of those likely to be affected.

In addition it should be noted that all ventilation structures are required to have a fire rating or be flame resistant. The suggested ratings were :

Type of Structure	Fire Rating	Rationale
Type A (refer Table 1)	Flame resistant only	Reduced requirements due to less permanent nature of structures
Туре В	AS 1530.4 - 1990 60 minutes	To prevent destruction of structures and short circuiting of main ventilation
All others	AS 1530.4 - 1990 60 minutes	To prevent the release of combustible or asphyxiating gases

The intention of the proposed explosion resistance ratings and fire ratings developed by the Task Group is to provide a degree of protection to the ventilation structures in the event of a fire or explosion which would otherwise cause their destruction.

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Protection of ventilation stoppings, doorways and overcasts (i.e. Type A and B structures) is to prevent destruction in the event of relatively weak explosions of a limited volume of methane in or about the face. This will limit the damage to the overall ventilation system and permit the restoration of normal ventilation as quickly as possible with minimal repairs. It is intended that this will rapidly clear the explosion site of noxious gases and limit the requirement for survivors to travel long distance to regain fresh air.

It should be noted that included in this category are stoppings along the goaf edge while ever the goaf remains open to ventilation at some point. When the goaf is sealed and isolate from the ventilation system the explosion resistance ratings of these stoppings changes, and the stopping is more correctly referred to as a seal.

Seals are required to isolated goaf areas and worked out panels from the mine ventilation system. For these structures the recommended explosion resistance rating is determined by the presence of explosive mixtures of methane in the goaf area. For mines in which the seam gas composition is such that an explosive mixture cannot form under any circumstances eg. carbon dioxide content of 90%, protection is required only against damage caused by windblast due to goaf fails.

In this case, a lower explosion resistance rating has been selected (Type B). In the event that an explosive mixture is formed in the goaf area and there is a hazard associated with the ignition within the sealed area and hence a higher explosion rating is required (Type D). The requirement for construction of this type of seal can be avoided by either evacuating the mine until mine air monitoring indicates the goaf atmosphere is above the explosive range, or by inertising the goaf atmosphere to ensure that the mixture of goaf gases does not pass through the explosive range.

In this case protection is required against an explosion originating outside the goaf area and a lower explosion resistance can be utilised (Type C).

Protection of surface facilities is also required (Type E) to prevent damage to the mine fan and portal infrastructure (evasee etc) to allow rapid re-establishment of the mine ventilation. This can be by way of pressure venting to protect fans etc, which could not be designed to withstand the explosion ratings required. At the surface is the only position where pressure venting can be applied.

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# OTHER FACTORS CONSIDERED

### (A) Effect of Sealed Volume-

The volume of the area to be sealed did not appear to be a matter for consideration in any seal design nor in the expected explosion pressures underground. Factors more likely to affect explosion pressures were the concentration of explosive gases, and the presence of turbulence.

It is considered, however, that goaf volume and the emission rate of seam gas will influence the time that a goaf requires to pass through the explosive range and become inert by displacement of oxygen. This will be an important consideration in the development of action plans for sealing an area and the time required for construction and curing of any seals.

## (B) Time of Erection -

The time required to erect seals and for curing of construction materials, to allow the seal to attain the rated explosion resistance, is of considerable importance. A seal cannot be considered to be explosion resistant if the construction materials have yet to achieve their design strength. Under some circumstances the strength of the "explosion resistant" seal may not have reached the design strength before the goaf atmosphere has reached the lower explosive limit. In these cases, the management of the risk will dictate the materials used, the desirability of inertization and the presence of personnel underground during the curing phase.

#### (C) Prevention of water build up behind seals -

It is to be expected that any pipes or structures intended to drain water accumulations are installed so that they do not affect the strength of the seal.

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# **FUTURE RESEARCH**

While the Task Group has developed a system of recommended explosion resistance ratings for ventilation control structures, there are a number of areas considered worthy of further investigation. These included:

- development of methods of assessing designs of ventilation structures,
- development pressure venting systems where applicable,
- design of airlocks with venting protection for re-entry purposes,
- monitoring of seal integrity to ensure long-term stability with regard to compliance with the recommended standards,
- optimisation of seals location with regard to the requirements for replacement, pressure balancing, remedial repairs and access,
- development of foam plug seals,
- development of foam inertization,
- development of new seal construction methods,
- development of new seal materials.

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Table 1 - Task Grou	p 5 Recommended Ex	plosion Resistance R	atings for Undergroun	d Ventilation Structures.

DESIGN CRITERIA- EXPLOSION RESISTANCE RATING	LOCATION	PURPOSE OR INTENT OF THE DESIGN CRITERIA	COMMENTS
Type A 14 kPa (2 psi)	Limited life production panels	To maintain the integrity of the ventilation structures in a production area in the event of an overpressure incident. All ventilation control devices installed are to remain It for purpose" for the life of the panel and withstand an overpressure of 14 kPa.	<ul> <li>Plasterboard stoppings are unlikely to be considered acceptable.</li> <li>Considered at this stage to be a well constructed concrete mesh and sprayed structure tied into the roof, ribs and floor.</li> <li>To be installed within the distance that a person cam walk from a production panel while wearing an oxygen self-rescuer.</li> </ul>
Type <b>B</b> 35 kPa (5 psi)	Main roadways	To maintain the integrity of the ventilation structures of the main ventilation system in the event of an overpressure incident. All ventilation control devices constructed as part of the main ventilation system installed are to remain "fit for purpose' for the life of the mine and always be capable of withstanding an overpressure of 35 kPa.	Considered at this stage to be a well constructed brick stopping tied into the roof, ribs and floor. Excludes conveyor segregation stoppings. Intended to prevent a direct short circuit from intake to return.
Type <b>B</b> 35 kPa (5 psi)	Sealed areas: For use in mines where the level of flammable gas is insufficient to reach the lower explosive limit under any circumstances.	To maintain the integrity of the seals in the event of a windblast up to 35 kPa.	Construction and maintenance to manufacturers' specification.
Type C 140 kPa (20 psi)	Sealed areas: For use in circumstances not covered by Type B and D seals	To maintain the integrity of the seals in the event of an external explosion to 140 kPa.	Construction and maintenance to manufacturers' specification.
Type D 350 kPa (50 psi)	Sealed areas: When persons are to remain underground while the general body atmosphere within the sealed area is in the explosive range	To maintain the integrity of the seals in the event of an internal explosion to 350 kPa.	Construction and maintenance to manufacturers' specification.
Type E 70 kPa (10 psi) Pressure relief	Surface infrastructure including fans, access tunnels, shafts and surface entries	To maintain the integrity of the seals in the event of an overpressure/explosion incident such that the mine can be re- entered with minimal delay.	Can be achieved by building structures to withstand overpressure or by providing overpressure venting. Able to be installed or repaired from a position of safety. Able to facilitate the use of inertisation equipment.

Note these standards are not applicable during emergency sealing.

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# APPENDIX

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## SAFETY IN MINES TESTING AND RESEARCH



**STATION Mining Research Centre** 

2 Smith Street, REDBANK, QLD 4301, Australia Postal Address: PO Box 467, GOODNA, QLD, 4300 Australia Phone (07) 3810 6333 Fax (07) 3810 6363 International Fax (617) 3810 6363

REPORT ON

# THE DEVELOPMENT OF EXPLOSION RESISTANT RATINGS

## **OF UNDERGROUND VENTILATION DEVICES**

ΒY

## DAVID HUMPHREYS



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## Mining Research Centre



#### EXECUTIVE SUMMARY.

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One of the tasks assigned to Moura Implementation Task Group 5 was to investigate the requirement for explosion resistant ventilation seals for underground coal mines. This report discusses the background to this requirement arising from the Moura No.2 inquiry.

A short review of some of the factors affecting the development of explosion pressures is given. It is clear that in some circumstances very high pressures can be developed from underground gas and dust explosions especially if there are large volumes of flammable gas, high degree of confinement and the possibility of pressure piling. These are just the circumstances that could arise during the sealing of an abandoned or goaf area. Very high pressures have been generated in large scale testing of explosions in blind entries with reports of pressures up to 595 psi. A face explosion is less likely to develop high pressures because there is less likelihood that there will be an extensive volume of flammable gas and there will be a degree of pressure relief as the explosion gases expand into other roadways.

Little data was found to be available on explosion pressures of actual mine explosions although in reviewing the incidence of mine explosions and ignitions it is clear that the majority in the USA and UK occur in the face area. There are few recorded incidents of explosions in goaf or sealed areas overseas.

The development of design criteria for seals in other counties is reviewed. From the UK and Europe it appears that seals are intended to withstand explosion pressures of about 75 psi and that in the USA the requirement is reduced to 20 psi. The differences between the design criteria are considered in the context of the perceived risk. In the UK and Europe, seals are intended to prevent the propagation of pressure and flame from within a sealed area, providing protection to the remainder of the mine. In the USA, the seals are intended to provide protection to the sealed area against explosions originating in the active work areas of the mine. The different design criteria between the UK/European and USA standards, are therefore based upon the expected explosion pressures likely to arise under very different conditions of gas volume, confinement and pressure piling. Each standard appears to be valid for the conditions considered and care must be taken in setting a standard for Queensland given the nature of recent major explosions.

In light of the rationale behind the UK and USA standards, and consideration of the results of large scale testing, various scenarios for sealing are considered and a number of sealing responses are suggested. The pros and cons of various options under different conditions during sealing are considered and presented for consideration by Task Group 5. It is concluded that the most significant level of protection is required when there is a need to seal a panel in which a flammable gas mixtures may exist with an ignition source. Four options are proposed depending upon the perceived risk of explosion during construction of the seals.

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#### **INTRODUCTION**

As a result of the Wardens Inquiry into the explosion at Moura No 2 Underground Mine on Sunday 7th August, 1994, a number of recommendations affecting mine safety were made and are now the subject of investigations by various task groups. One such area of concern was with regard to the design construction and installation practices for the sealing of worked out areas, especially in the presence of methane seam gas. The role of reviewing mine seal design was assigned to Task Group 5 along with an investigation of the role of inertization in underground coal mines.

The intention of this report is to provide a review of the issues considered to be pertinent to the examining of mine seal design, in the context of the deliberations already undertaken by the Task Group scope of the Task Group Study.

The scope of the study to be undertaken by Task Group 5 in considering the design and construction of mine seals is shown below. Unstated and unclear from this scope document is the nature of the explosion event against which it is expected that the mine seals are to provide protection. It may seem trite to question this matter, but its significance will be clear later.

From the findings of the Wardens Inquiry it is clear that the requirement is to recommend suitable design and construction methods of seals to prevent the passage of pressure and flame due to an explosion originating from within a sealed panel.

"The evidence from Moura No 2 makes it crystal clear that the sealing of an area in a gassy mine should never be considered a routine or trivial event. The Inquiry established that seals were destroyed as a result of one or other of the explosions at Moura No 2 which gives rise to important questions on the adequacy of current designs of seals and sealing practices. "(1)

The explosion which occurred at Moura No 2 in 1994, was similar in a number of respects to other major explosions that have occurred in the last twenty-five years. In this time there have been 4 major explosions in Queensland that have claimed 53 lives. In all cases the explosion resulted from the ignition of a large volume of flammable gas. In three cases including Moura No 2, the source of the flammable gas was a goaf area and this accumulation was a natural consequence of the mining operations. Further in three cases the ignition source for the explosion was spontaneous combustion, involving in all cases a lack of understanding of the dire consequences that can result from inappropriate control activities..

There have been ignitions of methane in other areas of mines in Queensland, but it is clear that the consequences of such an ignition are not nearly as severe and the explosion pressures are not nearly as high as in explosions originating in goaf areas.

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#### **Mining Research Centre**



#### REPORT 2 - MINE SEAL DESIGN

SCOPE

The second report should review the best technology and sealing practices as assessed worldwide. The report will recommend appropriate seal design and installation standards for the Chief Inspector of Coal Mines to establish as a standard for the Queensland Coal Industry.

#### TERMS OF REFERENCE

The task group should review world wide practice in the design of mine seals. The review should establish design criteria which are practicable and achievable in Queensland mines. Various methods for determining the suitability of construction materials should also be identified. Any evidence of failures in explosion resistant seals installed in mines should be investigated and any modes of failure be specifically covered by the design process. As a minimum, the design criteria must establish:

- a) worldwide practice in Australia and designing of mine seals: - current design options available.
- b) effects of volume of sealed area (if any);
- c) time of erection; - strength of materials relating to time
- d) engineering standards for dimensions/design of seals for various width and height of roadways;
- e) standards for attachment of seals to floor roof and sides;
- f) standard method for preventing water build up behind a seal; and
- g) recommend installation standards which might include stone dust or inert gas barriers immediately inside of a sealed area

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THE DEVELOPMENT OF A DESIGN CRITERIA FOR EXPLOSION RESISTANT SEALS.

One of the principal tasks of the Task Group 5 arising from the scope document shown above, is to establish design criteria which are practicable and achievable in Queensland mines. Of primary concern in establishing such a design criteria is the explosion resistance rating which must be achieved, particularly for seals which are intended to isolate goaf areas and other abandoned districts from the rest of the mine.

There are a number of sources of information that can be used to assist in this task being primarily:-

- (I) an examination of the nature of methane and coal dust explosions based on laboratory and large scale testing
- (ii) the investigation of explosion pressures developed in actual mine

explosions and

(iii) consideration of the design criteria used in other countries in which explosion resistant seals are also a requirement.

In the case of item (iii) it is likely that the established design criteria in other countries will have been derived by a similar process to that proposed here.

(1) LABORATORY AND LARGE SCALE TESTING RESULTS

There is a considerable knowledge base on the fundamentals of methane and coal dust explosions and a plethora of large scale test results. Nagy (2) provides a succinct review of the fundamentals of methane and coal dust explosions and points out the main issues to be considered.

There are a number of factors which Nagy points out which indicate that explosion pressures developed within sealed areas may become very high. Of greatest concern are the volume of the explosive gas accumulation, the degree of confinement of the explosion and the possibility of pressure piling.

So long as the volume of explosive gas involved in an explosion is small compared to the volume of the enclosure ie. the degree of confinement is low, the pressure developed will remain relatively low. However, as the volume of the gas accumulation increases and or the degree of confinement increases, the pressure developed will increase. Further *"if the methane accumulation is extensive, pressure piling or detonation can occur and higher pressures are attained."(2)* 

Pressure piling is the effect whereby an explosive gas mixture is compressed ahead of the flame front as may occur in a blind entry, against a restriction or, say, against a goaf seal. Because the explosive gas is already compressed to some pressure before the flame arrives, the resulting explosion pressure is much higher than if pressure piling had not occurred.

It is possible to gauge the effect of pressuring piling on explosion pressures from the citations of Nagy (2). Cybulski cited in Nagy reports on an experimental coal dust explosion in a dead end entry in which the peak static pressure exceeded 595 psi.

#### Stephan (3) reports that:-

"Explosion research in the BOM Experimental Coal Mine in Bruceton, Pennsylvania, has shown that up to 127 psig may be developed during a worst-case underground coal mine explosion, where optimum concentrations of coal dust and methane exist. <u>Pressure piling may also account for even higher pressures, especially in areas that are not adequately vented.</u>" (Authors emphasis).

Mitchell (4) makes a very similar observation with the addition that during some trials "pressure piling caused higher unrecorded pressures, and considerable damage."

In the event of an explosion occurring in a sealed area, it is evident that if there are explosive concentrations of

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gas present on the inbye side of the seals, pressure piling, leading to very high pressures can occur. There may also be some form of pressure piling associated with a presence of a seal in a roadway even if the explosion does not propagate up to the seal. Clearly the pressures developed at the seal site will be higher with the seal in place than if the explosion forces were allowed to vent into the remainder of the mine. This can make it very difficult to extrapolate from many of the experimental coal mine explosions carried out in USA, UK and Poland, because most of these trials involved explosions in open-ended roadways which at some point vented to the atmosphere. Little test data is available to the authors knowledge on confined explosions simulating the conditions likely to occur in a sealed goat.

There may be some perceptions that an explosion cannot propagate through the broken material which forms a goat area due to the restricted void area available. Consider, however the data relating to methane - air explosions shown below:

Some properties of CH<sub>4</sub> - Air Explosions (5)

m
bar/ 230psi
m/s
ım
K

The quenching diameter Dq is the smallest diameter pipe in which a self sustaining flame can propagate and the detonation critical diameter (Dc) is the smallest diameter pipe in which a self sustaining detonation can propagate. Given the small dimensions involved at which a flame and detonation can propagate, it is not possible to say that an explosion will be inhibited in any way by the porous nature of goaf material. Therefore an explosion originating in a goaf must be treated with as much caution as an explosion in an open roadway. There are ample pathways in goaf material in which a flame can propagate possibly leading to detonation.

#### (ii) ACTUAL MINE EXPLOSIONS

Another source of information on the likely pressures to be developed in underground coal mine explosions is from the forensic examination of actual mine explosions and ignitions. There does not appear to be much information in this category which is directly useful. In USA the analysis of "flames and forces" plays a significant part in the analysis of coal mine explosions, but there appear to be few recorded instances of explosions in sealed areas. Almost all explosions appear to originate in the face areas of the mine and are characterized by relatively low volumes of explosive gas and low confinement (2,3,4). This will be discussed in section (iii) below.

In the UK and Europe, explosions have occurred in sealed and unsealed goaf areas but again there is little reported data especially in literature of the last 30 years or so. The establishment of design criteria for seals in these areas, appears to have been undertaken some time ago and have clearly contributed to the reduction of facilitates associated with sealed area explosions.

