QUEENSLAND DEPARTMENT OF MINES AND ENERGY

TASK GROUP 5
MOURA 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

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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 Appendix B.

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 Appendix D. The hand written notes taken at the second meeting have been reproduced as Appendix E.

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 Table 1) 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
- Mr. 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. 06-213-90. 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 Appendix C) were tendered by McCracken Consulting Services in support of the Facilitator's argument[1] 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.

[1] 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.

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.

- *Hazard Analysis Course Notes.* ICI Engineering Australia Pty. Ltd. Pages 61-62. (1988)
- *Loss Prevention in the Process Industries.* F.P. 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 Figure 1 and Table 1 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 Figure 1 and Table 1 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)

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- 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 Figure 2a)
- qualitative assessment of un/acceptability of total risk with industry goals

- Establishment of **guideline design criteria** to provide acceptable risk and be cost-effective
  - 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 reducing 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.

a1 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. a1) 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 at/near the face.* The scenarios of windblast or an explosion at the face impacting on temporary stoppings in cut-throughs 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 expected high costs of providing explosion resistant stoppings by reviewing/upgrading other explosion prevention measures. In summary:

Type of Structure	Suggested Explosion Resistance Rating
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. a1) 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 all 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 a1 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 a1 above.

b1 Permanent seals installed in maingates at bleeder heading after extraction completed

- *Impairment to integrity/strength of seal.* As for a1 above.
- *Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under a1 above.
- *Overpressure from explosion.* An explosion resistance rating of 35 kPa is recommended but this subject to review as stated under a1 above.

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

- *Impairment to integrity/strength of seal.* As for a1 above.
- *Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under a1 above.
- *Overpressure from explosion.* An explosion resistance rating of 70 kPa is recommended but this subject to review as stated under a1 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 a1 above.
- *Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under a1 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 a1).

c1 Stoppings around main designated escapeways

- *Impairment to integrity/strength of seal.* As for a1 above.
- *Fire on combustible stopping materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under a1 above.
- *Overpressure from explosion.* An explosion resistance rating of 35 kPa is recommended but this subject to review as stated under a1 above.

c2 Segregation (belt isolation) stoppings

- *Impairment to integrity/strength of seal.* As for a1 above.
- *Fire on combustible stopping materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under a1 above.
- *Overpressure from explosion.* An explosion resistance rating of 14 kPa is recommended but this subject to review as stated under a1 above.

d Permanent overcasts

- *Impairment to integrity/strength of seal.* As for a1 above.
- *Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under a1 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 a1 above.

e Temporary overcasts

- *Impairment to integrity/strength of seal.* As for a1 above.
- *Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under a1 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 a1 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 a1 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 a1 above.

- *Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under a1 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 a1 above.

- *Fire on combustible door seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under a1 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 a1 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.

i **Ventilation doors for personnel**

- *Impairment to integrity/strength of seal.* As for a1 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 a1 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 a1 above.

j **Regulators**

- *Impairment to integrity/strength of seal.* As for a1 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 a1 above.

- *Fire on combustible seal materials.* To comply with AS1530.4 with a 60 minutes fire rating subject to review as stated under a1 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 a1 above.

l **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.

m **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 Figure 1. The code used for the type and location of each stopping or seal is disclosed in Table 1 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 Table 1). 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)
  - 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 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 performance

- 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 Table 1)
  - 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

Table 1 - 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 roof/ribs/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 all 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.

TABLE 1: DESIGN LIFE, FIRE RESISTANCE AND EXPLOSION RESISTANCE PERFORMANCE GUIDELINES RECOMMENDED FOR STOPPINGS AND SEALS IN UNDERGROUND COAL MINES

Stopping/Seal	Code (Fig. 1)	Location	Design Life	Fire Rating [1]	Explosion Resistance [2]
Panel Stoppings (development roadways)	a1	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 'a1' stoppings but usually rebuilt closer to the tailgate	temporary, life of panel	flame resistant	35 kPa
Goaf Seals (after longwall extraction)	b1	as for 'a1' stoppings but in a bleeder heading	permanent, life of mine	AS1530.4, 60 minutes	35 kPa
Goaf 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 'a1' stoppings but in main headings	permanent, life of mine	AS1530.4, 60 minutes	35 kPa
Segregation (Belt Isolation) Stoppings	c2	as for 'a1' stoppings but in main headings	permanent, life of mine	AS1530.4, 60 minutes	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 'a1' 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	l	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.

