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Technical reference guide

Airblast management in non-coal underground mines

(MDG 1031)

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Date	Version	Amendment
August 2023	Consultation draft	Consultation draft. This guide replaces MDG1031 Managing airblast risk, MDG1031 TR Managing the risk of airblast in an undergound mine
October 2023	2.0	Amendments made to address stakeholder feedback during consultation

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1. Introduction

This technical reference guide (TRG) replaces MDG1031 Managing airblast risk, and MDG1031 TR Managing the risk of an airblast in an underground mine. It applies to non-coal underground mines.

This TRG guides non-coal underground mine operators in developing and documenting an airblast management plan. An airblast management plan forms part of the mine's principal hazard management plan (PHMP) for ground or strata failure in underground mining operations. This document is intended for non-coal, underground metalliferous mines. For underground coal mines refer to Technical reference guide – Managing windblast in underground coal mines.

This document should be read in conjunction with:

- NSW WHS Acts and Regulations[1]
- NSW codes of practice:
  - Work health and safety consultation, cooperation, and coordination (NSW State Government, Safe Work NSW. August 2019b)
  - How to manage work health and safety risks (NSW State Government, Safe Work NSW. August 2019a)
  - Safety management systems in mines (NSW State Government, Feb 2015a)
- Planned inspection program ground or strata failure – underground metalliferous consolidated report (NSW State Government, January 2020) NSW Resource Regulator's guidance material, for example:
  - Guide - Preparing a principal hazard management plan (NSW State Government, Sep 2022b)
- Australian and International Standards in related fields, for example:
  - AS ISO 31000: 2018 Risk Management — Guidelines
  - AS/NZ ISO 45001: 2018 Occupational Health and Safety Management Systems – Requirements with guidance for use.

2. Complying with the legislative and regulatory requirements

2.1. Legislative and regulatory requirements

Airblast poses significant risk to worker health and safety. Accordingly, PHMPs for ground or strata failure must detail the management of airblast if it is identified as a hazard at an underground mine2.

The mine operator must conduct a comprehensive and systematic investigation and analysis of all aspects of airblast risk by appropriate persons and detail this in the PHMP ground and strata and its supporting risk assessment3. Mine operators must also review the airblast management plan in response to any meaningful changes such as changes in extraction rates, geology, or mining method. Mines must model the size of an airblast risk using the recognised modelling and classification methods such as the leaky piston model.

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[1] The NSW WHS laws are:

Work Health and Safety Act 2011 (WHS Act)

Work Health and Safety Regulation 2017 (WHS Regulation)

Work Health and Safety (Mines and Petroleum Sites) Act 2013 (WHS(MPS) Act)

Work Health and Safety (Mines and Petroleum Sites) Regulation 2022 (WHS(MPS) Regulation)

[2] Schedule 1, section 1(k) WHS (MPS) Regulation 2022

[3] Section 14 WHS (MPS) Regulation 2022

The development of an airblast management plan also requires active workforce participation.

2.2. Interaction with the safety management system

The Ground and Strata PHMP forms part of the Safety Management System (SMS) for a mine. For more information about SMSs, see the Safety management systems in mines - code of practice (NSW State Government, Feb 2015).

The airblast management plan within the ground and strata control PHMP must;

- provide a description of the context in which the hazard exists at the mine
- provide a description of how the implementation of measures under the PHMP – ground or strata failure for the area will be coordinated with other PHMPs and principal control plans.

When developing an airblast management plan the mine operator must consider its relationship with other plans. The airblast management plan will cross reference the following plans:

- Ventilation control plan
- Fire and explosion PHMP
- Emergency plan
- Inrush and inundation PHMP
- Subsidence PHMP

2.3. Consultation

When managing risks, the mine operator must consult with workers and other duty holders at the mine[4] on airblast risk. This includes other persons conducting a business or undertaking (PCBUs) such as contractors. Details are found in the Guide – Preparing a principal hazard management plan (NSW State Government, Sep 2022b) (section 2.4). Further guidance on consultation, cooperation and coordination can be found in the;

- NSW Code of practice: Work health and safety consultation, cooperation, and coordination (NSW State Government, Safe Work NSW. August 2019b)
- Contractors and other businesses at mines and petroleum sites guide (NSW State Government, June 2016)
- Consulting workers fact sheet (NSW State Government, May 2022).