A search of abstracts databases has revealed one paper by Baltaitus (6), which conducted an analysis of 50 underground explosions in the USSR between 1934 and 1966. It is indicated that *"the shock wave of the explosion did not exceed 25 ats(atmospheres)."* No indication of the conditions leading to this explosion or the method of analysis are given in the abstract.

<sub>i</sub>iMTAi

## Mining Research Centre



(iii) REFERENCE TO DESIGN CRITERIA IN OTHER COUNTRIES.

Explosion resistant seals have been in use for sometime in many coal mining countries and these can be considered to provide guidance.

(a) UK

In the UK, the issue of explosion resistant stoppings was addressed by a committee established in 1942 so that:-

"The accumulated knowledge and experience of the Coal Mining Industry on the construction of stoppings and the methods of quickly effecting the final sealing of Mine fires should be assembled and embodied in a Paper or Memorandum for the guidance of Managers who have to face such a task." (7)

Without specifically stating a design criteria in terms of explosion pressure resistance, the committee reported on illustrative construction techniques for explosion resistant seals. Many of the examples had withstood explosions. Two of the seals illustrated had partially failed despite being about 30 feet long in roadways about 8 feet high by 12 feet wide, and constructed from brick walls, stones and sand fill. The other seals which had successfully withstood explosions varied from 19 feet to 60 feet long, although of a similar manner of construction to those reported to have partially failed.

In 1962 a similar report was again prepared by a committee (8). In this case the committee reported that:-

"it is not possible to assess the intensity of pressure which might be applied to the inbye face of a stopping on the occurrence of an explosion. The pressure will usually be less, and perhaps much less, than the maximum pressures which have been measured in tests in experimental galleries. In our view, however, it is desirable in designing explosion-proof stoppings to assume that pressures of 20 to 50 lb per sq. in. may be developed, eg a total pressure of 80 to 200 tons on a stopping built in a cross-sectional area of 60 sq.ft."

Again construction details of various recommended explosion resistant seals were given, some of which were reproduced from the 1943 Memorandum.

In 1985, the design of explosion resistant seals was updated by a further Memorandum (9). In this case it was indicated that advances in the construction of seals had been made, eliminating the use of rubble, steel reenforcement, section walls and sandbags previously used. New construction methods were based on the formation of monolithic gypsum packs. It was stated that:-

"Experience has proved the resistivity of the monolithic design to the forces created by an explosion. It has been proved in experimental galleries that pressures developed by methane and/or coal dust explosions range up to 524 kPa (76psi)."

A formula for calculating the length of the seal was given as:-

 H
 W + 0.6 (m)

 Where L
 length of the seal

 width of the roadway
 width of the roadway

It is clear from reviewing these memorandum that the intention of the seals described was to prevent the passage of pressure and flame from within a sealed area to the remainder of the mine. There is an examination of the various circumstances in which it may be necessary to seal off an area due to a fire or heating and in most cases it is considered that explosion resistant seals should be built. However it is also acknowledged that:

"if it were not for the possible risk of explosion, the operation of sealing-off would consist simply of providing a seal designed solely to prevent access of air to the fire and requiring little or no mechanical strength. The main principles to be considered, therefore, are those relating to the onset and control of conditions conducive to the risk of an explosion." (9)

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There is therefore, some provision in the UK for construction of less substantial ventilation seals, which are only required to provide ventilation control, in circumstances where there is no risk of explosion. This likelihood appears to be mainly accessed on the absence of potential flammable mixtures rather than the absence of ignition sources.

Although not clearly indicated in the 1985 Memorandum, it would seem that after sealing the usual protocol is to withdraw men to a safe distance from the sealed area until a safe condition is established by atmosphere monitoring in the sealed area. This is clearly spelt out in the 1943 and 1965 Memoranda, but is less clear in the 1985 Memorandum, despite extensive discussion on atmospheric sampling, calculation of flammable limits and interpretation of the state of a mine fire.

There do not appear to be any requirements for explosion resistant ratings on any other ventilation structures other than seals or stoppings built to control fire and spontaneous combustion.

#### (b) EUROPE

Very little information has been obtained on the standards for explosion resistant seals in European coal mining operations. Michelis and Klein (10) discussed the design and construction of ventilation structures to withstand explosion pressure of about 1 MPa (10 bar or 150 psi). These were intended to comply with West German coal mines *"Directive for the construction of stoppings"*, which requires the explosion resistant stoppings be capable of withstanding maximum static pressures of 0.5 MPa (5 bar, 75 psi). They describe the construction and testing of various structures such as doors in manways, haulage road doors and belt conveyor locks.

It would appear that these structures are intended to "seal off hermetically parts of the mine workings," to prevent the propagation of "mechanical, thermal and toxic effects" to other areas of the mine.

From a search of abstracts, Cybulski *et al* (11), indicate that explosion pressures in sealed off areas had been recorded at more than 30 bar (450psi). However, conceding the difficulty of building a stopping of such a strength, it is assumed that less strong stoppings of about 5 bar (75psi) would be sufficient in practice. Again it is considered that explosion resistant stoppings are required to prevent an explosion from propagating from within a sealed area.

#### (C) USA

The development of design criteria for explosion resistant seals in USA has taken a somewhat different path to that in the UK and Europe. An examination of the reports of Nagy (2), Mitchell (4) and Stephan (3) illustrate the differences in perceived hazard from coal mine explosions and the resulting philosophy regarding the design of explosion resistant seals.

An analysis of the causes of coal mine explosions was carried by Nagy (2) in 1981. Of 391 explosions and ignitions reported between 1970 and 1978, 317 were attributed to frictional sparking from cutting bits at the face. There were no explosions associated, with spontaneous combustion or frictional ignition in goaf areas. All explosions and ignitions were attributed to human actions. Spontaneous combustion is not listed as a possible ignition source in a list of 26 common sources of ignition which included the safety lamp, rock on rock frictional ignition and lightning. Nagy also considered the occurrences of major explosions from 1958 in drawing his conclusions.

The standard for design and construction of explosion resistant seals in USA is based on withstanding explosion pressures of 20psi. This appears to originate from Mitchell (4) who stated that:

"Seldom, however, do pressures 200 feet and more from the origin of an explosion exceed 20 psig unless coal dust accumulations are excessive and the incombustible content of the dust is less than required by law."



## Mining Research Centre



Stephan (3) also indicated that:

"Based on the investigation of the major underground coal mine explosions that have occurred in the last 13 years, it is reasonable to believe that seals are not generally subjected to pressures exceeding 20 psig during explosions. This pressure of 20 psig is a suitable performance characteristic for identifying the flexural strength requirements of seals constructed in underground coal mines."

There does not appear to be any concession from these requirements granted to mines in which methane cannot form explosive mixtures eg mines with very high carbon dioxide concentration in the seam gas and insignificant methane emissions. It is considered by Stephan that explosion resistant seals built to the same standard are still required to protect seal areas in these mines due to the possibility of coal dust explosions.

However, Stephan also indicates, that there are circumstances in which a seal constructed to withstand a 20psi pressure wave may not be adequate. These relate particularly to the ignition of explosive mixtures **within a sealed area**, due to frictional ignition or spontaneous combustion. Under these circumstance it is recommended that the situations be evaluated on a case-by-case basis.

It is clear from the discussion of Stephan, Mitchell and Nagy, that the intention of the use of 20psi explosion resistant seals in USA is to prevent the passage of pressure and flame from currently active areas of the mine **into** abandoned and worked out areas. This is also clear from the style of explosion testing undertaken at Lake Lyne, in which the explosion pressure is generated in an unsealed drift and it is only the static pressure applied to the seals (see Figure 1). The situation depicted simulates the passage of an explosion front propagating down C drift as if from a face explosion.

As in the UK and Europe there do not appear to be any explosion resistance standards for any structures other than the seals described above.

It would appear that the US standard for seals, while different to the UK and Europe, is based on a careful consideration of the hazard of explosion as they occur in their mines. Clearly the percieved hazard is very different to that in the UK, where the emphasis is on the explosion hazard associated with ignition from within the area to be sealed. Great care must therefore be taken in adapting the standards outlined here to Queensland mining conditions, given the nature of the major explosions that have occurred.





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DISCUSSION

From the foregoing analysis a number of clear conclusions can be drawn.

Pressure developed by an explosion can be very high - given the infinite range of circumstances that can arise in a coalmine it is impossible to place a limiting pressure that can be developed. There are many factors that may help to limit explosion pressures and equally as many that exacerbate the problem. The explosion pressure developed clearly depends upon the prevailing circumstances and there is nothing about the coal mining operations that places any limit to what this may be.

Factors affecting explosion pressures developed - not withstanding anything in (i) above it is also clear that there is a distinction to be drawn between explosions that occur at the face and explosions that occur within a sealed area. There are additional factors involved in sealed areas which may not be so significant though not necessarily absent at the face. There is a greater potential to develop a large volume of explosive gas; there is a higher degree of confinement; and there is a higher potential for pressure piling adding to the likely explosive pressure. This is not to say these circumstances do not arise in the event of a face ignition but have a greater potential in the event of a goaf or sealed area ignition. The potential for high pressure explosions is far greater for sealed areas and goafs than for face ignitions.

iii. The control standards applied depend upon the perceived hazard - other countries have developed design criteria for explosion resistant seals and these criteria depend upon the perceived hazard. In the UK perceived hazard is that of an explosion occurring within the sealed area. The UK and European design criteria appears to be based on ability to withstand explosion pressures of 70-75 psi. In the USA, the perceived hazard is that of inbye face explosions, imploding seals surrounding worked out and abandoned areas. The requirement in this case is for structures capable of withstanding explosions of 20psig. It is also clear from discussion in the US reports that this standard would not be regarded as adequate in the event of an internal explosion, in a goaf or sealed area. However it must also be noted that explosion resistant seals in the UK are associated with the control of fires and heatings where there is known ignition source and a known source of flammable gas.

#### **APPLICATION TO QUEENSLAND**

In attempting to utilize the knowledge of explosion pressures and overseas practices it is necessary to recognize that there are a range of circumstances which must be covered. For any area in an underground coal mine which must be sealed there are four (4) possible situations which need to be considered as shown. They result from the combination of the presence or absence of a flammable atmosphere and of an ignition source.

The possible actions that can be taken in sealing an area of a mine are outlined in Table 1, according to the circumstances surrounding the presence of an explosive atmosphere and an ignition source. Some of the options canvassed may not be acceptable.

For Scenario 1, Explosive atmosphere with an ignition source, it is considered that the actions to be taken will be dictated by the risk of explosion during sealing operations. No particular option can be excluded as a possible course of action as the risk of injury to personnel and damage to the mine will vary from situation to situation. As there does not appear to be any certainty that the strength of an explosion resistant stopping can be assured to withstand every explosion, it is considered necessary to withdraw men from undergound until a safe condition is established in the area to be seal. This can only be considered safe when the atmosphere within the sealed area is above the upper explosive limit for flammable gases.

For Scenarios 2 & 3, Explosive atmosphere without ignition source and non-explosive atmosphere with ignition source respectively, a compromise between over-reaction and inadequate protection is the construction of seals to the standards use in the USA. In the case of the development of explosive atmospheres (Scenario 2), there is a danger that misdiagnosis of the lack of an ignition source, such as spontaneous combustion, could lead to catastrophic failure. Clearly there is a requirement for high quality mine air monitoring to enable the early detection of spontaneous combustion with skilled operators to conduct careful analysis. In the event that the possibility of an ignition source cannot be eliminated an increase in level of protection to that suggested for



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enario 1, should be made. Similar comments can be made with regard to the absence of an explosive atmosphere.

The final combination of conditions, a non-explosive atmosphere without an ignition source, Scenario 4, does not on face value require any explosion protection. It may be possible to accept low strength ventilation stoppings as seals, but this should be upgraded to seals built to US standards if there is a hazard associated with inbye explosions.

The options canvassed here 'are based upon the application of the knowledge of pressures likely to develop under different circumstances, and overseas practices in the context of their perceived hazard. There may well be reasons why the UK standard of 75psi for sealing of explosive atmospheres with an ignition source cannot reasonably be applied, say for logistical reasons in building such large structures. A reduction in this rating could be justified so long as there was no exposure of personnel until a safe condition was established within the sealed area. So long as this is practised, any reduction in design criteria will only increase the short term risk exposure of the mine.

Finally, there must also be consideration of the hazards associated with a mixture of different ratings in a mine and more particularly in a single panel. If a panel, or series of interconnected panels should be sealed with a mixture of seals of different explosion resistant ratings, the overall protection to the mine and its personnel is limited by the seal of lowest rating. In the case that a series of longwalls with interconnected goafs are sealed with medium strength seals prior to the outbreak of spontaneous combustion in the goaf of the current production face, there may be a requirement to upgrade previously installed seals or accept the increased risk of lower strength seals.





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SCENARIO	ATMOSPHER E CONDITION	IGNITION SOURCE	POSSIBLE ACTIONS	PROS	CONS
1	Explosive	With	(a) Build high strength explosion resistant seals as for UK/European standards - withdraw men until safe.	High degree of long-term protection to mine.	Short-term exposure during construction if construction is slow. Loss of production during withdrawal. Expensive I difficult to build?
			(b) Build low strength ventilation seals - withdraw men until safe.	Rapid sealing operation reducing short-term exposure of men to explosion hazard if faster than 1(a)	High degree of risk exposure to mine. Loss of production during withdrawal. May require re-enforcement later.
			(c) Inertisation with 1(a)	As per 1(a) plus reduced time to develop safe conditions.	As per 1(a). Currently lack suitable equipment for inertisation.
			(d) Inertisation with 1(b)	As per 1(b) plus reduced time to develop safe conditions.	As per 1(b). Currently lack suitable equipment for inertisation
2.	Explosive	Without	(a)As per 1	Provides a higher level of protection than may be necessary against an internal explosion	May be over-reaction.
			(b) Build intermediate strength explosion resistant seals as per US standards	Provides protection of sealed area against inbye explosion.	May be inadequate if lack of ignition source is misdiagnosed.
			(20psi) (c)Build low strength ventilation seals.	Rapid construction low cost.	May be inadequate if lack ignition source is misdiagnosed. May be inadequate in the event of an inbye explosion.
3	Non-explosive	With	(a)As per 1	Provides higher level of protection than may be necessary against an internal explosion.	May be over-reaction.
			(b) Build intermediate strength explosion resistant seals as per US standards	Provides protection of sealed area against inbye explosion.	May be inadequate if absence of explosive atmosphere is misdiagnosed.
			(c)Build low strength ventilation seals.	Rapid construction - low cost.	May be inadequate if absence of explosive atmosphere is misdiagnosed. May be inadequate in the event on an inbye explosion.
4.	Non- Explosion	Without	(a)As per 1	Provides higher level of protection than may be necessary against internal explosion.	Unnecessary unless absence of explosive atmosphere and ignition source both misdiagnosed.
			(b)As per 2 (b)	Provides protection of sealed area against inbye explosion.	May be inadequate if absence of explosive atmos-phere & ignition source are both misdiagnosed.
			(c)Build low strength ventilation seals.	Rapid construction low cost.	May be inadequate if absence of explosive atmos-phere and ignition source are both misdiagnosed. May be inadequate in the event of an inbye explosion.

#### Table 1. ANAYLSIS OF VARIOUS SCENARIOS REQUIRING CONSTRUCTION OF SEALS

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# **Mining Research Centre**



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QUEENSLAND DEPARTMENT OF MINES AND ENERGY

# TASK GROUP 5MOURA IMPLEMENTATION PROGRAMME

# REPORT ON MEETINGS HELD ON 3, 4, 26 & 27 JUNE 1996 TO DEVELOP APPROPRIATE PERFORMANCE GUIDELINES FOR STOPPINGS AND SEALS IN UNDERGROUND COAL MINES

PREPARED BY

## McCRACKEN CONSULTING

20 CHRISTINA PLACE, KAREELA, N.S.W., 2232 Tel: (61-2) 9528-2870 Mobile 018-460-188

30 GLENVIEW STREET, GORDON, N.S.W., 2072 Tel: (61-2) 9498-4372 Messages (61-2) 9498-4372

JULY 1996

## DISCLAIMER

This Study was facilitated and reported on by Dr. John McCracken, Principal Consultant of McCracken Consulting Services, as an impartial and independent participant. The documentation puts on record the details of the Study and presents its findings. However, any use which any party makes of the documentation is the responsibility of such party. McCracken Consulting Services accepts no responsibility whatsoever for damages, if any are suffered by any party in reliance on information contained in this report.

REPORT STAGE	DA I, OF SUBMISSION
First Draft	21 June 1996
Final Report	25 July 1996
## 1. INTRODUCTION

The Chief Inspector of Coal Mines, Mr. Brian Lyne, of Queensland's Department of Mines and Energy, commissioned Dr. John McCracken, Principal Consultant of McCracken Consulting Services, to be the Facilitator at Task Group 5 meetings convened with the brief to develop appropriate risk-based performance guidelines for stoppings and seals used in underground coal mining. Dr. McCracken was subsequently requested to prepare a report on the findings of the meetings. The Chief Inspector provided a list of matters for consideration which is attached as <u>Appendix A</u> and initially briefed the Facilitator on 28 May, 1996, in Sydney on the objectives and scope of Task Group 5. The Facilitator was also provided (via Mr. Rick Davis of Technical Effectiveness, a participant of Task Group 5) with copies of *Sealing-off Fires Underground* a *Memorandum Prepared in 1985* for the *Institution of Mining Engineers* (UK), and the 1985 German *Guidelines for Sealing and Stopping of Pits in Underground Coal Mines* (this latter document was translated into English by McCracken Consulting Services), which he reviewed prior to the meetings.