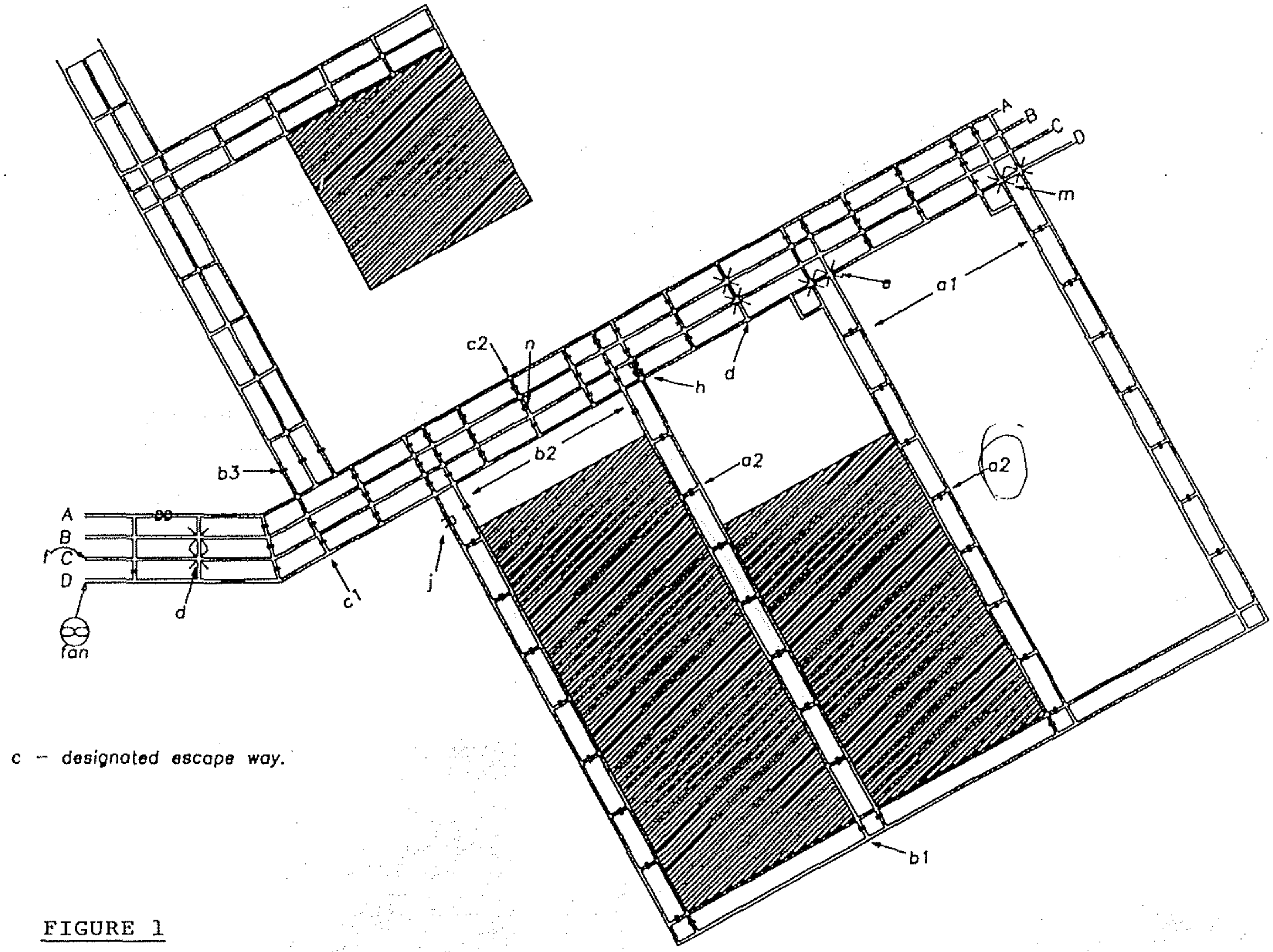

FIGURE 1

SCALE	N.T.S.		MINE LAYOUT MODEL USED FOR DEVELOPMENT OF APPROPRIATE DESIGN CRITERIA FOR SEALS
DESIGN			
DRAWN	A.B.	06/07/96	
CHECK			
APPROV			
ACAD FILE No. G:\ABUNCO\MOURANC	DRAWING No.	REV.	0