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[4] Section 19 WHS (MPS) Regulation 2022

3. Risk management

3.1. Fundamentals of airblast

An airblast is the sudden displacement of large quantities of air caused by a rockfall event throughout the constrained underground mining environment. The safety consequence of an airblast event depends on the maximum airspeeds reached and the location of mine workers.

There is an airblast risk where there is:

1. a void – this is typically the airgap in a block cave; and
2. a source of potential energy – typically an unsupported rock mass; and
3. an opening from the void into the mine workings.

Typical control measures to manage airblast risk involve:

- modelling void geometry and conducting a risk assessment to determine the maximum void before production rates are to be slowed or stopped in accordance with a trigger action response plan (TARP)
- systematic monitoring of the void size
- inducing rock failure to reduce the size of the void typically via explosives or hydrofracturing.
- increasing and maintain the size of any muck pile in a caving operation to dampen and lengthen the time of an airblast event
- increasing the area of any entries into the void.

Openings into the mine workings may be managed by:

- the use of bulkheads
- the use of a muck pile in caving operations.

To effectively manage airblast risk, a mine operator should appropriately model the airblast risk of their operation. Models must be based on the current mine plan and site-specific parameters for the porosity and height of a muck pile. This ensures they are as accurate as possible.

Air velocities modelled against different inputs are typically compared with recognised wind velocity scales used to categorise weather[5]. These inputs include muck pile height, void volume, and cave geometry. This data is then used to develop a trigger action response plan (TARP) which is triggered based on the monitoring of identified controls.

3.2. Hazard Identification

As discussed in Section 3.2 there are 3 conditions that must be satisfied for an airblast to occur. These 3 conditions provide a good starting point to identify relevant hazards related to airblast, however hazard identification is not limited to this.

The learnings from previous airblast events in metalliferous mines show that the hazards and the controls to manage them, are typically understood by the mine operator. It is having robust management systems so that controls are implemented and are effective where mine operators have historically generated an airblast risk for workers. Management systems must be independent of individual persons so that if there is a change in personnel, the system is robust enough to continue to be effectively implemented. The mine operator must consider the hazard that monitoring results will not be effectively actioned in the risk management process.

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[5] Refer to additional information Appendix A – Darington 2000; Logan 2004 and Tyler 2001 and Appendix C p65

The mine operator must also have effective systems to monitor for and action change. There is a large hazard that modelling, and any systems will not be effective if the inputs used to develop any airblast model have changed.

Once the hazards have been identified the mine operator must effectively model the airblast risk. Appendix C outlines how this modelling can be conducted; however, it must involve competent persons and consider all aspects of the mining method. The modelling allows the mine operator to determine the true size of the airblast hazard. This will be the basis of the risk assessment process.

Finally, the mine operator can then systemically review each of the 3 conditions required for an airblast to occur and identify and quantify the hazards around each of these 3 conditions.

3.3. Risk assessment

Once a mine operator has systematically and comprehensively identified the hazards associated with airblast, mine operators must undertake a risk assessment of the hazards and the controls for those hazards. Persons conducting risk assessments must be competent to do so. This will likely be an iterative process, as the risk assessment may identify hazards that pose an unacceptable risk to worker health and safety. Therefore, mine operators should develop additional controls accordingly.

For example, the risk assessment may determine that the risk of a build-up in ground stresses is too great. Accordingly, managing this risk before mining commences will require further controls like the pre-conditioning of ground with a process like hydrofracturing. The risk then needs to be re-assessed to satisfy the mine operator that this control now adequately manages the risk. Despite being written for underground coal mines, the following documents may be useful:

- NSW code of practice: How to manage work health and safety risks (NSW State Government, Safe Work NSW. August 2019a)
- National Minerals Industry Safety and Health Risk Assessment Guideline (Joy, J. & Griffiths. D. 2007)
- RISKGATE, an interactive online risk management tool designed to assist in the analysis of priority unwanted events unique to the Australian Coal Mining industry[6].

For further information on managing risks under WHS MPS Regulation, including specific obligations for conducting risk assessments, see Managing risks in mining and petroleum operations: Guide (NSW State Government, Sep 2022).