The first meeting of Task Group 5 was held at the Department's Mary Street offices in Brisbane over the two days 3 and 4 June, 1996. Following discussions on other task group matters, the subject meeting on seals began at 11.40 a.m. on 3 June, stopping at 6.15 p.m. and resuming at 8.40 a.m. on 4 June, finishing at 3.00 p.m. with three rest breaks on each day. Between 7 and 12 of the participants listed below were in attendance at this meeting during these periods.

The second meeting of Task Group 5 was held at the same offices in Brisbane over the two days 26 and 27 June. The meeting opened at 10.00 a.m. Following a presentation by Wilson Mining Services Pty Limited on the Micon 550 explosion resistant seal the company is marketing in Australia, the subject meeting on seals began at 11.30 a.m. on 26 June, stopping at 5.35 p.m. and resuming at 9.10 a.m. on 27 June, finishing at 2.20 p.m. with three rest breaks on each day. Between 8 and 10 of the participants listed below were in attendance at this meeting during these periods.

Insofar as it was possible, the Facilitator endeavoured to conduct the meetings in the manner of a Hazard and Operability (HAZOP) Study. This initially involved having participants develop a model of a mine with all of the stoppings and seals that might be considered in this study. Then followed the routine analysis of each of several stoppings and seals deemed to be critical (see Figure 1 and Table 1), commencing with design intent, industry practice and safeguards available, and progressively moving onto an examination of the hazards of asphyxiation, toxicity, fire and explosion including as a result of credible deviations from the design intent, the consequences and likelihoods of these hazardous events, judgment of the risks involved to life and property given the safeguards available, assessment of the un/acceptability of the risks, and finally the development of guideline performance criteria for the specific type of critical stopping/seal which can be considered to provide an acceptable level of risk and also be cost-effective. Although consensus of agreement on the matters discussed was sought, this was not always possible so the outcomes recorded from the meeting attempt to reflect this where applicable. Also, in some instances, insufficient information was available to arrive at appropriate guidelines and these were recorded as actionable matters which were left over for review at the next meeting following further investigation by nominated participants.

At the outset of the meetings, the Facilitator, using <u>Figure 2a</u>, provided some limited direction on how risk to life and property may be qualitatively evaluated from consideration of the possible consequence(s) and likelihood of a hazardous incident. This was done in an attempt to keep participants focused throughout the meetings on the primary factors that affect the level of risk and on how it might be assessed as being acceptable or unacceptable. He also introduced another visual aid (reproduced here as

Figure 2b) to draw attention to such relationships between the urgency of controlling a fire or heating in a mine and the risk of explosion as might concern the appropriate design mechanical strength of a seal, or in providing insight to cost-effective management of resources generally (such as the preplanning and/or partial construction of seals when the risk of explosion is high). Note that Figure 2b was based on the opening introductory paragraphs on page 7 of the document quoted above; *Sealing-off Fires Underground* a *Memorandum Prepared in 1985* which paragraphs have been reproduced here as <u>Appendix B.</u>

Mr. David Humphreys, Principal Engineer (Mining Research) of SIMTARS, was appointed Secretary to minute the proceedings of the meetings. The majority of the notes from the first meeting were recorded on 'butchers paper' hung around the walls of the meeting room and these notes have been reproduced as <u>Appendix D</u>. The hand written notes taken at the second meeting have been reproduced as <u>Appendix E</u>.

The preparation of a draft report was completed by the Facilitator and submitted to the Chairman by 21 June, to enable review of progress by Task Group 5 participants prior to the second meeting held over 26 and 27 June. Although feedback was invited from participants on the draft report, virtually none was received by the Facilitator. An interim draft of the recommended risk-based performance guidelines for seals and stoppings (see Section 6) that also included a chart providing specific recommendations on design life, fire rating and explosion resistance (see <u>Table 1</u>) was prepared by the Facilitator and submitted to the Chairman on 16 July, for his review and subsequent discussion at a Task Group 5 meeting (not attended by the Facilitator) scheduled for 18 July, 1996. This final report was completed and submitted by the Facilitator to the Chairman on 25 July.

The following Section 2 notes the participants in attendance at the meetings. Section 3 lists the documentation provided to the Facilitator or tabled at the meetings. Section 4 lists the particularly noteworthy or significant matters that were covered during the meetings. Section 5 provides an account of the resolutions of the meetings. Section 6 provides a summary of the recommended risk-based guidelines for the performance of stoppings/seals. The two outstanding actionable matters raised at the meetings are given in Section 7. Sections 4 to 7 of this report were largely based on the record of notes made by the Secretary, and on the notes made by, and recollections of the Facilitator.

## 2. PARTICIPANTS

Task Group 5 Chairman - Mr. Brian Lyne, Chief Inspector of Coal Mines, Queensland

Facilitator - Dr. John McCracken, Principal Consultant, McCracken Consulting Services

Secretary - Mr. David Humphreys, Principal Engineer (Mining Research), SIMTARS

- Mr. Bill Allison, Confederated Forestry, Mining & Energy Union
- Mr. Stewart Bell, Manager, Occupational Hygiene Env. & Chemistry Centre, SIMTARS
- Mr. Mike Caffrey, Queensland Mining Council, Capricorn Coal Management Pty. Ltd.
- Mr. Rick Davis, NSW Minerals Council representative, GM, Technical Effectiveness
- Mr. Mike Downs, Queensland Mining Council, Principal Dev. Eng., BHP Australia Coal
- Mr. Graham Fawcett, NSW Department of Mineral Resources
- Mt Bruce Ham, observer
- Mr. Tony Hazeldean, Australasian Colliery Staff Assoc., Train. Off., Sth Blackwater Coal
- Mr. Tony Sellars, Manager, Queensland Mines Rescue Board

## 3. DOCUMENTATION

The following documents were provided to the Facilitator prior to the meetings:

- *Sealing-off Fires Underground.* Second revision of a memorandum prepared in 1943 by a Committee of The Institution of Mining Engineers (UK). (1985)
- *Guidelines for Sealing and Stopping of Pits in Underground Coal Mines* Circular from the Coal Board, Nordrhein-Westfalen, West Germany. Update 20.12.85 from 21.4.71. Reference 18.13.1 II 1.

The following documentation was provided/used during the initial meeting:

- *Evaluation of Solid-Block and Cementitious Foam Seals.* N.B. Greninger, E.S. Weiss, S.J. Luzik & C.R. Stephan. Report of Investigations 9382. U.S. Dept. of the Interior, Bureau of Mines. (1991)
- Construction of Seals in Underground Coal Mines. C.R. Stephan. Report No. 06213-90. Ind. Safety Div., Pittsburgh Safety & Health Technol. Centre, Tech. Support, Mine Safety and Health Admin. (MSHA), U.S. Dept. of Labour (USDOL). (1990)
- A Manual on Mines Rescue, Safety and Gas Detection. J. Strang & P. Mackenzie-Wood. CSM Press. 2nd Ed. (1990)

The following documentation was provided/used during the second meeting:

- Wilson Mining Services Pty. Ltd. Marketing material in relation to the Micon 550 permanent ventilation seal.
- *Tests for Fire Resistant Rating of Stoppings*. A two page document submitted by Mr. Graham Fawcett (Task Group 5 participant).
- *Figures presented by C. Stephen during his visit in July 1995.* A three page document on the consequences of explosion overpressures submitted by Mr. Graham Fawcett (Task Group 5 participant).

The Following several documents (see <u>Appendix C</u>) were tendered by McCracken Consulting Services in support of the Facilitator's argument' to seriously consider the strategic use of low design overpressures for explosions in underground coal mines.

• *Risk Criteria For Land Use Safety Planning*. Hazardous Industry Planning Advisory Paper (HIPAP) No. 4. Department of Planning, Sydney (1990). Section 4.2.2 on page 5, and Table 4 "Effects of Explosion Overpressure" on page 14.

The key point is that there are a number of contributors to fatal consequences and it would be wrong to base an analysis on direct blast overpressure effects only unless the other effects can be shown to be absent (as might be the case if standing in an open sandy desert). Note that the chance of fatality from direct blast overpressure effects, which is primarily due to lung haemorrhage, is often quoted as 1% at 105 kPa (15 psi) and 100% at 210 kPa (30 psi).

The other fatal effects referred to include impact from missiles, whole body translation, burns sustained from being within/inhaling an ignited flammable mix, breathing toxic combustion products and/or perhaps asphyxiation as oxygen is lost. Presumably, the latter inhalational effects would not be present if full breathing apparatus was being worn at the time of ignition.

The NSW (then) Department of Planning's Table 4 in HIPAP No. 4 suggests that there is a 20% chance of fatality to a person in a building at an explosion overpressure of 21 kPa (3 psi), 50% chance of fatality to a person in a building at an explosion overpressure of 35 kPa (5 psi and the threshold of eardrum damage), and 100% chance of fatality to a person in a building or in the open at an explosion overpressure of 70 kPa (10 psi and the threshold of lung damage). This table was largely based on ICI work which attempted to integrate all mechanisms for fatality from explosion overpressure into one graph.

- Hazard Analysis Course Notes. ICI Engineering Australia Pty. Ltd. Pages 61-62. (1988)
- Loss Prevention in the Process Industries. EP. Lees. Butterworths. Vol. 1. (1986) Extract from Section 17.9.6, "Effects (of explosions) on People" pp. 598-600. Extracts from Section 9.6; Table 9.12 "Transformation of Percentages to Probits" p.206, and Table 9.13 "Probit Equations for Some Major Hazards" p. 208.
- Risk Assessment of the Transportation of Hazardous Substances Through Road Tunnels in the United Kingdom. M. Considine, S.T. Parry & K. Blything. Transport & Road Research Laboratory, Dept. of Transport. Contractor Report 139. (1989) Extract from Section 4.5.8 "Effects of Explosions on Tunnel Occupants". Refers to two comprehensive reviews on the damage caused to people by explosions:

Ref. 46: *A Short Course on Explosion Hazards Evaluation*. W.E. Baker et al. SR1, Houston. (1979)

Ref. 63: *Vulnerability Model Enviro Control Incorporated*. N.A. Eisenberg. U.S. Coast Guard Report No. CG-D-137-75. (1975)

• ABR 862, Royal Australian Navy Ordnance Safety Manual, Volume 1 (1994). Instructions for Establishments, Commands and Navy Office, Part 2. Table 1 in Appendix 2 to Annex C to Section 5 of Chapter 1; "Equivalent overpressure values to give defined blast damage descriptions". [Commonwealth of Australia copyright reproduced by permission.]

## 4. MATTERS COVERED

All of the following matters were addressed, some at length whilst others were merely mentioned, where considered relevant to the stopping/seal under investigation. Many issues were common to other stoppings/seals and once addressed were not generally raised in subsequent analysis.

- Types of stoppings/seals (refer to the mine layout model in <u>Figure 1</u> and <u>Table 1</u> for the stoppings/seals and corresponding locations considered for this study)
  - simple temporary brattice stoppings to permanent explosion resistant seals
  - conveyor belt seals
  - emergency seals
  - overcasts regulators
  - emergency air locks personnel and machinery ventilation doors mine fan seals
- Locations of stoppings/seals (refer to the mine layout model in <u>Figure 1</u> and <u>Table 1</u> for the stoppings/seals and corresponding locations considered for this study)
  - surface (at/near the portals, mine fans, etc.)
  - underground (in main headings, bleeder headings, in development panel roadways, surrounding goaves, between mine districts or old workings, etc.)
- Design intent/purpose of stoppings/seals may include
  - effective segregation of intake ventilation air from return air whilst possibly providing access for personnel, machinery, conveyors, etc.
  - containment of inert/flammable/toxic gases
     containment of ground water
  - resistance to windblast from goaf fall, or from outburst
  - resistance to overpressure from gas or coal dust explosion resistance to heat/flame
  - separation of mine areas
- Required life of stoppings/seals
  - temporary (routine such as stoppings in cut-throughs during panel development or during an emergency)
  - permanent (at least for life of mine and as used in main headings or following longwall extraction or for sealing off a district)
  - final (sealing off a mine district or the mine at the surface)
  - emergency (in the event of ventilation failure or a heating or fire, etc.)
- Consideration of environmental conditions stability of roof, floor, ribs (strength, shear planes, geological stresses and other geological factors in relation to damage from strata movements)
  - permeability/breaks of/in local coal and strata (in relation to gas leakage) atmospheric pressure differentials at the location (in relation to gas leakage) humidity of the atmosphere (in relation to effect on construction materials) presence of ground water (in relation to effect on construction materials via direct contact in strata or dammed behind stopping/seal) presence of acid in ground water (in relation to effect on construction materials) significance of the volume of gas inbye requiring containment and/or requiring resistance to sudden pressures (in relation to mine safety, recoverability and ongoing viability)

- location (in relation to the suitability of available space, access for transportation of materials and for construction, and for subsequent access including for maintenance, inspection and monitoring, and in relation to vulnerability to damage by machinery or fire or windblast or explosion or water pressure or geological pressures or from other processes of natural deterioration, and in relation to difficulty of retreating to safety when constructing an emergency seal or at a critical time of demand)

## • Industry practice

regulation (government, departmental guidelines, industry standards and codes, and industry self-regulation)

in-house standards and certification as appropriate (in relation to type and quality of materials used and methods of construction, inspection, maintenance, and performance monitoring of ventilation, gas leakage, integrity/strength of seal over time, water drainage, damage from ground movement, etc.)

- other safeguards (eg. pressure balancing, limiting the size of goaf areas, providing crumple zones or explosion elimination zones including water or stonedust or triggered barriers, use of water seals, natural and active inertisation including use of recirculation of gas make and/or nitrogen or jet engine exhaust, extra ventilation capacity or modified ventilation patterns, tight control on frictional ignitions, and quality safety management systems including emergency planning which in high risk mines could include partial construction of seals that can be rapidly completed in the event of a heating emergency, etc.)

use of relevant experience and experiential databases of successful performance

### • Materials used for construction

type (brattice, plasterboard, steel sheeting, blockwork including light weight aerated concrete, infills of hard setting materials such as gypsum, and cements or polyurethane foam possibly containing aggregate materials eg. Micon 550 seals) rigid or flexible? (in relation to potential damage from ground movement) resistance to fire

- effects of humidity
- effects of water
- effects of acidity
- strength (in relation to impacts from pressure differentials including between intakes and returns but particularly from windblast or explosion or ground movement or dammed water, and also in relation to deterioration due to corrosion/assault from humidity, water, acidity, microorganisms etc.)
- curing time versus strength (for when installation is urgent) permeability (in relation to water penetration and particularly gas leakage) safe and convenient to use (in relation to occupational health, access and transport) material and transport costs

## • **Construction** of stopping/seal

methods in use (erection of brattice, plasterboard or steel sheeting on a timber frame, laying of concrete blocks, and infilling the void between widely spaced temporary or permanent walls with hard setting cementitious materials or polyurethane foam and aggregate, or filling an inflatable bag such as Monier's 'Big Bag')

possibility of using earth plugs capped with stonedust

- bulk and dimensions
- attention to adhesion to roof/ribs/floor
- possible grouting of strata for gas tightness
- provision of a pressure balancing chamber
- provision of a doorway or emergency access pipe through the stopping/seal

self closing doors resistance of seal and doorways to overpressure from windblast or explosion provision of gas monitoring tubes provision of water drainage pipes

- extensive stonedusting inbye
- construction safety
- construction costs
- construction time (particularly when installation is urgent)

## • Potential failure of seal integrity due to external impacts on the stoppings/seals

- windblast from goaf fall, or from outburst
- overpressure from gas or coal dust explosion
- pressure from dammed water
- fire on combustible seal material
- ground movement
- machinery damage
- inadequate strength prior to complete curing
- inadequate adhesion to roof/ribs/floor deterioration of material and loss of strength from corrosion/assault from humidity, water, acidity, microorganisms etc.
- **Potential hazards** in relation to **poorly designed/constructed** stoppings/seals
  - oxygen passes inbye to a zone of flammable gas due to a leaking seal raising the possibilities of a heating and flammable gas mixtures
  - flammable/toxic gases pass into a crucial 'fresh air' zone due to a leaking seal
  - increased leakage from greater pressure imbalances due to inadequate monitoring and control of ventilation, or to failure of pressure balancing, or to choked airways (eg. from roof fall in bleeder headings)
- **Potential hazards** in relation to all **deviations from the design intent/purpose** of the stoppings/seals
  - loss of segregation of intake ventilation air from return air loss of segregation of ventilation air with flammable gases
  - loss of containment of inert/flammable/toxic gases
  - loss of containment of ground water
  - loss of separation of mine areas
- **Consequences** in relation to impacts on life, health and property
  - potential exposure of employees to unacceptably high levels of toxic or asphyxiating gases with injury/fatal outcomes
  - should a flammable mixture form and ignite, potentially exposed employees may be injured/killed from direct blast overpressure effects, or impact from missiles, or whole body translation, or sustain serious/ fatal burns from being within/inhaling the flame, or be injured/killed from breathing the toxic combustion products and/or perhaps asphyxiated as oxygen is lost (these inhalational consequences may not be present if full breathing apparatus was being worn at the time of ignition)
  - cost of potential explosion damage to mining facilities cost of lost production whilst ever mine is inoperable
- Likelihood of potential hazards and consequences given available safeguards
  - based on logic but mostly on experience for qualitative analysis
- Judgment and assessment of un/acceptability of **risk to life and property** given available safeguards

- combination of consequences and likelihoods to infer levels of risk (see <u>Figure 2a</u>) - qualitative assessment of un/acceptability of total risk with industry goals

• Establishment of guideline design criteria to provide acceptable risk and be costeffective

if no risk or total risk is acceptable, do nothing (other than to avoid avoidable risk) if the total risk is unacceptable, identify and rank major risk contributors, and then establish guidelines for these that cost-effectively reduces the total risk to acceptable levels

cost-effective reduction of risk should involve examination of the use of alternative measures and safeguards, possibly unrelated to the functions of stoppings/seals, but which have the desired effect of reducina or eliminating the hazard and so avoiding the imposition of high costs on uprating the stoppings/seals

## 5. AN ACCOUNT OF THE MEETINGS AND RESOLUTIONS

The following notes only the significant contributors to unacceptable risk, followed by review action and follow-up, where applicable, and/or guideline resolved at the meetings. Refer to Figure 1 and Table 1 for the code, description and location of stoppings/seals.

al Temporary stoppings/seals installed in cut-throughs during panel development

*Impairment to integrity/strength of seal.* It is the responsibility of management to develop and use in-house standards in relation to the design, type and quality of materials used and methods of construction, inspection, maintenance, and performance monitoring of ventilation, gas leakage, water drainage, integrity/strength of seal over time, damage from ground movement or from accident with equipment, etc.