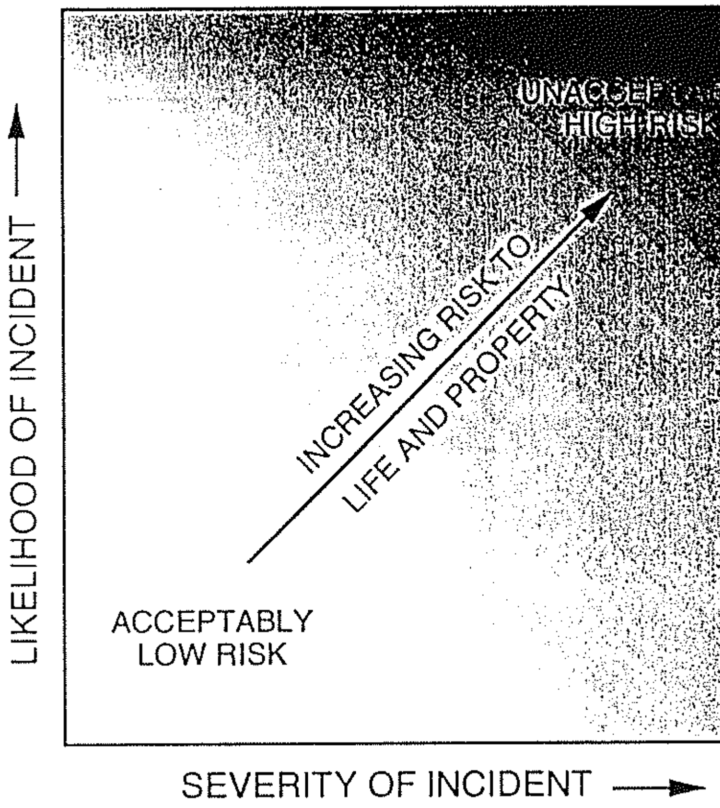

FIGURE 2a

RELATIONSHIP OF RISK TO CONSEQUENCE AND LIKELIHOOD OF A HAZARDOUS INCIDENT

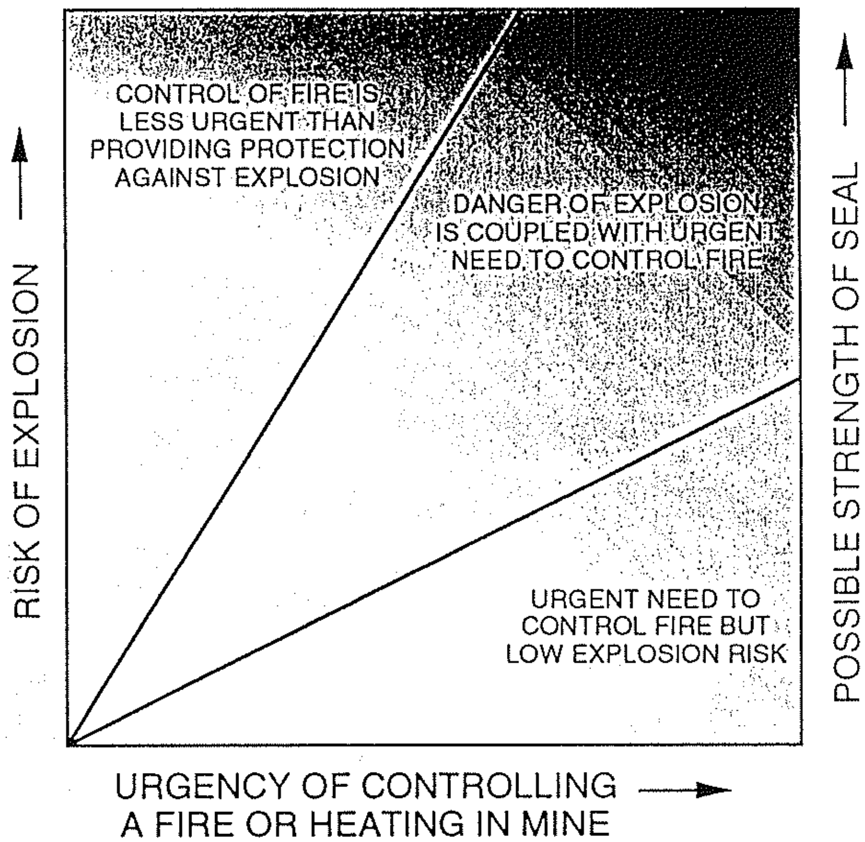

FIGURE 2b

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

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

APPENDIX A

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 SEAL RISK ASSESSMENT

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

MATTERS 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
  - fire 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 (goaf fall)
  - geotechnical pressures

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

APPENDIX B

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

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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 Hazard

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 more 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 stoppings 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:

(i) The uncontrolled spread of fire may involve danger to men;
(ii) control of ventilation may be needed to prevent undesirable 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

APPENDIX C

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

DEPARTMENT OF PLANNING
SYDNEY

1990

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/m² 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/m² 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/m² 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 short 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)	• 90% glass breakage • No fatality and very low probability of injury
7 kPa (1 psi)	• Damage to internal partitions and joinery but can be repaired • Probability of injury is 10%. No fatality
14 kPa (2 psi)	• House uninhabitable and badly cracked
21 kPa (3 psi)	• Reinforced structures distort. • Storage tanks fail • 20% chance of fatality to a person in a building
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)	• Threshold of lung damage • 100% chance of fatality for a person in a building or in the open • Complete demolition of houses

70 - 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 corresponding 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 supported by the latest review outlined in Reference 9.