*Fire on combustible stopping materials.* The scenario of a fire on a combustible (partially or totally) temporary stopping in a cut-through during panel development was discussed. If the stopping was lost rapidly then life and health of employees inbye could be jeopardised by short circuiting of air between intake and return. Mr. Graham Fawcett was nominated to review fire resistance ratings that might be applied to stoppings/seals. He subsequently prepared and submitted a two page document on tests for fire resistant rating of stoppings which summarised the MSHA Standard (actually ASTM-E119, Fire Tests of Building, Construction and Materials), and the Australian Standard AS1530.4-1990. Following discussion of these standards, the following general fire ratings or flame resistance were suggested:

Type of Structure	Fire Rating	Rationale
Permanent Goaf Seals	AS1530.4-1990 60 minutes	To prevent release of combustible or asphyxiating gases
Explosion Resistant Seals	AS1530.4-1990 60 minutes	To prevent release of combustible or asphyxiating gases
Main Ventilation Structures	AS1530.4-1990 60 minutes	To prevent destruction of structures and short circuiting of main ventilation
Panel Ventilation Structures and all Regulators	Flame resistant only	Reduced requirement due to less permanent nature of structures

It was resolved that the following caveat should be attached to any such fire ratings: Where it can be demonstrated there is a low risk of fire, flame resistance will be required but not a standard fire rating.

These temporary stoppings (viz. <u>a1</u>) fall under the category of Panel Ventilation Structures and therefore would require only a flame resistance rating.

Action arising - Mr. Graham Fawcett to visit the CSIRO, North Ryde, to obtain more information on fire rating tests before a final recommendation is made.

Overpressure from windblast, or explosion atlnear the face. The scenarios of windblast or an explosion at the face impacting on temporary stoppings in cutthroughs during panel development was discussed. If stoppings were lost then life and health of surviving employees inbye could be jeopardised by short circuiting of air between intake and return. The appropriateness for the integrity of these stoppings to be maintained at least up to blast overpressures at which survival of employees inbye was likely was discussed. Some evidence suggested the upper limit may be only 70 kPa (10 psi) [see footnote on page 4]. The Facilitator and Mr. Graham Fawcett both submitted documents describing the consequences of various explosion overpressures. In light of this information it was suggested that, regardless of the coal gas composition, final seals should be explosion resistant to 140 kPa, goaf seals should be explosion resistant to 70 kPa, structures affecting the integrity of main entry escapeways should be explosion resistant to 35 kPa, and all other stoppings should be explosion resistant to 14 kPa, all subject to review including research on the distribution of explosion overpressures in a mine and on the strength of existing structures. It was also noted that due consideration could be given to offsetting the of providing explosion expected high costs resistant stoppings by reviewing/upgrading other explosion prevention measures. In summary:

Type of Structure	Suggested	<b>Explosion Resistance Rating</b>
Final Seals for Mine District etc.	140 kPa	(20 psi)
Permanent Seals in Maingates to Main Headings After Extraction Completed	70 kPa	(10 psi)
Permanent Seals in Maingates to Bleeder Headings After Extraction Completed	35 kPa	(5 psi)
Temporary Seals in Gateroads	35 kPa	(5 psi)
Temporary Stoppings/Seals in Gateroad Development	14 kPa	(2 psi)

These temporary stoppings (viz. al ) would therefore require a 14 kPa rating but this subject to research on the distribution of explosion overpressures and particularly on the strength of existing structures.

Action arising - SIMTARS to undertake a literature review and research on the likely distribution of explosion overpressures in a mine and on the strength of existing structures.

- *Personnel access doors remain open following windblast or explosion.* The scenario of an explosion at the face or a windblast impacting detrimentally on access doors in stoppings in cut-throughs during panel development was discussed. If these access doors were to remain open (even though pressure relief from the doors opening was considered to be a positive attribute) then life and health of surviving employees inbye could be jeopardised by short circuiting of air between intake and return. The Task Group recommended that the mine design stipulates <u>all</u> ventilation doors be self-closing and should be capable of maintaining operational integrity at the relevant stopping's fire and explosion resistance ratings.

# a2 Temporary seals installed in cut-throughs prior to extraction phase (the original stoppings are mostly rebuilt as rigid seals closer to the tailgate side of the cut-throughs)

Impairment to integrity/strength of seal. As for al above.

Fire on combustible seal materials. Required only to be flame resistant.

- Overpressure from explosion. An explosion resistance rating of 35 kPa is recommended but this subject to review as stated under al above.

### bl Permanent seals installed in maingates at bleeder heading after extraction completed

- Impairment to integrity/strength of seal. As for al above.

*Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under al above.

*Overpressure from explosion.* An explosion resistance rating of 35 kPa is recommended but this subject to review as stated under al above.

## b2 Permanent seals installed in maingates at main heading after extraction completed

Impairment to integrity/strength of seal. As for al above.

- *Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under al above.
- Overpressure from explosion. An explosion resistance rating of 70 kPa is recommended but this subject to review as stated under al above. The precautionary measure of heavy stonedusting inbye of the seal was also suggested.

## b3 Permanent seals installed in driveways to seal off a mine or mine district

- Impairment to integrity/strength of seal. As for al above.
- *Fire on combustible seal materials.* **To** comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under al above.

Overpressure from explosion. At the first meeting two acceptably low risk sealing options were discussed. In each case it was considered that due diligence monitoring of inbye gases would be essential to ensure full knowledge of the possibility/presence of a heating and/or a flammable gas mixture. Personnel should be removed from the mine immediately if a flammable gas mixture was detected and should remain on the surface until the mixture had passed safely through the flammable range. The two options were:

- (i) A non explosion resistant seal could be installed where active or natural inertisation can be used in a manner which unequivocally prevents the formation of flammable gas mixtures.
- (ii) An explosion resistant seal to standard design could be installed. The U.S. standard design which requires resistance to 20 psi overpressure was considered to be the most appropriate but a review was suggested of the whole U.S.

standard to justify its application to Queensland and possibly New South Wales mines (Mr. Bill Allison and Mr. Mike Downs were nominated for this task). Only one change to the U.S. standard was suggested, i.e. heavy stonedusting at least up to 100m inbye of the seal instead of the standard 200 feet.

Further discussion at the second meeting of the Task Group leant to scrapping the first option because the integrity of the structure and the gases meant to be contained can be compromised by a potential explosion occurring outbye. Thus the resolution reached was that final seals should probably be explosion resistant to 140 kPa but this subject to review including the literature review and research to be undertaken by SIMTARS on the likely distribution of explosion overpressures in a mine and on the strength of existing structures (as reported above under al).

- cl Stoppings around main designated escapeways
  - Impairment to integrity/strength of seal. As for al above.
  - *Fire on combustible stopping materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under al above.
  - Overpressure from explosion. An explosion resistance rating of 35 kPa is recommended but this subject to review as stated under al above.

Segregation (belt isolation) stoppings

- Impairment to integrity/strength of seal. As for al above.
- *Fire on combustible stopping materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under al above.

*Overpressure from explosion*. An explosion resistance rating of 14 kPa is recommended but this subject to review as stated under al above.

- d Permanent overcasts
  - Impairment to integrity/strength of seal. As for al above.
  - *Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under al above.

*Overpressure from explosion.* If explosion damage to an overcast can affect the integrity of a main entry escapeway then it should be explosion resistant to 35 kPa otherwise it should be 14 kPa, subject to review as stated under al above.

Temporary overcasts

- Impairment to integrity/strength of seal. As for al above.
- *Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under al above.

*Overpressure from explosion.* Although an explosion resistance rating is not considered necessary for temporary overcasts, these structures must be approved by a mining inspector.

- f Emergency airlock installed at the portal of the driveway designated as an escapeway providing access into a sealed mine following a major fire or initial explosion incident and to prevent ingress of air
  - *Impairment to integrity/strength of seal*. As for al above, and also refer to `overpressure from explosion' below.
  - *Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under al above.

*Overpressure from explosion.* At the first meeting the following two acceptably low risk sealing options were discussed:

- (i) Pre-installed airlock should be resistant to the attenuated low pressure of an underground explosion. However, it need not be resistant to the higher pressures that would be experienced from potential subsequent explosions when the mine was sealed off.
- (ii) An airlock installed at the time of sealing off the mine is not required to be explosion resistant.

Following considerable debate at the second meeting the Task Group resolved to word its recommendations in the following manner:

Facilities shall be provided at one entry to a mine which after an initial explosion or emergency event shall

- have operational integrity after the initial explosion or event
- be able to be installed or operated readily with minimal exposure of persons to hazards
- be capable of preventing entry of air into the mine
- facilitate the introduction of an inert atmosphere into the mine
- facilitate the exit or re-entry of persons

Design criteria for elements of the facilities affected by an initial explosion shall have regard to a prospective explosion overpressure of 140 kPa and flying debris.

However, consensus of opinion was not achieved on the explosion overpressure criterion of 140 kPa because some participants felt that prior to an initial explosion or emergency event the structure would be so located as not to be affected by an explosion. Since an adequate location and suitable design can not be guaranteed, the Chairman insisted that the criterion remains, subject to further review.

## g Emergency seals installed at the portals of driveways to seal off a mine following a major fire or initial explosion incident and to prevent ingress of air

Impairment to integrity/strength of seal. As for al above.

- *Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under al above.

*Overpressure from explosion.* The same recommendations and reservation apply as for the emergency airlock (f above) except for the capabilities of facilitating the introduction of an inert atmosphere into the mine or the exit or re-entry of persons.

## h Ventilation double doors

Impairment to integrity/strength of seal. As for al. above.

*Fire on combustible door seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under al above.

*Overpressure from explosion.* If explosion damage to the doors can affect the integrity of a main entry escapeway then they should be explosion resistant to 35 kPa otherwise they should be explosion resistant to 14 kPa, subject to review as stated under al above. The ventilation doors should be designed to be self-closing and should be capable of maintaining operational integrity at the relevant explosion resistance ratings.

## Ventilation doors for personnel

Impairment to integrity/strength of seal. As for al above.

- *Fire on combustible door seal materials.* The ventilation doors must maintain operational integrity at the stopping's flame resistance or fire rating, subject to review as stated under al above.

*Overpressure from explosion.* The ventilation doors should be designed to be self-closing and should be capable of maintaining operational integrity at the stopping's explosion resistance rating, subject to review as stated under al above.

### Regulators

Impairment to integrity/strength of seal. As for al above.

Fire on combustible seal materials. Required only to be flame resistant.

Overpressure from explosion. Explosion resistance not required.

## k Surface fan seal permanently available for emergency use at the junction of shaft and fan

Impairment to integrity/strength of seal. As for al above.

*Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under al above.

- Overpressure from explosion. Effective protection of the fan from underground explosions was considered to be critical since restarting of the fan was essential to facilitate rapid mine recovery operations. Means of protection considered included offsetting the fan to the suction duct work and upstream blow-out panels in line with the suction duct work. Following much debate which did not produce a consensus of opinion, the Chairman recommended that the surface fan installation be capable of surviving an explosion overpressure of 70 kPa internally unless appropriate strategies for venting at lower overpressures can be devised, and subject to review as stated under al above,

## I Emergency prep seals intended to isolate a section of the mine in an emergency (fire or spontaneous combustion) by stopping ventilation

It was recommended that these seals be pre-prepared and that construction materials be available and capable of being supplied in a manner which would allow rapid installation, and to be as air-tight as practicable.

- Impairment to integrity/strength of seal. As for al above.
- Fire on combustible seal materials. No requirement recommended.
- Overpressure from explosion. No requirement recommended.
- in Conveyor coffin seal
  - Impairment to integrity/strength of seal. As for al above.
  - *Fire on combustible seal materials*. Required only to be flame resistant.

*Overpressure from explosion*. An explosion resistance rating of 14 kPa is recommended but this subject to review as stated under al above.

## 6. A SUMMARY OF THE RISK-BASED PERFORMANCE GUIDELINES RECOMMENDED BY TASK GROUP 5 FOR SEALS AND STOPPINGS IN UNDERGROUND COAL MINES

The following provides the Facilitator's summary (as submitted to the Chairman on 16 July for his review and for discussion at the next scheduled meeting on Thursday 18 July) of the risk-based performance guidelines recommended by Task Group 5 for the types of stoppings and seals noted by code on the mine layout model in <u>Figure 1</u>. The code used for the type and location of each stopping or seal is disclosed in <u>Table 1</u> which also provides summarised guidance on design life, fire rating and explosion resistance.

In relation to the potential impairment to integrity/strength of a stopping or seal, specific guidance was not proffered because it was considered unequivocally the responsibility of management to develop and use in-house standards, and certification as appropriate, for the type and quality of materials that are used and the methods of construction, inspection, maintenance, and performance monitoring employed for ventilation, gas leakage, water drainage, integrity/strength of seal over time, damage from ground movement or from accident with equipment, etc.

Therefore, in designing, locating, constructing, monitoring and maintaining stoppings and seals, all of the following factors should be taken into consideration, where relevant:

- Develop a clear understanding of the design intent/purpose. This may include any of the following;
  - effective segregation of intake ventilation air from return air whilst possibly providing access for personnel, machinery, conveyors, etc
  - containment of inert/flammable/toxic gases
  - containment of ground water
  - resistance to windblast from goaf fall, or from outburst
  - resistance to overpressure from gas or coal dust explosion
  - resistance to heat/flame -

separation of mine areas

- Determine the required life of the stopping or seal (see recommendations in <u>Table 1</u>). The design life might be:
  - temporary (routine such as stoppings in cut-throughs during panel development or during an emergency)

- permanent (at least for life of mine and as used in main headings or following longwall extraction or for sealing off a district)
- final (sealing off a mine district or the mine at the surface) emergency (in the event of ventilation failure or a heating or fire, etc.)
- Identify and take account of the environmental conditions that may affect the required performance and/or integrity/strength of the stopping or seal, such as;
  - stability of roof, floor, ribs (strength, shear planes, geological stresses and other geological factors in relation to damage from strata movements)
  - peimeability/breaks of/in local coal and strata (in relation to gas leakage)
  - atmospheric pressure differentials at the location (in relation to gas leakage)
  - humidity of the atmosphere (in relation to effect on construction materials)
  - presence of ground water (in relation to effect on construction materials via direct contact in strata or dammed behind stopping/seal)
  - presence of acid in ground water (in relation to effect on construction materials)
  - significance of the volume inbye requiring containment and/or requiring resistance to sudden pressures (in relation to mine safety, recoverability and ongoing viability) location (in relation to the suitability of available space, access for transportation of materials and for construction, and for subsequent access including for maintenance, inspection and monitoring, and in relation to vulnerability to damage by machinery or fire or windblast or explosion or water pressure or geological pressures or from other processes of natural deterioration, and in relation to difficulty of retreating to safety when constructing an emergency seal or at a critical time of demand)
- Adopt appropriate industry practice including;

regulation (government/departmental guidelines, industry standards and codes, and industry self-regulation)

- in-house standards (in relation to type and quality of materials used and methods of construction, inspection, maintenance, and performance monitoring of ventilation, gas leakage, integrity/strength of seal over time, damage from ground movement, water drainage, etc.)
- other safeguards (eg. pressure balancing, limiting the size of goaf areas, providing crumple zones or explosion elimination zones including water or stonedust or triggered barriers, use of water seals, natural and active inertisation including use of recirculation of gas make and/or nitrogen or jet engine exhaust, extra ventilation capacity or modified ventilation patterns, tight control on frictional ignitions, and quality safety management systems including emergency planning which in high risk mines could include partial construction of seals that can be rapidly completed in the event of a heating emergency, etc.)
- use of relevant experience and experiential databases of successful perfolinance
- Examine the applicability and suitability of materials available for constructing the stopping or seal;

type (brattice, plasterboard, steel sheeting, blockwork including light weight aerated concrete, infills of hard setting materials such as gypsum, and cements or

- polyurethane foam possibly containing aggregate materials eg. Micon 550 seals)
- rigid or flexible? (in relation to potential damage from ground movement)
- resistance to fire (see recommendations in <u>Table 1)</u>
- effects of humidity
- effects of water
- effects of acidity
- strength (in relation to impacts from pressure differentials including between intakes and returns but particularly from windblast or explosion - see recommendations in

<u>Table 1</u> - or ground movement or dammed water, and also in relation to deterioration due to corrosion/assault from humidity, water, acidity, microorganisms etc.)

- curing time versus strength (for when installation is urgent)
- permeability (in relation to water penetration and particularly gas leakage) safe and convenient to use (in relation to occupational health, access and transport) material and transport costs
- Determine the means available and the extent of construction required for the stopping or seal, such as;
  - methods in use (erection of brattice, plasterboard or steel sheeting on a timber frame, laying of concrete blocks, and infilling the void between widely spaced temporary or permanent walls with hard setting cementitious materials or polyurethane foam and aggregate, or filling an inflatable bag such as Monier's Big Bag')
  - possibility of using earth plugs capped with stonedust bulk and dimensions
  - attention to adhesion to roof/ribs/floor
  - possible grouting of strata for gas tightness
  - provision of a pressure balancing chamber
  - provision of a doorway or emergency access pipe through the stopping/seal self closing doors
     resistance of seal and doorways to overpressure from windblast or explosion provision of gas monitoring tubes
     provision of water drainage pipes
  - extensive stonedusting inbye
  - construction safety
  - construction costs
     construction time (particularly when installation is urgent)
- Identify all mechanisms of potential failure of seal integrity due to external impacts on the stopping or seal which could include; windblast from goaf fall, or from outburst overpressure from gas or coal dust explosion
  - pressure from dammed water fire on combustible seal material
  - ground movement machinery damage
  - inadequate strength prior to complete curing
  - inadequate adhesion to roofhibs/floor deterioration of material and loss of strength from corrosion/assault from humidity, water, acidity, microorganisms etc.
- Identify the potential hazards in relation to all deviations from the design intent/purpose of the stopping or seal. This is likely to involve; loss of segregation of intake ventilation air from return air such that flammable/toxic gases pass into a crucial 'fresh air' zone

loss of segregation of ventilation air with flammable gases such that oxygen passes inbye to a zone of flammable gas raising the possibilities of a heating and/or flammable gas mixtures

 loss of containment of flammable/toxic gases raising the possibilities of flammable gas mixtures and/or zones of toxic gas particularly in travel roadways loss of containment of ground water loss of separation of mine areas

- Analyse the consequences of failure in the required performance of the stopping or seal in relation to impacts on life, health and property. These might include;
  - potential exposure of employees to unacceptably high levels of toxic or asphyxiating gases with injury/fatal outcomes
  - should a flammable mixture form and ignite, potentially exposed employees may be injured/killed from direct blast overpressure effects, or impact from missiles, or whole body translation, or sustain serious/ fatal burns from being within/inhaling the flame, or be injured/killed from breathing the toxic combustion products and/or perhaps asphyxiated as oxygen is lost (these inhalational consequences may not be present if full breathing apparatus was being worn at the time of ignition)
  - cost of potential explosion damage to mining facilities
  - cost of lost production whilst ever mine is inoperable
- Contemplate the likelihood of the identified potential hazards and associated consequences given all available safeguards. This will be largely based on experience.
- Evaluate and assess the un/acceptability of risk to life and property given <u>all</u> available safeguards. The risk is evaluated from the combination of consequences and likelihoods to infer levels of risk. A qualitative assessment of un/acceptability of the total risk can be made by comparison with industry goals.
- Establish in-house risk-based guidelines for the most appropriate set of design, location, materials, construction, monitoring and maintenance parameters for the stoppings and seals that provides an acceptable level of risk and is cost-effective. Decision making here will include;
  - if no risk or total risk is acceptable, do nothing (other than to avoid avoidable risk)
  - if the total risk is unacceptable, identify and rank major risk contributors, and then review alternative parameters for these that cost-effectively reduces the total risk to acceptable levels
  - cost-effective reduction of risk should involve examination of the use of alternative measures and safeguards, possibly unrelated to the functions of stoppings and seals, but which have the desired effect of reducing or eliminating the hazard and so avoiding the imposition of high costs on uprating the stoppings or seals

## **6.** OUTSTANDING ACTIONABLE MATTERS The

following two matters were noted for review.

- 1. Mr. Graham Fawcett to visit the CSIRO, North Ryde, to obtain more information on fire rating tests, prior to further review by Task Group 5 to assist in drawing up appropriate guidelines on fire ratings for seals and stoppings.
- 2. SIMTARS is to undertake a literature review and research on the likely distribution of explosion overpressures in a mine and on the strength of existing structures, prior to further review by Task Group 5 to assist in drawing up appropriate guidelines on explosion resistance ratings for seals and stoppings.

## <u>TABLE I:</u> DESIGN LIFE, FIRE RESISTANCE AND EXPLOSION RESISTANCE PERFORMANCE GUIDELINES RECOMMENDED FOR STOPPINGS AND SEALS IN UNDERGROUND COAL MINES

Stopping/Seal	Code	Location	Design Life	Fire Rating	Explosion Resistance
	(F1g. 1)			[1]	[2]
Panel Stoppings (development roadways)	al	in cut-through, inbye of regulator between intake and return	temporary, <12 months	flame resistant	14 kPa [4]
Panel Stoppings (during longwall extraction)	a2	as for 'al' stoppings but usually rebuilt closer to the tailgate	temporary, life of panel	flame resistant	35 kPa
Goaf Seals (after longwall extraction)	hl	as for 'al' stoppings but in a bleeder heading	permanent, life of mine	AS1530.4, 60 minutes	35 kPa
Goat Seals (after longwall extraction)	b2	driveways on both sides of goaf at main heading	permanent, life of mine	AS1530.4, 60 minutes	70 kPa
Final Seals (for mine district etc)	b3	in all driveways to mine district etc	permanent, life of mine	AS1530.4, 60 minutes	140 kPa
Stoppings Around Main Escapeways	c1	as for `al' stoppings but in main headings	permanent, life of mine	AS1530.4, 60 minutes	35 kPa
Segregation (Belt Isolation) Stoppings	c2	as for 'al' stoppings but in main headings	pings but in main headings permanent, life of mine AS1530.4, 60 m		14 kPa
Permanent Overcast	d	in main headings	permanent, life of mine	AS1530.4, 60 minutes	14 kPa or 35 kPa [5]
Temporary Overcast	e	in main headings	temporary, life of panel	AS1530.4, 60 minutes	not required [6]
Emergency Air Lock (at Surface)	) f at portal to designated escapeway permanent, life of mine AS1530.4, 60 minutes		140 kPa [7]		
Emergency Seal (at Surface) g		at each portal	permanently available	AS1530.4, 60 minutes	140 kPa [7]
Ventilation Double Doors for Machines	h	as for 'al' stoppings but in main headings	temporary, life of panel	AS1530.4, 60 minutes	14 kPa or 35 kPa [5]
Ventilation Doors for Personnel [3]	i	in stoppings as required	temp./perm. as required	equivalent to stopping	equivalent to stopping
Regulators	j	ends of tailgates and returns of main headings	temp./perm. as required	flame resistant	not required
Mine Fan Seal	k	junction of shaft to fan	permanently available	AS1530.4, 60 minutes	70 kPa
Emergency Prep Seals	1	in all driveways to panel or mine district	permanently available	not required	not required
Conveyor Coffin Seal	m	junctions of belt roads and return headings	temporary, life of panel	flame resistant	14 kPa

Notes:

[1].Suggested fire ratings are under review. Where it can be demonstrated there is a low risk of fire, a fire rating will not be required.

[2]. Suggested explosion resistance ratings are under review. Subject to research on explosion pressure distribution and on strength of existing structures.

[3]. Ventilation doors in stoppings for personnel access must be designed to be self closing and to maintain operational integrity at the stopping's fire and explosion resistance ratings.

[4].Suggested explosion resistance rating of stoppings in development roadways is subject to Note 2 but particularly research on strength of existing structures.

[5].If explosion damage to a structure can affect the integrity of a main entry escapeway then it should be explosion resistant to 35 kPa otherwise it should be 14 kPa subject to Note 2. [6].Although an explosion resistance rating is not recommended for temporary overcasts these structures must be approved by a mining inspector.

[7]. Design and location of an emergency airlock and seals shall have regard to maintaining operational integrity after an initial explosion with flying debris and an overpressure up to 140 kPa.





SEVERITY OF INCIDENT -

## **FIGURE 2b**

A FIRE OR HEATING IN MINE

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SOME PRIMARY **CONSIDERATIONS FOR SEALING OFF A MINE TO AVOID AN EXPLOSION** 

McCracken Consulting Services Date: June 1996 20 Christina Place Kareela NSW 2232 Tel: (61-2) 9528-5680 Fax: (61-2) 9528-2852

## **FIGURE 2a**

**RELATIONSHIP OF RISK TO CONSEQUENCE AND** LIKELIHOOD OF A **HAZARDOUS INCIDENT** 

## <u>APPENDIX A</u>

### NOTES PREPARED BY MR BRIAN LYNE, CHIEF INSPECTOR OF COAL MINES, ON MATTERS FOR CONSIDERATION AT THE MEETINGS OF TASK GROUP 5 HELD OVER 3, 4, 26 & 27 JUNE 1996

## MINE sr,, a, RISK ASSESSMENT

Scope: To determine the critical parameters required for mine seals used in. underground coal mines.

## mAs<sup>-</sup>rnRs TO CONSIDER:-

- What is the purpose of the seal
  - contain / resist an explosion
  - contain inert/toxic gas
  - contain water special purpose (e.g. to separate two mines)
- Design Life
  - short term (1 to 5 years)
  - long term (5 years plus)
  - temporary (0 to 1 yr)
- Environmental considerations
  - stability of roof, floor, sides
  - effect of moisture/water
  - dimensions
- Location
  - surface
  - underground (district and panel)
  - Materials used
    - Ere resistance rating
    - curing time
    - effect of acid water
    - effect of humid atmosphere
- General matters
  - quality of air tight seal
  - adhesion to roof, rib and floor
  - volume of materials and transport options
  - variations in quality of installation in relation to life expectancy installation time.
  - pressure equalisation
  - use of explosion resistant doors

Potential hazards and possible control methods

- coal dust explosion
- gas explosion/ignition
- wind blast (goal fall) -

geotechnical pressures

- Performance monitoring requirements
  - air leakage
  - strength of materials over time
  - evidence of damage

## <u>APPENDIX B</u>

### EXTRACT FROM `SEALING-OFF FIRES UNDERGROUND' MEMORANDUM PREPARED IN 1985 THE INSTITUTION OF MINING ENGINEERS, U.K.

#### 1. PRINCIPLES OF SEALING-OFF AND THE DESIRABLE FEATURES OF STOPPINGS

The operation of sealing-off a mine fire or heating is intended to prevent access of air to the fire zone and to confine any possible explosion which might arise. Given this twofold purpose, the obviously desirable feature of any design is a construction using materials with a high bulk content which are safe and convenient to handle, are low in cost and have immediate strength and air tightness. Stoppings should be completed in the safest possible manner and provide facilities for subsequent re-entry.

Primary considerations to be borne in mind when sealing off are the urgency of bringing the fire (or heating) under control and the possibility of an explosion occurring whilst doing so. Thus, the type of incident may range from: (i) where there is an urgent need to control the fire, but no risk of explosion; (ii) where fire control is less urgent than protection against a likely explosion; and (iii) where danger of explosion may be coupled with an urgent need to control the fire in order to safeguard men and equipment.

These considerations, together with the associated mining conditions, form the main basis of the classification of incidents dealt with in the succeeding sections of the memorandum. It will be appreciated that, if it were not for the possible risk of explosion, the operation of sealing-off would consist simply of providing a seal designed solely to prevent access of air to the fire and requiring little or no mechanical strength. The main principles to be considered, therefore, are those relating to the onset and control of conditions conducive to the risk of an explosion.

#### 1.1 Onset of Explosion 1-Frzard

#### 1.1.1 Cause of Explosion Hazard

With few exceptions, the explosion hazard arising from mine fires is due to the accumulation of methane or, less frequently, carbon monoxide and hydrogen produced by the fire itself after the ventilation has either stopped or been seriously reduced. Wherever there is the possibility of such an accumulation near the fire, or of migration of methane to the seat of the fire, it follows that unless there are overriding reasons to the contrary the ventilation should be maintained as near as possible to its normal rate or at least reduced under control to a still safe rate during the operation of building seals. The permissible extent by which the ventilation can safely be reduced (with a view to delaying the progress of the fire or to facilitate fire-fighting or constructing stoppings down-wind of the fire) can only be determined by a sound knowledge of the make of methane within the district, supported by continuing appraisals of the changing nature of the atmosphere throughout the district so far as is available.

#### 1.1.2 Fire Gases

Fire gases are seldom formed in quantity by an exposed fire in the presence of excess air, since they then burn at the fire itself, but when the fire is well-developed and there is much hot material these gases may escape and accumulate in sufficient quantity to present a serious hazard. Usually, such a dangerous accumulation is on the down-wind side of the fire and is protected from ignition by the products of combustion, though this cannot be safely relied upon. As a consequence of the danger of even momentary reversal of the air over the fire it is desirable that to prevent surges of air, undue sudden stopping or an unduly sharp reduction of ventilation should be avoided.

#### 1.1.3 Effect of Stopping Ventilation

When the ventilation is stopped there is an immediate readjustment of the atmosphere in the controlled area, due both to pressure changes and to local heat convection, followed by further adjustment as natural ventilation caused by the fire asserts itself (if indeed it has not done so previously). Following this there is a general build-up of hazard due to the progressive accumulation of methane and/or fire gases countered by loss of oxygen to the fire. The atmosphere usually passes through a period when it is explosive, either locally or over a large area, unless the make of methane is very low and the fire and consequent rate of oxygen take-up is large. Because of a lack of data the frequency of gas ignitions cannot be stated - however it would be reasonable to assume that mere have occurred than have been observed. An estimate can be made of the duration of this danger period from the known make of methane, coupled with an appraisal of the conditions within the sealed area, based on analyses of such samples of the contained atmosphere (See Section 11).

#### 1.1.4 Operation of Stopping Ventilation

The above considerations imply that wherever there is a gas hazard, the act of sealing should be effected within as short a time as possible and should be carried out at all stop-pings simultaneously.

When building explosion-proof stoppings it is essential to incorporate a tunnel through which ventilation is maintained until the time for sealing. The tunnel should be formed of steel ducting with end plates and closing doors of adequate strength to withstand any likely explosion providing for rapid closure, as well as the convenience of re-opening.

#### 1.1.5 Exceptional Circumstances

Circumstances may arise in which it is desirable to slow down, stop or divert the ventilation, before building the stoppings. Such circumstances might include cases where:

- The uncontrolled spread of fire may involve danger to men;
- control of ventilation may be needed to prevent tin,desirable migration of poisonous products of combustion away from the fire, or conversely, accumulation and migration of methane towards it; and
- (iii) the layout and gradients are such that the fire itself could otherwise take control of the ventilation in the affected area.

In cases where such difficulties occur, the necessary action must be decided in the light of the circumstances prevailing. The question arises that it may be necessary to resort to temporary sealing to give immediate control of air flow, and accept the risk of destruction of the temporary seal by explosion after all men have been withdrawn and, if so, what form of temporary seal should be recommended.

#### 1.2 Protection Against Explosion

Explosions are most likely to occur within a short period after ceasing to ventilate the area. A stopping intended to

## <u>APPENDIX C</u>

## PAPERS TENDERED BY McCRACKEN CONSULTING IN SUPPORT OF USE OF LOW DESIGN OVERPRESSURES

## **RISK CRITERIA FOR LAND USE SAFETY PLANNING**

HAZARDOUS INDUSTRY PLANNING ADVISORY PAPER NO. 4

SYDNEY

### 4.2 Injury Risk Levels

Relying entirely upon fatality risk criteria may not account for the following factors:

• Society is concerned about risk of injury as well as risk of death.

Fatality risk levels may not entirely reflect variations in people's vulnerability to risk. Some people may be affected at a lower level of hazard exposure than others.

It is therefore appropriate that risk criteria also be set in terms of injury, i.e. in terms of levels of effects that may cause injury to people but will not necessarily cause fatality.

#### 4.2.1 Heat Radiation

Table. 3 indicates the effects of various heat flux (radiation) as the result of a fire incident. The ultimate effect would depend on the duration of people's exposure to the resultant heat flux.

For the purpose of injury, a lower heat radiation level (relative to that level which may cause fatality) is appropriate. The 4.7 kW/m<sup>2</sup> heat radiation level (see table 3) is considered high enough to trigger the possibility of injury for people who are unable to be evacuated or seek shelter. That level of heat radiation would cause injury after 30 seconds' exposure. Accordingly, a risk injury criteria of 50 in a million per year at the 4.7 kW/m<sup>2</sup> heat flux is suggested. The department's experience with the implementation of that criteria indicates that it is achievable and appropriate.

The suggested injury risk criteria for heat radiation can therefore be expressed as follows:

 Incident heat flux radiation at residential areas should not exceed 4.7 kW/m<sup>2</sup> at frequencies of more than 50 chances in a million per year.

#### 4.2.2 Explosion Overpressure

Table 4 indicates the effect of various levels of explosion overpressures resulting from explosion scenarios.

Using a similar analysis to that adopted in establishing a heat flux injury level, it can be suggested that an explosion overpressure level of 7 kPa be the appropriate cut-off level above which significant effects to people and property damage may occur. Accordingly, an injury risk criteria of 50 in a million at the 7 kPa explosion overpressure level is suggested. The department's experience with implementation confirms this level as appropriate.

The suggested injury/damage risk criteria for explosion overpressure can therefore be expressed as follows:

Incident explosion overpressure at residential areas should not exceed 7 kPa at frequencies of more than 50 chances in a million per year.