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

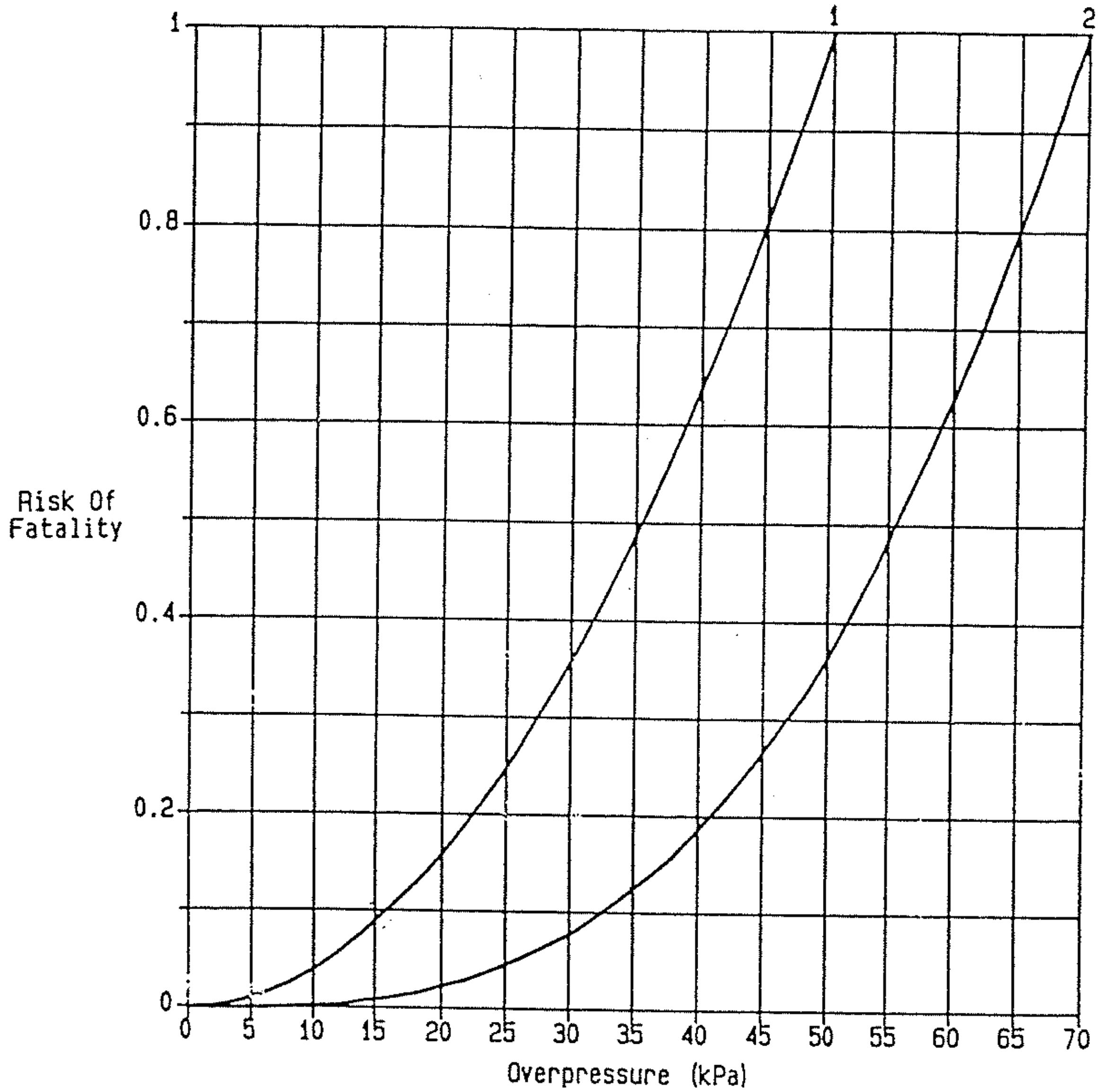
A probit method has been developed to estimate the probability of fatality from blast overpressures, similar to the one for thermal radiation [Reference 11]. However it does not take account of structural collapses, missiles, flame inhalation etc, which are the main causes of fatality with an UVCE. The 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 compared to Figure 4.3-2.

4.3.2.2 Flash Fire Effects

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.