#### 4.2.3 Toxic Exposure Criteria

Depending on the concentration, the nature of the material, the duration and mode of exposure (i.e. via the respiratory tract, lungs, skin or ingestion), the effects of toxicants range from fatality, injury (e.g. damage to lungs and respiratory system, damage to nervous system, emphysema, etc.) to irritation of eyes, throat or skin through to a nuisance effect. Effects can also be classified as acute, chronic or delayed.

There are a number of assessment criteria and dose-effect relationships that vary from one chemical to another. Toxic criteria applicable to one chemical may not necessarily be appropriate for others. The department's experience conclusively shows that the formulation of a uniform specific criteria to cover all toxic effects is not appropriate or valid. Instead, each case should be justified on its merits using a thorough search of available and known dose-effect relationships as the basis for assessment. Incidents with injurious impact on people should be kept to low frequencies.

The suggested injury risk criteria for toxic gas/ smoke/dust exposure are as follows:

> Toxic concentrations in residential areas should not exceed a level which would be seriously injurious to sensitive members of the community following a relatively ..port period of exposure at a maximum frequency of 10 in a million per year.

> > Toxic concentrations in residential areas should not cause irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community over a maximum frequency of 50 in a million per year.

## TABLE 4: EFFECTS OF EXPLOSION OVERPRESSURE

Explosion Overpressure	Effect
3.5 kPa (0.5 psi)	<ul><li>90% glass breakage</li><li>No fatality and very low probability of injury</li></ul>
7 kPa (1 psi)	<ul> <li>Damage to internal partitions and joinery but can be repaired</li> <li>Probability of injury is 10%. No fatality</li> </ul>
14 kPa (2 psi)	House uninhabitable and badly cracked
21 kPa (3 psi)	<ul> <li>Reinforced structures distort</li> <li>Storage tanks fail</li> <li>20% chance of fatality to a person in a building</li> </ul>
35 kPa (5 psi)	House uninhabitable Wagons and plants items overturned Threshold of eardrum damage 50% chance of fatality for a person in a building and 15% chance of fatality for a person in the open
 70 kPa (10 psi)	<ul> <li>Threshold of lung damage</li> <li>100% chance of fatality for a person in a building or in the open</li> <li>Complete demolition of houses</li> </ul>



Section 4.3 Page 61

70

Engineering

Almost complete demolition of all ordinary structures. Assumed edge of cloud. Damage to most chemical plants would be severe although some compressors, pumps and heat exchangers could be salvaged.

Missile effects are unlikely at distances coiLesponding to overpressures less than 0.7 - 1.4 kPa [Reference 9].

#### 6. Risk of Fatality

Very rough graphs are shown in Figure 4.3-2, indicating the probability of fatality for people exposed to overpressure. They are only rough estimates, constructed from a variety of sources, but supt, urted by the latest review outlined in Reference 9.

When better information becomes available, that should be used in preference to Figure 4.3-2.

A probit method has been developed to estimate the probability of fatality from blast overpLessures, similar to the one for thermal radiation [Reference 113. However it does not take account of structural collapses, missiles, flame inhalation etc, which are the main causes of fatality with an UVCE. The equation predicts only a 1% risk of fatality for an overpressure of 100 kPa, which is within the burning cloud of a UVCE. It generally under-estimates the risk by about an order of magnitude ccapared to Figure 4.3-2.

#### Flash Fire Effect:::

A flash fire, not generating percussive shock waves, can kill people mainly by envelopment. The radiation from a flash fire is too brief to cause serious injury unless the person is very close to the flame. A major cause of fatality in a flash fire is flame inhalation.

A reasonable working assumption is to calculate the radius of the flame as the radius of a 70 kPa overpressure (if the cloud had exploded), i.e. use a scaled distance of around 4.0, and then to assume a probability of fatality of 100% within that radius and zero outside.



### Hazard Analysis Course Notes

Section 4.3 Page 62



1 Person in conventional building

2 Person in open in chemical plant

Note : This is only a rough guide for use in the absence of better information

## **Loss Prevention in the Process Industries**

Hazard Identification, Assessment and Control

Volume 1

### Frank P. Lees

Professor of Plant Engineering, Department of Chemical Engineering, Loughborough University of Technology

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#### 598 Explosion

grOund surface, the nature of the ground, and the type and quantity of explosive. A charge exploded at the ground surface gives a wider and shallower crater than one exploded just beneath the surface.

The crater is larger in rock than in soft sand (Clancey, 1977d). In the latter there is very little shock transmission; in the former, however, the initial shock propagates and produces cracks as the pressure wave passes. The expanding gases enter the cracks and accelerate the fragmented rock.

It may be noted that understanding of the effects of the nature of the soil on crater size has developed over the years and the effects just outlined differ from those described by Robinson (1944).

A high brisance explosive generally gives a large crater and a low brisance explosive a small one or none at all. The explosion at Flixborough did not make a crater.

An equation for crater size which applies to the explosion of dynamite, a high brisance explosive, at the ground surface on average soil is the Olsen formula

$$V, \dots 0.4Q^{81}$$
 (17.9.15)

where Q is the mass of explosive (lb), and V the volume of crater (f1<sup>3</sup>).

Robinson (1944) gives the experimental data on crater size shown in *Table 17.16*. The third case is the

Table 17.16 Crater dimensions (after Robinson, 1944)

Ex	plosiv	Crater dimensions					
type	charge (ib)	diamete (ft)	er height (ft)	volume (ft')			
Dynamite	50	6	2	30			
Dynamite	2 400	31	9	3 2C-			
Ammoniu nitrate	m 9000000	400	90	10 000 000			

explosion at Oppau it 1921, which is described in Case History AI in Appendix 3. The corresponding crater volumes calculated from equation (17.9.15) are 32, 3200 and 75000000 ft<sup>3</sup>, respectively. Thus the low brisance ammonium nitrate gave a crater size considerably smaller than that calculated by the equation derived for the high brisance dynamite.

Assuming that crater volume is proportional to the cube of the radius, equation (17.9.15) is broadly consistent with the other main relation used to describe crater dimensions

$$r cc W'''$$
 (17.9.16)

where r is the radius of crater, and W the mass of explosive.

As mentioned in Section 17.2, there is a reasonably good correlation between the crater radius and the

mean detonation distance for ground surface explosions, so that relations (17.2.9) and (17.9.16) are similar to relation (17.2.3).

Further information on crater size is given by Robinson (1944) and by Clancey (1972b).

#### 17.9.6 Effects on people

A large explosion can cause injury to man mostly through the following effects: (I) heat radiation, (2) blast, and (3) combustion products.

The effects of heat radiation have been described in Chapter 16. It has been estimated that in the nuclear explosions at Hiroshima and Nagasaki approximately half of the short-term fatalities were caused by burns.

Injury from blast includes

- (1) Direct blast injury.
- (2) Indirect blast injury
  - (a) secondary blast injury
  - (b) tertiary blast injury.

These three types of injury are associated:, respectively, with the three blast effects: (1) blast overpressure, (2) missiles, and (3) whole body translation.

Injury may also be caused by hot, toxic and dusty gases produced by the explosion.

Information on injury to people from explosion has been given by Glasstone (1962), by White (1968, 1971). by the Department of the Army (1969), by Fugelso. Weiner and Schiffman (1972) and by Eisenberg *et al.* (1975).

The effect of blast overpressure depends on the peak overpressure, the rate of rise and the duration of the positive phase. The damaging effect of a given peak overpressure is greater if the rise is rapid Damage also increases with duration up to a value of several hundred milliseconds after which the effect level: off. Glasstone (1962) gives the following estimatPd Peak overpressure, for lethality for a relatively fast explosion with a positive phase duration of 400 ms:

Peak orerpressure (psi)

Probability of fateiity (%)	35-45 45-55 55-65
50 99	Much higher overpressures are required to effect the same levels of

fatality for the durations of the order of 1-15 ms typical of high explosives.

A more recent account of the work on which these data are based has been given by White (1968). His data are correlated in terms of the peak effective overpressure, the relation of which to the peak incident

Effects of explosion 599

overpressure depends on the situation of the subject. The overpressures quoted are thus somewhat higher than those given in other work described below.

The problem of the injury effects caused by an explosion is a complex one. There is a considerable literature on the degrees of injury associated with the various explosion effects.

Using some of these data, Eisenberg *et al.* (1975) have developed a number of probit equations for the injury effects caused by explosion. These equations are given below. It is emphasized, however, that the assessments of injury which are made are very approximate.

For lethality from direct blast effects, which is primarily due to lung haemorrhage, Eisenberg *et* al. quote the following data derived from information given by Fugelso, Weiner and Schiffman (1972):

Probability of fatality	Pea	ık overpressure	
(V.)	(psi)	$(N/m^2)$	
1 (threshold)	14.5	100 000	
10	17.5	120 000	
50	20.5	140 000	
90	25.5	175 000	
99	29.0	200 000	

They derive from these data the probit equation relating lethality from direct blast effects to peak overpressure

$$Y = -77.1^{4-} 6.91 \ln p^{\circ}$$
(17.9.17)

where  $, \circ$  is the peak overpressure (N/m<sup>2</sup>).

For eardrum rupture, which is the main non-lethal injury from direct blast effects, Eisenberg *et al.* quote the following data again derived from information given by Fugelso, Weiner and Schiffman:

Probabilit of	Peak or	verressure	
eardruv? rupture (7.)	(psi)	(N/m <sup>2</sup> )	_
1 (threshold)	2.4	16 500	_
10	2.8	19 300	
50	6.3	43 500	
90	12.2	84 000	

They derive from these data the probit equation relating eardrum rupture from direct blast effects to peak overpressure

$Y = -15.6 + 1.93 \ln p^{\circ}$	(1	17	7.	9.	1	8	)
----------------------------------	----	----	----	----	---	---	---

For other types of injury use is made of the blast impulse which is defined as

where J is the impulse (N s/m<sup>2</sup>); p the overpressure (N/m<sup>2</sup>); and  $t_d$  the duration time (s).

The impact velocity of a missile V is related to the blast impulse *J* by the equation

$$MV = C0AJ \tag{17.9.20}$$

where A is the presented area of missile (m<sup>2</sup>); C,,, the drag coefficient; M the mass of missile (kg); and 1; the impact velocity of missile (m/s). The value of the drag coefficient C<sub>o</sub> is taken as unity.

For injury from a missile Eisenberg *et al.* consider a flying fragment of glass of 10 g with aClensity 2.65 g/cm<sup>3</sup>. They quote the following data derived from information given by the Department of the Army (1969):

Injury	Peak overpressure (psi)	Impact velocity (m/ s)
Skin laceration		
threshold	1-2	15
Serious wound		
threshold	2-3	30
Serious wounds near		
50 % probability	4-5	55
SerioUs wounds		
near 100%		
probability	7-8	90
probability	7-8	90

and derive from these data the following data:

Injury	In	npulse
	(psi ms)	$(N s/m^2)$
Skin laceration		
threshold	74.2	512
Serious wound threshold Serious wounds near	148.4	1024
50% probability Serious wounds near	272.1	1877
100 % probability	445.3	3071

They then derive from these data the probit equation relating serious injury from missiles, particularly glass, to blast impulse

$$J = j_{o} p(t) dt$$
 (17.9.19)

$$Y = -27.1 \qquad 4.26 \ln J \qquad (17.9.21)$$

It is assumed in the derivation of equation (17.9.21) that all personnel not inside buildings who are in a region traversed by a blast wave of sufficient strength suffer injury from missiles. The density of flying fragments and the target area presented by people are not factors affecting the probability of injury in this analysis. Thus the equation overestimates the extent of injury from flying fragments by a considerable factor. This particular probit equation, therefore, should be regarded as representing an upper bound.

#### 600 Explosion

In general, much of the concern about possible injury from flying glass relates to injury to people indoors. The shattering of glass as a result of an explosion has occurred at distances of up to 20 miles. In

such cases, however, the energy of the fragments is very low. The evidence appears to indicate that there

are surprisingly few injuries to people from glass fragments even in buildings where most of the windows have been shattered by blast.

The question of injury from flying glass is considered in the Second Report of the Advisory Committee on Major Hazards (Harvey, 1979).

The report describes first the historical record. A large number of windows was broken in the unconfined vapour cloud explosions both at Flixborough and at Beek.

At Beek there were 2508 cases of damage, outside the factory and these were almost entirely **glass** 

breakage. One person was injured by glass. The Beek explosion is described in Case History A20 in Appendix 3.

The report refers to the experimental work by the Gas Council (Marshall, Harris and Moppets, 1977) on

the breakage of glass windows by explosions inside

buildings. In this work the peak overpressure was in the range 0.03-0.25 bar. The fragment velocities measured were high, being of the order of 40 mis. and varied relatively little. The report argues, however. that these results are not applicable to the very different conditions of breakage by explosions outside buildings.

This latter situation is t hen considered. It is estimated in the report that the overpressures required to effect 50 % and 90% breakage of windows are about 0.016 and 0.038 bar, respectively. A breakage of 50% implies non-breakage of 50% of the windows. "•hi\_11 suggests that the fragment velocity is likely to he iow.

The report quotes experimental work in the U.S.A. in which windows  $_{\rm s}$  in and in thick were mo.intcd at various distances from large masses of TNT so that overpressures of T3 osi (0.02 bar), 0.5 psi (0.03 Jar) and 0.6 psi (0.04 bar) with a duration time of 250 ms were applied to them and fragment masses and velocities were determined. Separate experiments were conducted to find the probability that such fragments would penetrate bare skin, or clothed skin, or 1 cm of soft tissue. Only one fragment, out of 90, from the thicker windows broken at the highest pressure **was found to** have a 10% probability of penetrating 1 cm. No other fragment had even 1 % probability of this degree of penetration.

It is concluded in the report that there is ample justification for regarding as negligible the risk of

injury from flying fragments of window glass for an explosion which gives a peak overpressure outside the building of 0.6 psi (0.04 bar) or less.

For death and injury from whole body translation the assessment made by Eisenberg *et al.* is somewhat complex. They derive from this assessment the probit

equation relating lethality for whole body translation to blast impulse

$$Y = -46.1 + 4.82 \text{ In } J \tag{17.9.22}$$

and the probit equation relating serious injury from whole body translation to blast impulse

$$Y = -39.1 + 4.45 \text{ in } J$$
 (17.9.23)

The relations **for** injury from explosion which have just been described are applicable to exposed populations in general. In assessing **potential injury** within the factory, the special conditions **of the** chemical industry should be borne in mind. **In** particular, personnel are exposed on open structures from which they may be translated by blast impulses less than those which might otherwise be necessary to cause injury.

Further information on the effects **of** explosion on people is given in the *Canvey Study*, which is described in Appendix 10.

#### 17.10 EXPLOSION HAZARD

The types of explosion typical of the chemical industry are those just described. The hazard of a large process explosion may be studied b. **consideration of assumed** scenarios of release with **appropriate estimates of emission**, dispersion **and ev plosion effects or of the historical** record **of explosions and their consequences**.

#### **17.10.1** Historical experience

A large number of the major **accidents** given in the loss prevention literature are explosions. As already stated, most of the accidents involving large loss of life are explosions.

Large accidents due to fires and **explosion** are much more numerous, than those due. ,to toxic release. According to Kletz (19770) in ti :z ;'eriod 1970-75 there '..'ere reports worldwide for the oil and chemical industries, including transport, of some 34 fires and explosions, each involving 5 or more fatalities. The total number of deaths was 600. In the same period there were only two comparable large toxic releases, which together killed 28 people. One of these incie.nts was the Potchefstroom disaster in which 18 people died and which is described in Case History A18 in Appendix 3.

Thus there are many more historical data available on explosions than on toxic releases.

Some major explosions in the **process** industries are listed in *Tables A3.1* and *A3.3*.

Many of the large explosions in the early years of the chemical industry involved explosives, including

ammonium nitrate (AN). The effects of a large number of these explosions have been collated by Robinson (1944). These were discussed in Section 17.9. A further

#### 206 Hazard assessment

Little Inc. is described in Hazard Assessment Computer S ystem(H ACS)User Manuai(1974a)andin Assessment Models in Support of the Hazard Assessment Handbook by Raj and Kalelkar (1974).

The models given by Raj and Kalelkar include treatments of the following situations:

- (1) venting rate;
- (2) spreading of liquid on water:
- (3) mixing and dilution:
- (4) vapour dispersion;
- (5) flame size;
- (6) thermal radiation from flames:
- (7) spreading of a low viscosity liquid on a high viscosity liquid ;
- (8) simultaneous spreading and evaporation of a cryogen on water;
- (9) simultaneous spreading and cooling of high vapour pressure chemical;
- (10) mixing and dilution of a high vapour pressure, highly water soluble chemical:
- (11) boiling rate of heavy liquids with boiling temperature less than ambient;
- (12) radiation view factor between an inclined flame and an arbitrarily oriented surface in space.

Model 1 deals with the emission of material from containment and model 4 with dispersion of vapour in the atmosphere. Models 3, 6 and 12 relate to the flame on a pool of burning liquid. The other models are concerned with evaporation and dilution of spillages of material of different volatilities under different conditions. A 'tensitivity analysis of the models is given.

Another vulnerability model is the *Pit.incruhitit,t* Model. -1 Simulation System jOr Assessing Damage Resultidu from Marine Spills by Eisenberg et al. (1975). This model is concerned with the problem of spillage or hazardous materials on to water in locations as ports where large numbers of people may be put at risk. The model is in two phases: phase I--(1) venting of cargo, (2) spill development, (3) air dispersion, and (4) fire and explosion; phase II--(5) damage assessment.

In phase I there are five submodels for spill development. These deal with

- spreading and evaporation of an immiscible, floating, cryogenic liquid;
- (2) spreading and evaporation of an immiscible, floating liquid with high vapour pressure :
- (3) sinking and boiling of an immiscible liquid;
- (4) mixing, advection and dilution of a miscible liquid in a tidal river, non-tidal river, or still water;
- (5) mixing, dilution and evaporation of a miscible liquid with high vapour pressure.

The submodels for air dispersion include both plume and puff submodels applicable, respectively. to continuous and instantaneous releases.

There are four submodels for fire and explosion. These deal with (1) ignition, (2) explosion, (3) flash fire, and (4) pool burning.

In phase II there are damage assessment submodels which may be used to estimate damage to vulnerable resources from the four events: (1) flash fire. (2) pool burning, (3) explosion, and (4) toxic release.

The population exposed is represented by a submodel consisting of cells containing different :lumbers of people.

The authors give a detailed treatment of air dispersion, of flash fires and pool burning, and of injury and damage effects, which are described by probit equations. They alsO explore various scenarios of lire, explosion and toxic release and give casualty estimates. Some of this work is described in the following sections and chapters.

The *Cancer Study*, which is described in Appendix 10. also contains a set of models which constitute. in s:rfect a vulnerability moiel.

Table 9.<sup>1</sup>2 Transformation of percentages to pro!'its (Finney. 1971) (*Courtesy of Cambridge University PressI* 

0	Ι	2	3	4	5	6	7	8	9
	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
4.75	4.7,	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
6.28	6.34	6.41	6,48	6.55	6.64	6.75	6.88	7.05	7.33
0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
7.33	7.37	7.41	7.46	7.51	7.58	7.65	7.75	7.88	8.09
	0 3.72 4.16 4.48 4.75 5.00 5.25 5.25 5.52 5.84 6.28 0.0 7.33	$\begin{array}{cccccc} 0 & I \\ \hline & & 2.67 \\ 3.72 & 3.77 \\ 4.16 & 4.19 \\ 4.48 & 4.50 \\ 4.75 & 4.7, \\ 5.00 & 5.03 \\ 5.25 & 5.28 \\ 5.52 & 5.55 \\ 5.84 & 5.88 \\ 6.28 & 6.34 \\ 0.0 & 0.1 \\ 7.33 & 7.37 \end{array}$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$						
Phenomenon and type	Causative	sative Prohit equation able parameters		Data from which the probit equation was derived					
-----------------------------------	------------------------------------	---	-------	---	--	----------------------	--	-------------------	---
of injury or damage	variable			per cent affected	value of variable	per cent affected	value of variable	per cent affected	value of variable
Fire:									
Burn deaths from flash fire	V: <sup>13</sup> /10 <sup>4</sup>	-14.9	2.56	I 1 i	1099 1073 1000	50 50 50	2417 2264 2210	99 99 99	7008 6546 6149
Burn deaths from pool burning	$t1^{4/3}/_{1}0^{4}$	- 14.9	2.56	I I 1	1099 1073 1000	50 50 50	2417 2264 2210	99 99 99	7008 6546 6149
Explosion:									
Deaths from lung haemorrhage	$p^{\circ}$	- 77.1	6.91	1 10	1.00 x 10' 1.20 x 10'	50 90	$\begin{array}{rrrr} 1.41 \ x & 10^5 \\ 1.76 \ x & 10^5 \end{array}$	99	2.00 x 10 <sup>5</sup>
Eardrum ruptures	$p^{\circ}$	- 15.6	1.93	1 10	$\begin{array}{rrrr} 16.5 \text{ x} & 10^3 \\ 19.3 \text{ x} & 10^3 \end{array}$	50 90	43.5 x 10' 84.3 x 10 <sup>3</sup>		
Deaths from impact	J	- 46.1	4.82	0 8	$\begin{array}{rrr} 18.0 \text{ X} & 10^3 \\ 28.6 \text{ x} & 10^3 \end{array}$	31 63	$37.3 \text{ x}  10^3$ $45.2 \text{ x}  10^3$	96 100	$\begin{array}{rrrr} 49.7 \text{ x} & 10^3 \\ 60.7 \text{ x} & 10' \end{array}$
Injuries from impact	J	-39.1	4.45	. I 50	$\begin{array}{rrr} 13 \ x & 10^{3} \\ 20 \ x & 10^{3} \end{array}$	90	$28 \text{ x}$ $10^3$		
Injuries from flying fragments	J	-27.1	4.26	Ι	1024	50	1877	99	3071
Structural damage	p°	-23.8	2.92	I 50	6.2 x 10' 20.7 x 10 <sup>3</sup>	99	34.5 x 10'		
Glass breakage	$\mathbf{p}^{\circ}$	- 18.1	2.79	1	1700	90	6200		
Toxic release: Chlorine deaths	1 <sup>-</sup> .C <sup>2</sup> " T	-17.1	1.69	3	$14.1 \times 10^4$	50	$34.05 \times 10^4$	97 97	$105.8 \times 10^4$
				3	$17.0 \times 10^{4}$ 21.5 x $10^{4}$	50 50	$47.0 \times 10^{-10}$ 64.7 x 10 <sup>4</sup>	97	129.4 x 10
Chlorine injuries	С	-2.40	2.90	1 25	6 10	50 90	13 20		
Ammonia deaths	<sub>E</sub> C2.75 7	-30.57	1.385		37.3 90.9 44.6	50 50 50	74.6 204.6 148.6	99 99	411.8 334.4

# Table 9.13 Probit equations for some major hazards (after Eisenberg et al., 1975) (Courtesy of the U.S. Coast Guard)

key:

effective time duration's)

I, = effective radiation intensity (

time duration of pool burning's)
 radiation intensity from pool burning (W/m')

n') C = concentration (ppm' T = ti)me interval (min)

= peak overpressure  $0.1/in^{21} J = impulse (N s(ns'))$  203

High explosive effects tended to be mitigated by the inability of some larger structural meabers in the tunnels to respond significantly to treasure loanng on the short tImescalts indicated. Therefore, in spite ai the relatively high overpressures created locally, serious 'structural failures were limited to two of the four tunnels considered. These failures were the roof and median wall of the Holmesdale tunnel and the road support for the Nev Dartford tunnel. These structural failures would. :e expected :o be confined to the region within a few tens of. metres of the detonation, although the damage would tend to be more widespread for

Neu Dartford than for the nolmesdale. The effects of CIE quantity of high explosive on tunnel damage *are* highlighted In Table 4.25, fror which It is apparer.t that the effects do nac worsen dramatically for increasing sizes of charge. In addition, Table 4.25 also illustrates the widespread damage expected for internal structvres, due partly to blast and partly to thermal

damage expected for internal structvres, due partly to blast and partly to thermal and missile loadings. Some damage is expected for some internal structures for ail cases considered.

The effects of rapid release of pressurised liquids an: vapourr are generally not serious :n spite of the retatively long uuration .of the impulse. This is because the peak pressures are quite low. The only exception to this is fof the Rev Dartford tunnel where roadway failure

aapears to be possible. Otherwise, these loadings do not threaten the structural integrity of arty of [he Connell. Damage to internal structures is likewise not predicted for the larger cross-section cut-end-cever tunnels, although the extra confinement provided by the smaller bore driven tunnels could allow some limited damage to particularly weak internal structures. The nature of me Loading, combined oith the lack of significant thermal effects and the implausibility of damaging missiles, ensures chat my damage would be confined to the locality of the release.

The most damaging loads considered In this report ace those determined for the combustion of fuel/air mixtures which fill the entire tunnel crosssection with a flammable mixture for appreciable lengths of the tunnel. The effects found are comparable to those determined for the ITT detonations. However, for large releases the damage would extend over the entire length of tunnel, given the modelling assumptions made {see Section

4.5.5.1). For releases in the region of 10-200  $IL_A$  of flaamable vapour, the effects could be largely eel aimed to perhatlf zr...100rs or so of the

tunnel length. Thus, Otte of ilamaable vapour .0.uld provide a level of damage similar to that cf its of **iSr**, but over m rather greater tunnel length, Table 4.25.

4.5.8 <u>Effects of explosions</u> on tunnel <u>occupants</u>

Eisenberg f63; and ilaaer (46) provide comprehensive review on the damage caused co per4le by explosions.

Essentially people can be harmed by one of four mechanisnN.

a Direct blast damage. For people in [he open eardrum :upture can se caused by overpressures as low as 2.Sps1. At overpressure of approximately 1 bar there is about a IX thence of being killed by lung damage and at overpressures of approximately 2 bar this chance rises co almost 100i. bDamage by inpact from priaary missiles.Primary missiles areaissiles generated at the site of the expiosicl.hfssile velocities canrange up to several thousand mettes(second.In the confines of a runnelsuch missilesereunlikely to travel greatdistanceagainst the walls.Primary missiles

c Damage by impact from secondary missiles. The blast wave from the explosion can raise objects Into the air and propel them at velocities that relate to the site and shape of the missile and chc impulse delivered by the blast wave.

Little information is available on levels of damage caused by mechanisms and c although Lt is known that a 4.5 kg non-penetrating fragment impacting at  $3ms^{-}/$  is unlikely to cause death whereas for fragment velocities of approximately 10 ms<sup>--</sup> death is almost certain. The fins: damage mechanism is

Tertiary damage. The impulse from a blast cave is sometimes sufficient co lift a person from his feet and hurl him against a val.. Reference 63 suggests that injury is unlikely to occur at impulses below 14 kPas. At 18 lcPas there is a Li chance of death by the mecianism and at 60 kPaa this chance becomes almost IDDX.

#### 4.5.8.1 <u>TUT explosions</u>

Hazard distances for direct blast damage were evaluated for Injury threshold, lethality threshold and 912 lethality for each tunnel and *eac;* -- charge sire by referring to Figure 4.7.

similarly hazard ranges for tertiary blast damege were eval\_ated making use of figure 4.B. In all of the cases examined, the hatard range proved negligible for this mechanism.

The hazard range for primary fragments was determined by the distance a fragment coeld travel before impacting against the tunnel walls. For a /ow trajectofy missile (5' to the horizontal) and travelling parallel to the tunnel walls the maximum distance travelled before hiatteg the tunnel roof would be ca 70m.

The hazard range from secondary fragments necessitated postulating a missile size mod shape. A 4.5 kg missile vas assumed and two shapes were considered:- a steel ball and f" thick steel plate. In order to attain the critical velocities for onset of lethality (3m/s) and 10% lethality (10m/s) these missiles wculd have to be provided with sufficient impuire from the blast. This impulse was evaluated neglecting drag and lift effects and :e corresponding hazard ranges determined for each runnel an:: charge else from Figure 4.8.

The above analyst, /resumes people in the open It not within vehicles. It is likely that remaining within a vealcle would considerably increase the prospect of survival from all of the above darage mechanisms although there is a lack pi Information tfet allows cne to quaetify such an influence.

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# ABR 862

# ROYAL AUSTRALIAN NAVY EXPLOSIVE ORDNANCE SAFETY MANUAL VOLUME I

# INSTRUCTIONS FOR ESTABLISHMENTS, COMMANDS AND NAVY OFFICE PART 2

This publication supersedes BR 1030 (Naval Armament Supply Instructions), NAVSUPMAN 7 Volume 2, Chapters 1 to 11 (RAN Explosives Storage Manual), Weapons Instructions Volume 1 and those aspects of ABR 862 (Naval Magazine and Explosives Instructions for HMA Ships and Establishments) dealing with storage, handling and transport of explosive ordnance, ordnance and small arms weapons at HMA Establishments.

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R.G. TAYLOR AO VICE ADMIRAL RAN CHIEF OF NAVAL STAFF

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#### **APPENDIX 2**

# EQUIVALENT OVERPRESSURE VALUES TO GIVE DEFINED BLAST DAMAGE DESCRIPTIONS

#### TABLE I EQUIVALENT OVERPRESSURE VALUES TO GIVE DEFINED BLAST DAMAGE DESCRIPTIONS

Damage Details			• Overoressu re in bir (itt it ,		
	[Effects on Persons				
Fars					
Cound Noted on on unuquel our	t on avalagion		0.0002 (0.005)		
Sound Noted as an unusual even	it -an explosion		0.0003 (0.005)		
Loud noise at 143 dB		JD	0.002 (0.04)		
Thread ald for terms are a loss of	ype at 10-15 Hz and 137	uв	0.001 (0.02)		
Threshold for temporary loss of	nearing		0.013 (0.2)		
Infestional for eardrum rupture			0.13(2)		
50% eardrum rupture			0.33 (4.8)		
90% probability of eardrum rup	ture		0.34 - 0.48 (5 - 7) 0.68 - 1.03 (10 - 15)		
Wounds					
Minimum for penetration injur)	y by small glass fragm	nents	0.05 (0.8)		
Threshold of skin laceration by	missiles		0.06 - 0.13 (1 -2)		
Serious missile wounds of abou	t 50% fatal_it)		0.27 - 0.34 (4 - 5)		
Serious missile wounds of near	100% fatality		0.48 - 0.68 (7 - 10)		
External Injury					
Low personnel risk when inside	0.06 (1)				
Personnel knocked down or thro	own to ground		0.10 - 0.19 (1.5 - 2.9)		
Possible death by persons being	projected against obstac	cles	0.13 (2)		
People standing up will be throw	0.55 - 1.10 (8 - 16)				
People lying flat on the ground	about	0.82 - 1.65 (12 - 24)			
Internal Injury					
Threshold of internal injuries			0.48 (7)		
Threshold of lung haemorrhage		0.82 - 1.03 (12 - 15)			
50% fatality from lung haemorr		1.37 - 1.72 (20 - 25)			
99% fatality from lung haemorr	2.06 - 2.41 (30 -35)				
Immediate blast fatalities			4.82 - 13.78 (70 - 200)		
	Primary Missiles				
General					
Limit of travel of primary missi	0.008 -0.013 (0.12 - 0.20)				
Missile limit (negligible effects	0.02 (0.3)				

Damage Details	Incident Equivalent Peak Overpressure in bar (psi)	
Damage to Buildings		
Glass Failure		
Exceptional cases of large windows under strain failing	0.001 (0.015)	
Occasional breakage of large glass windows already under strain	0.002 (0.03)	
Sonic boom glass failure	0.002 (0.04)	
Breakage of small windows under strain	0.006 (0.1)	
Typical pressure for glass failure	6.01 (0.15)	
Large and small windows usuallyshattered. occasional damage to window frame	0.03 - 0.06 (0.5 - 1.0)	
5°,.0 of exposed glass panes broken	0.001 - 0.002 (0.018 - 0.042)	
10% of exposed glass panes broken	0.001 - 0.003 (0.026 - 0.058)	
25% of exposed glass panes broken	0.003 0.006 (0.045 - 0.10)	
50% of exposed glass panes broken	0.005 - 0.013 (0.03 - 0.19)	
75%of exposed glass panes broken	0.010 - 0.024 <b>(0.15 - 0.35)</b>	
90°, oof exposed glass panes broken	0.107 - 0.041 (0.26 - 0.60)	
99°, oof exposed glass panes broken	0.046 - 0.110 <b>(0.67 - 1.6)</b> × 2	
Double glazing is generally twice as strong as normal single glazing when	glass values	
glass panes of equal thickness	given above	
Damage to Houses - General		
House roof tiles displaced	0.02 - <b>0.04</b> (0.38 - 0.64)	
Minor damage to house structures	0.04 (0.7)	
Partial demolition of house - rendered uninhabitable	0.06 (1)	
Partial collapse of walls and roofs of houses	0.13 (2)	
Nearly complete destruction of houses	0.34 0.48 (5 - 7)	
Damage to Buildings - General		
Limited minor structural damage Doors and window frames may be blown in	0.020 - 0.027 (0.3 - 0.4 0.053 - 0.089 (0.77 - 1.3)	
'Safe Distance' (only 5% probability of serious damage beyond this value)	0.02 (0.3)	
Limit of eanhshock damage	0.08 (1.2)	
Boarding panels on roofs torn off	0.10 (1.5)	
Lower limit of serious structure damage •	0.13 - 0.20 (2 - 3)	
Moderate damage to massive, loadbearing wall type multistorey buildings	0.41 - 0.48 (6 - 7)	
Probable total destruction of buildings	<b>0.68</b> (10)	
Crater lip	<b>20.68</b> (300)	
UK Brick Built Houses		
Category 'D' Damage - Inhabitable, but require repairs to remedy serious inconveniences. Damage to ceilings, roof tiling, roof battens and roof coverings, minor fragmentation effects on walls and more 10% glass broken	0.017 - 0.051 (0.25 - 0.75)	
Category 'Ca' Damage - Uninhabitable, but repairable. Not more than minor structural damage with partitions and joinery wrenched from fixings	0.06 - 0.12 (1.0 1.8)	