Figure 4.3-2
Risk Of Fatality From
Unconfined Vapour Cloud Explosion



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 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

$$V = 0.4Q^{8/7} \qquad (17.9.15)$$

where Q is the mass of explosive (lb), and V the volume of crater (ft^3).

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)

Explosive		*Crater dimensions*		
type	charge (lb)	diameter (ft)	height (ft)	volume (ft^3)
Dynamite	50	6	2	30
Dynamite	2400	31	9	3200
Ammonium nitrate	9000000	400	90	10000000

explosion at Oppau in 1921, which is described in Case History A1 in Appendix 3. The corresponding crater volumes calculated from equation (17.9.15) are 32, 3200 and 75000000 ft^3, 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

$$r \propto W^{1/3} \qquad (17.9.16)$$

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: (1) 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 levels off. Glasstone (1962) gives the following estimated peak overpressures for lethality for a relatively fast explosion with a positive phase duration of 400 ms:

Probability of fatality (%)	*Peak overpressure* (psi)
1	35–45
50	45–55
99	55–65

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

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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 (%)	*Peak overpressure* (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

$$Y = -77.1 + 6.91 \ln p^{\circ} \tag{17.9.17}$$

where p° is the peak overpressure (N/m^2).

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:

Probability of eardrum rupture (%)	*Peak overpressure* (psi)	(N/m^2)
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

$$Y = -15.6 + 1.93 \ln p^{\circ} \tag{17.9.18}$$

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

$$J = \int_0^{t_d} p(t)\, dt \tag{17.9.19}$$

where J is the impulse ($N\,s/m^2$); p the overpressure (N/m^2); and t_d the duration time (s).

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

$$MV_i = C_D AJ \tag{17.9.20}$$

where A is the presented area of missile (m^2); C_D the drag coefficient; M the mass of missile (kg); and V_i the impact velocity of missile (m/s). The value of the drag coefficient C_D is taken as unity.

For injury from a missile Eisenberg *et al.* consider a flying fragment of glass of 10 g with a density 2.65 g/cm^3. 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

and derive from these data the following data:

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

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

$$Y = -27.1 + 4.26 \ln J \tag{17.9.21}$$

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.

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 Moppett, 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 m/s, 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 then 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, which suggests that the fragment velocity is likely to be low.

The report quotes experimental work in the U.S.A. in which windows $\frac{1}{8}$ in and $\frac{1}{4}$ in thick were mounted at various distances from large masses of TNT so that overpressures of 0.3 psi (0.02 bar), 0.5 psi (0.035 bar) 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

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

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

$$Y = -39.1 + 4.45 \ln J \tag{17.9.23}$$

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 by consideration of assumed scenarios of release with appropriate estimates of emission, dispersion and explosion 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 (1977a) in the period 1970–75 there were 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 incidents 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

Little Inc. is described in *Hazard Assessment Computer System (HACS) User Manual* (1974a) and in *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 5, 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 sensitivity analysis of the models is given.

Another vulnerability model is the *Vulnerability Model. A Simulation System for Assessing Damage Resulting from Marine Spills* by Eisenberg *et al.* (1975). This model is concerned with the problem of spillage of hazardous materials on to water in locations such 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

(1) 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 numbers 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 fire, explosion and toxic release and give casualty estimates. Some of this work is described in the following sections and chapters.

The *Canvey Study*, which is described in Appendix 10, also contains a set of models which constitute in effect a vulnerability model.

Table 9.12 Transformation of percentages to probits (Finney, 1971)
(Courtesy of Cambridge University Press)

%	0	1	2	3	4	5	6	7	8	9
0	—	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	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
99	7.33	7.37	7.41	7.46	7.51	7.58	7.65	7.75	7.88	8.09