Damage Details	Incident Equivalent Peak Overpressure in bar (psi) :
Categor 'Ch Damaite Uninhabitable until extensive repairs are made (k' partial of total collapse of roof structure. partial demolition of 1 or 2 external %%ails up to 25% of the whole -, severe damage to load bearing partition	0.13 - 0.24(2.0 - 3.5)
Categor 'B' Damage - Badly damaged beyond repair (i.e. 50% to 75% of the external brickwork destroyed or. with less damage. the remaining walls have gaping cracks rendering them unsafe)	0.34 - 0.58(5.0 - 8.5)
Cate 'or 'A' Damage - Completer demolished (i.e. with over 75% of external briek'% ork demolished)	0.68 - 1.82(10.0 - 26.5) i
50 <sup>0</sup> 0 destruction of brickwork	0.27 - 0.48(4 - 7)
US Typical Houses	
Minor damage to glass or miscellaneous small items (similar to that resulting from a high wind)	0.03 - 0.07(0.5 - 1.1)
Fastening of " ood panels for standard wood housing fail with panels blown in	0.06 - 0.13(1 - 2)
Slight damage: doors, sashes or frames removed, plaster and wallboard broken. singles or siding off	0.13 - 0.19(1.9 - 2.9)
ModeMte damage: walls bulged. roof cracked or bulged. studs and rafters broken	0.15 - 0.24(2.2 - 3.5)
So :ere damage; standing, but substantially destroyed, some walls gone	0.27 - 0.32(4.0 - 4.7)
Demolished. not standing	0.68 - 1.17(10 - 17)
Miscellaneous	
Industrial	
Corrugated asbestos sheets shattered	0.06 - 0.13 (I - 2)
Failure of joints or fastenings in aluminium or steel panels followed by buckling	0.06 - 0.13(1 - 2)
Steel frame of dad building slightlydistorted	0.08 - 0.10(1.2 - 1.5)
Collapse of steel panel construction	0.19 - 0.24(2.9 - 3.6)
Building steel frame distorted and pulled away from foundations .	0.20 (3)
Cladding of light industrial building demolished	0.27 (4)
Frameless steel panel building demolished	0.20 - 0.27(3 - 4)
tv19 <sup>.</sup> .ent:nt of bridge members on abutments and some distortion of bridge members	0.34 - 1.03(5 - 15)
Road Vehicles	
Cars and trucks blown over and displaced with frames sprung	0.55 - 0.82(8- 12)
Severe damage to cars and trucks1.37	- 2.06(20 - 30)
Rail Vehicles	
Superficial damage to rail wagons	0.17 - 0.31(2.5 - 4.6)
Rail wagons damaged, but easily repairable'	0.37 - 0.79(5.5 - 11.5)
Bodywork of rail wagons crushed	0.57 - 1.37(8.4 - 20)
Empty rail box car blown off tracks by side on loading	0.37 - 0.41(5.5 - 6.0)
Empty 50 tor. rail tank car blown off Tracks by Side on Loading	0.44 - 0.46(6.4 - 6.7)

Damage Details.	incident Equivalent Peak Overpressure in bar (psi)
Loaded train wagons overturned	0.48- 0.51 (7.0 - 7.5)
Loaded 50 ton rail tank car overturned by side on loading	0.55(8)
Loaded rail box cars completel;. demolished	0.62(9)
Steel towers blown down	2.06(30)
Displacement of rail ballast and rail movement	6.41- 14.13 (93 - 205)
Aircraft	
Damage to control surfaces and other minor damage to aircraft	0.06- 0.13 (1 - 2)
Major damage - DLM effort to restore aircraft	0.13- 0.24 (2 - 3.5)
Total destruction of aircraft	0.24(3.5)
Trees	
Some minor damage to branches of trees	0.06- 0.10 (1.0 - 1.5
Trees - leaves and branches blown off. but very few large trees blown down	0.11- 0.15 (1.7 - 2.3)
About 30% large trees blown down.0.16 -0.25 remainder having many leaves and branches blown off	(2.4- 3.7)
90% of large trees blown down	0.24- 0.41 (3.5 - 6.0)

#### ΝΟΤΕ

The above damage values have been collected from many different sources and selected/adjusted to form a logical and consistent series. Many quoted values in references will be somewhat different and are due to different interpretations of the assessment of blast damage values. The values appear to be suitable for work on accidental explosions where equivalent TNT type damage assessments are used. The above values are approximate and relate to conditions of unsheltered exposure and no blast reflection effects with the lower end of a band applying to large explosions and the upper end to small explosions.

# APPENDIX D

REPRODUCTION OF NOTES WRITTEN ON A WHITEBOARD (1 PAGE LABELLED AO) AND ON 'BUTCHERS PAPER' (14 PAGES LABELLED AI-A8, B1-B4, F1 & KG1) BY THE SECRETARY, MR DAVID HUMPHREYS, AT A MEETING OF TASK GROUP 5 HELD OVER 3 & 4 JUNE 1996

<u>AO</u>	DESIGN INTENT
	1> INBYE OF REGULATOR
TEMPORARY STOP	INGS/SEALS> LOCATION - C/T BETWEEN INTAKE & RETURN
$1 \rightarrow DURIN$	G PANEL DEVELOPMENT & POSSIBLE EXTRACTION
1-	-> SEGREGATION OF INTAKE/RETURN AIR
	INDUSTRY PRACTICE
	CEMENT PRODUCTS/AERATED BLOCKS PLASTERBOARD TIN
	BRATTICE
	DATITICL
	LIFE REQUIREMENT - LIFE OF PANEL, TO 3YRS > ENVIRONMENTAL COND'S
	I I
MACHINERY DAMA	GE HIGH HUMIDITY> SOFTENING
MANDOOKS	GKUUNDWATEK> ACID WATEK
	PRESSURE DIFFERENTIAL> LEAKAGE
	WINDBLAST> DAMAGE
	FIRE
	EXPLOSION —> OVERPRESSURE> DAMAGE
	GROUND MOVEMENT -> DAMAGE

2 - Hi HUMIDITY  $\longrightarrow$  LOSS OF IN I F,GRITY 1--> PLASTERBOARD ONLY L - Hi C - Lo SAFEGUARDS - M & I

20 Christina Place Kareela NSW 2232 (61-2) 9528-2870 Mobile 018460-188 Fax (61-2) 9528-2852

MCCRACKEN C ONSULTING - D2 - 30 Glenview Street Gordon NSW 2072 (61-2) 94984372 Fax (61-2) 9498-5582 Messages (61-2) 9498-5582 DEV 3 - GROUNDWATER ON STOPPING 1.--> LOSS OF INTEGRITY L - Lo C - Lo RECOMMENDATION - CHECK SUITABILITY OF STOPPING MATERIALS EG. METAL

4 - PRESSURE DIFFERENTIAL 1-4 LEAKAGE

A2

MANAGEMENT RESP TO DESIGN TO PREVENT LEAKAGE THRU & AROUND STOPPING

A3 DEV 4 - EXPLOSION -4 OVERPRESSURE -4 DAMAGE WINDBLAST -T

> ACTION TO DETERMINE LIKELY PRESSURE <u>DIFF</u> DUE TO EXPLOSION AT FACE TO ESTABLISH DESIGN GUIDELINES? NEED TO CONSIDER COSTS OF REQ'D STOPPINGS cf OTHER PREVENTATIVE SAFEGUARDS @ FACE

# A4 5 - GROUND MOVEMENT DEV MAINTENANCE ISSUE ONLY & CONSTRUC-IION STANDARD IN RELATION TO ANTICIPATE GROUND MOVEMENTS

6 - EXTERNAL DAMAGE MAINTENANCE ISSUE ONLY

## 7 - MANDOORS SELF CLOSING ACTION = INVESTIGATE SELF CLOSING DOORS

DURING EXTRACTION PHASE A5 TEMPORARY SEALS (CHAIN PILLARS) LOCATION - POSSIBLY REBUILT & RELOCATED FROM DEV PURPOSE - ISOLATE GOAF FROM VENTILATION SYSTEM (0<sub>2</sub> OUT, GASES IN) IND PRACTICE - RIGID STOPPINGS **CEMENTIOUS FOAMS** POLY URE FOAMS LIFE - OF PANEL < 18 MONTHS **ENVIRON CONDS - HI HUMIDITY** DAMMING GROUNDWATER ACID WATER AP -> LEAKAGE WINDBLAST & GRND MOVEMENT FIRE EXTERNAL DRAINAGE **EXPLOSION** 

Afi

1 WATER DAMMING / ACID WATER 1-4 DESIGN TO ACCOMODATE 1---> SELECT SUITABLE MATERIALS RESISTANT TO ACID ATTACK

2 AP -> LEAKAGE

1 MANAGEMENT RESP TO DESIGN TO MINIMIZE

I LEAKAGE THRU & AROUND STOPPING

1-> MONITORING & INSPECTION

A7

3 WINDBLAST DAMAGE

& GROUND MOVEMENT 1--> MINE }

--> MINE } & PANEL } SPECIFY RISK ASST & DESIGN

<u>GROUND MOVEMENT</u> STRATA CONDITIONS/STRENGTH/STABILIZATION GEOL FACTORS/SHEAR PLANES

4 FIRE REQUIRES FIRE RESISTANCE RATING

# <u>APPENDIX E</u>

# REPRODUCTION OF HAND WRITTEN NOTES BY THE SECRETARY, MR DAVID HUMPHREYS, AT A MEETING OF TASK GROUP 5 HELD OVER 26 & 27 JUNE 1996

#### DRAFT MINIJIES OF MEETING 26 & 27 JUNE 1996

#### MOURA IMPLEMENTATION PROGRAMME

#### TASK GROUP 5 - INERTIZATION AND MINE SEALS

Present Mr Brian Lyne	Task Group Chairman, Chief Inspector of Coal Mines, Qld
Mr Bill Allison	Confederated Forestry, Mining & Energy Union
Mr Stewart Bell	SIMTARS
Mr Rick Davis	NSW Minerals Council Representative
Mr Mike Downs	Queensland Mining Council
Mr Mike Caffrey	Queensland Mining Council
Mr Tony Sellars	Mines Rescue
Mr Graham Fawcett	NSW Department of Mineral Resources
Mr David Humphreys	Secretary
Dr John Mc Cracken	Facilitator

Absent: Mr Tony Hazeldean Australian Colliery Staff Association

At times during the meeting Mr Neil Galway, Chairman, Moura Implementation Programme attended to review certain aspects of business.

Meeting open 10.00 am. 26 & 27 June 1996.

Business of the Meeting.

- 1. Minutes of Last Meeting.
- 2. Wilson Mining Presentation.

The Chairman introduced Mr David Wilson, Managing Director and Mr Mitch Ostle, Director, Marketing and Sales of Wilson Mining Services Pty Ltd. They proceeded to make a presentation on the subject of a system of construction for explosion resistant seals being marketed by their Company. Wilson Mining were appointed Australian distributors for the Micon 550 system of seal construction, and also specialize in the use of polyurethane and silicate resin products for use in Australian mines.

Mr Wilson gave a detailed description of the type of explosion resistance stopping being offered. The main features of the Micon 550 system were described:

Seal consists of 2 dry block walls 16 to 23 inches apart depending on the opening height.

- ii The core between the walls is filled with a mix of aggregate and polyurethane foam. This is fully aired in 2-3 hours and hence achieves the required explosion resistance after this time.
- iii Construction methods are detailed and need to be followed correctly to ensure correct installation but are easily understood and followed.
- iv The Micon 550 seals have been tested at the USBM Lake Lynn facility and have withstood repeated tests at 20 psi. For an 8 ft opening a core of 16 inches would provide a 20 psi rating, 20 inches would provide a 50 psi rating.
- v Indicative costs were about \$7,000.00 per stopping and could be constructed at the rate of 2 seals/ shift with a 3 man crew.

A short video showing the construction method for the seals was viewed by the task group.

# **3.** Continuation of the Underground Sealing Hazop Exercise.

a) Industry Support

The Chairman advised that he had recently attended a meeting with the legislation Task Group and Mining Industry representatives. He briefed this meeting on the review being undertaken by Task Group 5 with regard to ventilation devices and seals, and that there was support expressed for this. There appeared to be support for the adoption of 20 psi explosion resistant stoppings and the establishment of design criteria for performance aspects.

b) Hazop Review of Underground Seals

Dr John McCracken, facilitator for the Hazop review distributed draft copies of his report from the previous meeting to each member. There were a number of "Actionable Matters" to be discussed as a result of the last meeting. These were:

Action 1: Review of Fire Resistance Standards that might be applied to Stoppings/Seals - Graham Fawcett.

Graham Fawcett provided a summary of the MSHA Standard (actually ASTM -E119, Fire Tests of Building, Construction and Materials), and the Australian Standard AS 1530.4 - 1990. These firing rating standards were discussed and suggested rating application were:

Type of Structure	SEAM GAS		Rationale
	CH4	CO2	
Permanent Goaf Seals	AS1530.4 60 mins	AS1530.4 60 mins	To prevent release of combustible or asphyxiating gases
Explosion Resistant Seals	44	44	44
Main Ventilation Structures	44	44	To prevent destruction of structures and short circuiting of main ventilation.
Panel Ventilation Structures and all Regulators	Flame resistant only	Flame resistant only	Reduced requirement due to less permanent nature of structures.

It was decided that a caveat should be attached to these rates that where it could be demonstrated there was low risk of fire there was no need for a fire rating.

Action arising - Graham Fawcett to visit CSIRO, North Ryde, to obtain more information on fire rating tests before a final recommendation is made.

Action 2: Expert review required to determine the likely pressure differences across stoppings in cut-throughs from an explosion at the development face in order to establish guidelines. - No participant nominated.

The Task Group discussed the issue in light of data on the effects of various explosion pressures supplied by Graham Fawcett. As a result it was decided that only structures affecting the integrity of main entry escape ways be explosion - resistance to 5 psi. All other stoppings (but not including goaf seals) were recommended to be 2 psi subject to research on explosion pressure distribution in a mine and on the strength of existing structures.

Action arising - SIMTARS to undertake a literature review and research on likely explosion pressure distribution and the strength of existing stopping constructive methods.

Action 3: Investigate Self-Closing doors - no participant nominated.

The matter was discussed and the task group recommended that self-closing ventilation door be stipulated in the mine design.

Action 5: Review Explosion Protection of surface fan. - no participant nominated.

After much debate which did not produce a consensus of opinion, the chairman suggested that the surface fan installation be capable of surviving an explosion pressure of 10 psi internally unless appropriate venting strategies at lower pressures can be devised. This is intended to provide protection to the most important ventilation device.

Action 6: Standard to use for explosion resistant seals. Review - Bill Allison & Mike Downs.

No action was required from Allison - Downs on this subject as the remainder of the meeting was spent on this particular subject.

Guidelines for Ventilation Structure

Design. Summary of Recommendations.

TYPE OF STRUCTURE	SUGGESTED EXPLOSION RESISTANCE RATING
a2 temporary seals in gateroads	5psi
bl Permanent seals in maingates after extraction completed.	5psi
b2 Permanent seals in maingates after extraction completed.	lOpsi
al Temporary stoppings/seals in gateroad development.	2psi

All explosion ratings were considered subject to review.

All environment conditions were considered to be as per Al J McCracken Draft Report June 1996.

f. Emergency airlock and seals (at surface)

Design intent - to provide access to a mine after an initial explosion and to prevent air ingress.

Facilities shall be provided at one entry to a mine which after an initial explosion or emergency event shall:

- \* have operational integrity after the initial explosion or event
- \* be able to be installed or operated readily with minimal exposure of persons to hazards
- \* be capable of preventing entry of air into the mine.
- \* facilitate the introduction of an inert atmosphere into the mine
- \* facilitate the exit or re-entry of person.

Design criteria for elements of the facilities affected by an initial explosion shall have regard to a prospective explosive pressure of up to 20 psi and flying debris.

# **1. Emergency Prep Seals**

Design Intent - to isolate a section of the mine in an emergency (fire, spontaneous combustion) by stopping ventilation

- to be pre-prepared and supplied to allow rapid construction

- to be as air-tight as practicable.

Requirements - no explosion rating required.

No flame resistance required.

## m. Conveyor coffin seal

Same explosion resistance and fire rating as al.

## n. Belt Isolation stoppings. No

explosion rating required.

# e. Overcasts - not affecting escape ways.

Explosion rating of 2 psi.

# (ei?) Temporary overcasts - as approved by an inspector.

No explosion rating required.

# h. Double Ventilation Doors.

Explosion rating of 5 psi if part of escape way, otherwise 2

psi. Must be self-closing.

# j. Regulators.

No explosion rating required.

Must be flame resistant but not fire resistant.

# k. Stoppings with man doors.

Some explosion - fire ratings as equivalent

stopping. Doors to be self-closing.

## Actions arising from completion of Hazop Study..

- 1 J McCracken to develop spreadsheet of performance guidelines for circulation and discussion by 5/7/96.
- 2. M McCaffrey to prepare generic mine plan showing positions of various ventilation structures and send to J McCracken by  $\frac{5}{7}$ /96.
- 3. All members to provide feedback on draft report of June 1996 to J. McCracken by  $\frac{5}{7}$ /96.
- 4. M. Downs/ M. Caffrey to investigate meeting with mine managers in. Emerald to discuss draft guidelines before 18/7/96.
- 5. Next meeting to finalize guidelines and for input to final report set for Thursday 18/7/96 10.00 am.

# 4. Mine Inertization.

a) Proposed Location of Inertization Trials.

T Sellers had undertaken a review of the two proposed sites, summarised on the attached table (attachment 1). On the basis of facilities and the absence of methane seam gas from Collinsville it was decided to stage the inertization trials in Collinsville.

B Lyne was to meet Collinsville management the next day to finalize legal aspects of the trials and prospective timetables.

b) Status of ACARP submission

M Downs reported that the SIMTARS submission to ACARP had been short listed in the initial selection round completed on 20 June, 1996. David Cliff (SIMTARS) was preparing a revised submission. The overall project cost was to be reduced and some aspects of the project eliminated from consideration eg investigations of refuge bays, large diameter bore holes. A submission had also been received from Cook Colliery to demonstrate the Tomlinson boiler and the SIMTARS submission was to resolve any duplication or conflicts with their proposal.

ACARP had undertaken to "fast-track" any Moura - type submissions and M Downs undertook to push through this particular project.

The timetable to achieve a demonstration in September was discussed and is attached (attachment 2).

Meeting closed at 4.00pm, 27 June 1996.

NEXT MEETING 10.00AM, 18 JULY, 1996.