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

Phenomenon and type of injury or damage	*Causative variable*	*Probit equation parameters* k_1	k_2	*Data from which the probit equation was derived* per cent affected	value of variable	per cent affected	value of variable	per cent affected	value of variable
Fire:									
Burn deaths from flash fire	$t_e I_e^{4/3}/10^4$	−14.9	2.56	1	1099	50	2417	99	7008
				1	1073	50	2264	99	6546
				1	1000	50	2210	99	6149
Burn deaths from pool burning	$tI^{4/3}/10^4$	−14.9	2.56	1	1099	50	2417	99	7008
				1	1073	50	2264	99	6546
				1	1000	50	2210	99	6149
Explosion:									
Deaths from lung haemorrhage	$p°$	−77.1	6.91	1	1.00×10^5	50	1.41×10^5	99	2.00×10^5
				10	1.20×10^5	90	1.76×10^5		
Eardrum ruptures	$p°$	−15.6	1.93	1	16.5×10^3	50	43.5×10^3		
				10	19.3×10^3	90	84.3×10^3		
Deaths from impact	J	−46.1	4.82	0	18.0×10^3	31	37.3×10^3	96	49.7×10^3
				8	28.6×10^3	63	45.2×10^3	100	60.7×10^3
Injuries from impact	J	−39.1	4.45	1	13×10^3	90	28×10^3		
				50	20×10^3				
Injuries from flying fragments	J	−27.1	4.26	1	1024	50	1877	99	3071
Structural damage	$p°$	−23.8	2.92	1	6.2×10^3	99	34.5×10^3		
				50	20.7×10^3				
Glass breakage	$p°$	−18.1	2.79	1	1700	90	6200		
Toxic release:									
Chlorine deaths	$\Sigma C^{2.75} T$	−17.1	1.69	3	14.1×10^4	50	34.05×10^4	97	105.8×10^4
				3	17.0×10^4	50	47.0×10^4	97	129.4×10^4
				3	21.5×10^4	50	64.7×10^4		
Chlorine injuries	C	−2.40	2.90	1	6	50	13		
				25	10	90	20		
Ammonia deaths	$\Sigma C^{2.75} T$	−30.57	1.385	3	37.3	50	74.6	99	411.8
				3	90.9	50	204.6	99	334.4
				3	44.6	50	148.6		

Key:
t_e = effective time duration(s)
I_e = effective radiation intensity (W/m^2)
t = time duration of pool burning (s)
I = radiation intensity from pool burning (W/m^2)
$p°$ = peak overpressure (N/m^2)
J = impulse ($N\,s/m^2$)
C = concentration (ppm)
T = time interval (min)

High explosive effects tended to be mitigated by the inability of some larger structural members in the tunnels to respond significantly to pressure loading on the short timescales indicated. Therefore, in spite of 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 New Dartford tunnel. These structural failures would be expected to be confined to the region within a few tens of metres of the detonation, although the damage would tend to be more widespread for the New Dartford than for the Holmesdale. The effects of the quantity of high explosive on tunnel damage are highlighted in Table 4.25, from which it is apparent that the effects do not worsen dramatically for increasing sizes of charge. In addition, Table 4.25 also illustrates the widespread damage expected for internal structures, due partly to blast and partly to thermal and missile loadings. Some damage is expected for some internal structures for all cases considered.

The effects of rapid release of pressurised liquids and vapours are generally not serious in spite of the relatively long duration of the impulse. This is because the peak pressures are quite low. The only exception to this is for the New Dartford tunnel where roadway failure appears to be possible. Otherwise, these loadings do not threaten the structural integrity of any of the tunnels. Damage to internal structures is likewise not predicted for the larger cross-section cut-and-cover 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 the loading, combined with the lack of significant thermal effects and the implausibility of damaging missiles, ensures that any damage would be confined to the locality of the release.

The most damaging loads considered in this report are those determined for the combustion of fuel/air mixtures which fill the entire tunnel cross-section with a flammable mixture for appreciable lengths of the tunnel. The effects found are comparable to those determined for the TNT 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 kg of flammable vapour, the effects could be largely confined to perhaps a 100m or so of the tunnel length. Thus, 0.1te of flammable vapour would provide a level of damage similar to that of 1te of TNT, but over a rather greater tunnel length, Table 4.25.

4.5.8 Effects of explosions on tunnel occupants

Eisenberg (63) and Baker (46) provide comprehensive reviews on the damage caused to people by explosions.

Essentially people can be harmed by one of four mechanisms.

a Direct blast damage. For people in the open eardrum rupture can be caused by overpressures as low as 2.5psi. At overpressure of approximately 1 bar there is about a 1% chance of being killed by lung damage and at overpressures of approximately 2 bar this chance rises to almost 100%.

b Damage by impact from primary missiles. Primary missiles are missiles generated at the site of the explosion. Missile velocities can range up to several thousand metres/second. In the confines of a tunnel such missiles are unlikely to travel great distance before impacting against the walls.

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 size and shape of the missile and the impulse delivered by the blast wave.

Little information is available on levels of damage caused by mechanisms b and c although it is known that a 4.5 kg non-penetrating fragment impacting at $3ms^{-1}$ is unlikely to cause death whereas for fragment velocities of approximately 10 ms^{-1} death is almost certain. The final damage mechanism is

d Tertiary damage. The impulse from a blast wave is sometimes sufficient to lift a person from his feet and hurl him against a wall. Reference 63 suggests that injury is unlikely to occur at impulses below 14 kPas. At 18 kPas there is a 1% chance of death by the mechanism and at 60 kPas this chance becomes almost 100%.

4.5.8.1 TNT explosions

Hazard distances for direct blast damage were evaluated for injury threshold, lethality threshold and 99% lethality for each tunnel and each charge size by referring to Figure 4.7.

Similarly hazard ranges for tertiary blast damage were evaluated making use of Figure 4.8. In all of the cases examined, the hazard range proved negligible for this mechanism.

The hazard range for primary fragments was determined by the distance a fragment could travel before impacting against the tunnel walls. For a low trajectory missile (5° to the horizontal) and travelling parallel to the tunnel walls the maximum distance travelled before hitting the tunnel roof would be ca 70m.

The hazard range from secondary fragments necessitated postulating a missile size and shape. A 4.5 kg missile was assumed and two shapes were considered:- a steel ball and ½" thick steel plate. In order to attain the critical velocities for onset of lethality (3m/s) and 10% lethality (10m/s) these missiles would have to be provided with sufficient impulse from the blast. This impulse was evaluated neglecting drag and lift effects and the corresponding hazard ranges determined for each tunnel and charge size from Figure 4.8.

The above analysis assumes people in the open ie not within vehicles. It is likely that remaining within a vehicle would considerably increase the prospect of survival from all of the above damage mechanisms although there is a lack of information that allows one to quantify such an influence.

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APPENDIX 2

EQUIVALENT OVERPRESSURE VALUES TO GIVE DEFINED BLAST DAMAGE DESCRIPTIONS

TABLE 1 EQUIVALENT OVERPRESSURE VALUES TO GIVE DEFINED BLAST DAMAGE DESCRIPTIONS

Damage Details	Incident Equivalent Peak Overpressure in bar (psi)
Effects on Persons	
Ears	
Sound Noted as an unusual event —an explosion	0.0003 (0.005)
Loud noise at 143 dB	0.002 (0.04)
Annoying noise of continuous type at 10–15 Hz and 137 dB	0.001 (0.02)
Threshold for temporary loss of hearing	0.013 (0.2)
Threshold for eardrum rupture	0.13 (2)
50% eardrum rupture	0.33 (4.8)
50% probability of eardrum rupture	0.34 – 0.48 (5 – 7)
90% probability of eardrum rupture	0.68 – 1.03 (10 – 15)
Wounds	
Minimum for penetration injury by small glass fragments	0.05 (0.8)
Threshold of skin laceration by missiles	0.06 – 0.13 (1 – 2)
Serious missile wounds of about 50% fatality	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 a resistant structure	0.06 (1)
Personnel knocked down or thrown to ground	0.10 – 0.19 (1.5 – 2.9)
Possible death by persons being projected against obstacles	0.13 (2)
People standing up will be thrown a distance	0.55 – 1.10 (8 – 16)
People lying flat on the ground are picked up and hurled 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 haemorrhage	1.37 – 1.72 (20 – 25)
99% fatality from lung haemorrhage	2.06 – 2.41 (30 – 35)
Immediate blast fatalities	4.82 – 13.78 (70 – 200)
Primary Missiles	
General	
Limit of travel of primary missiles	0.008 – 0.013 (0.12 – 0.20)
Missile limit (negligible effects beyond this range)	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	0.01 (0.15)
Large and small windows usually shattered, occasional damage to window frames	0.03 – 0.06 (0.5 – 1.0)
5% 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 (0.08 – 0.19)
75%of exposed glass panes broken	0.010 – 0.024 (0.15 – 0.35)
90%of exposed glass panes broken	0.107 – 0.041 (0.26 – 0.60)
99%of exposed glass panes broken	0.046 – 0.110 (0.67 – 1.6)
Double glazing is generally twice as strong as normal single glazing when glass panes of equal thickness	x 2 glass values given above
Damage to Houses – General	
House roof tiles displaced	0.02 – 0.04 (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	0.020 – 0.027 (0.3 – 0.4)
Doors and window frames may be blown in	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 earthshock 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	0.68 (10)
Crater lip	20.68 (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)
Category 'Cb' Damage Uninhabitable until extensive repairs are made (ie partial or total collapse of roof structure, partial demolition of 1 or 2 external walls up to 25% of the whole –, severe damage to load bearing partitions	0.13 – 0.24 (2.0 – 3.5)
Category '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)
Category 'A' Damage – Completely demolished (i.e. with over 75% of external brickwork demolished)	0.68 - 1.82 (10.0 – 26.5)
50% 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 wood 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)
Moderate damage: walls bulged, roof cracked or bulged, studs and rafters broken	0.15 – 0.24 (2.2 – 3.5)
Severe 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 (1 – 2)
Failure of joints or fastenings in aluminium or steel panels followed by buckling	0.06 – 0.13 (1 – 2)
Steel frame of clad building slightly distorted	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)
Movement 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 trucks	1.37 – 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 ton 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 completely 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)

NOTE

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 A0) AND ON 'BUTCHERS PAPER' (14 PAGES LABELLED A1-A8, B1-B4, F1 & KG1) BY THE SECRETARY, MR DAVID HUMPHREYS, AT A MEETING OF TASK GROUP 5 HELD OVER 3 & 4 JUNE 1996

A0 DESIGN INTENT

TEMPORARY STOPPINGS/SEALS → LOCATION - |→ INBYE OF REGULATOR
C/T BETWEEN INTAKE & RETURN
|→ DURING PANEL DEVELOPMENT & POSSIBLE EXTRACTION
|→ SEGREGATION OF INTAKE/RETURN AIR
|→ INDUSTRY PRACTICE
↓
CEMENT PRODUCTS/AERATED BLOCKS
PLASTERBOARD
TIN
BRATTICE

|→ LIFE REQUIREMENT - LIFE OF PANEL, TO 3YRS
|→ ENVIRONMENTAL COND'S

MACHINERY DAMAGE
MANDOORS

HIGH HUMIDITY → SOFTENING
GROUNDWATER → ACID WATER
PRESSURE DIFFERENTIAL → LEAKAGE
WINDBLAST → DAMAGE
FIRE →
EXPLOSION → OVERPRESSURE → DAMAGE
GROUND MOVEMENT → DAMAGE

A1 DEV L = LIKELIHOOD
DEVIATIONS C = CONSEQUENCE
1 - FIRE ON STOPPING
L - LO C - Hi
SAFEGUARDS - MONITORING/INSPECTION
|→ FIRE RESISTANCE RATING ON STOPPING
|⇒ ACTION GRAHAM FAWCETT

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2 - Hi HUMIDITY → LOSS OF INTEGRITY
|→ PLASTERBOARD ONLY
L - Hi C - Lo
SAFEGUARDS - M & I

A2 DEV

3 - GROUNDWATER ON STOPPING

|→ LOSS OF INTEGRITY

L - Lo C - Lo

RECOMMENDATION - CHECK SUITABILITY OF STOPPING MATERIALS EG. METAL

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4 - PRESSURE DIFFERENTIAL

|→ LEAKAGE

MANAGEMENT RESP TO DESIGN TO PREVENT LEAKAGE THRU & AROUND STOPPING

A3 DEV

4 - EXPLOSION → OVERPRESSURE → DAMAGE

WINDBLAST -↑

ACTION ⇒ TO DETERMINE LIKELY PRESSURE DIFF 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 & CONSTRUCTION STANDARD IN RELATION TO ANTICIPATE GROUND MOVEMENTS

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6 - EXTERNAL DAMAGE

MAINTENANCE ISSUE ONLY

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7 - MANDOORS

SELF CLOSING

ACTION ⇒ INVESTIGATE SELF CLOSING DOORS

A5 DURING EXTRACTION PHASE
TEMPORARY SEALS (CHAIN PILLARS)
LOCATION - POSSIBLY REBUILT & RELOCATED FROM DEV
PURPOSE - ISOLATE GOAF FROM VENTILATION SYSTEM
(O_2 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
ΔP → LEAKAGE
WINDBLAST & GRND MOVEMENT
FIRE EXTERNAL DRAINAGE
EXPLOSION

A6
1 WATER DAMMING / ACID WATER
|→ DESIGN TO ACCOMODATE
|→ SELECT SUITABLE MATERIALS RESISTANT TO ACID ATTACK

2 ΔP → LEAKAGE
| MANAGEMENT RESP TO DESIGN TO MINIMIZE
| LEAKAGE THRU & AROUND STOPPING
|→ MONITORING & INSPECTION

A7
3 WINDBLAST → DAMAGE
& GROUND MOVEMENT -↑
|→ MINE }
& PANEL } SPECIFY RISK ASST & DESIGN

GROUND MOVEMENT
STRATA CONDITIONS/STRENGTH/STABILIZATION
GEOL FACTORS/SHEAR PLANES

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4 FIRE REQUIRES FIRE RESISTANCE RATING

APPENDIX E

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 MINUTES 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:

i 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
	CH_4	CO_2	
Permanent Goaf Seals	AS1530.4 60 mins	AS1530.4 60 mins	To prevent release of combustible or asphyxiating gases
Explosion Resistant Seals	"	"	"
Main Ventilation Structures	"	"	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
b1 Permanent seals in maingates after extraction completed.	5psi
b2 Permanent seals in maingates after extraction completed.	10psi
a1 Temporary stoppings/seals in gateroad development.	2psi

All explosion ratings were considered subject to review.

All environment conditions were considered to be as per A1 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.

l. 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 a1.

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.