Mine operators should document risk analysis methods and maintain records. Documents should;

- describe the methods used at the site to identify the level of risk, threats, controls, and consequences (e.g., risk assessments, bow-tie methodology)
- describe scientific testing methods used to assist in the evaluation of the risks
- justify why they were valid and reliable methods
- record the most recent risk assessments.

Risks that need to be considered in the airblast risk assessment include but are not limited to:

- production rate (draw control) and relationship with cave propagation rate
- the accuracy of modelling of the size of the airblast risk. This includes making the correct assumptions on key constants in the model used and ensuring the calculations are based on the current mine plan. Due to the lack of precision in the use of constraints for swell factors and porosity, it is recommended that a range of numbers be used, and a statistical regression be undertaken to determine the peak air velocities at different stages of the mine's extractions

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[6] https://smi.uq.edu.au/project/riskgate

- the likely cause of instigation of a release of a source of energy and how to manage each of those causes: seismic event, water management, geological structures, blasting-induced failure in a caving operation, blast or hydrofracking induced failure, the Quality Assurance and Quality Control (QAQC) of any bulkhead material. The primary cause of a build-up of potential energy is a rock mass being stronger than anticipated, allowing the void to increase in size with excavation. As the void size increases, the airblast risk also increases. As stresses build up in the rock mass, the risk of an unplanned failure of rock mass increases.
- the geometry of the void.[7]
- monitoring equipment or procedures or insufficient monitoring providing inaccurate data. Monitoring includes the monitoring of void dimensions, wall strengths, muck pile height and porosity, water sources, seismic monitoring systems and geological structure monitoring
- controls detailed in any TARP not being actioned as prescribed when required by the operation
- housekeeping standards not being maintained properly
- loss of corporate knowledge around the design rationale and development of any TARP
- risks associated with entrances into the voids subject to an airblast risk
- air pathways of air in an airblast event and assess how airblast risk can be reduced in these areas with the placement and type of infrastructure and number of workers in these areas.
- Robustness of management systems.

3.4. Risk controls

3.4.1. Factors to consider

Mine operators must consider the following factors when developing control measures to manage the risks of airblast;

- void volume that is subject to an airblast risk. This is determined by;
- mining method
- mine geometry
- geotechnical conditions.
- sources of potential energy – typically a large rockfall event which displaces the air within the void.
- managing openings. By managing openings into the working areas of the mine the airblast event can be controlled by increasing the duration of the event, therefore lowering peak air velocities. Methods include:
- use of muck piles.
- use of bulkheads (sometimes referred to as airblast plugs);
- expanding the total area of drives that enter the void, to reduce the air velocities in an airblast event
- the size of the potential airblast risk (usually ascertained through modelling maximum air velocities in the event of an airblast)
- the required monitoring regime for openings into mine workings, sources of potential energy and void size and geometry.

[7] Fowler JCW and Hebblewhite BK. November 2003. Managing the hazard of wind blast / airblast in caving operations in Australian underground mines. UNSW presentation papers for 1st AGCM Conference 10-13.

Once the mine operator has identified the appropriate controls that are matched to the modelled airblast risk, the mine will typically determine the monitoring requirements for those controls.,

Mines will typically use a recognised wind speed categorisation standard to inform a TARP. The TARP will trigger a variety of responses depending on the status of identified airblast controls. The TARP should have clear accountabilities of who monitors each control and workers need to be trained in the airblast TARP.

Appendix C discusses specific technical issues in controlling airblast in underground mines.

3.4.2. Preventative controls

Mines should adopt new technologies as they become available and are reasonably practical to implement. This is important in the context of determining void dimensions as a preventative control measure. Greater accuracy in monitoring systems better reflects current mining conditions and better informs any TARP[8], including;

- mine plan design
- geotechnical design (e.g.; caveability assessments)
- reducing the hazard burden through hydrofracking and blasting [9]
- monitoring systems
- a well-defined TARP that is understood throughout the mine and actioned, with clear metrics for each control such as void size, void geometry, the forming of any stable arch, muck pile heights, gas levels and seismicity
- TARP to include the provision for pre-conditioning to reduce void size
- reduced production rates
- effective modelling of the airblast risk that is based on relevant mine designs and is updated as required. Modelling is then used to update the TARP.

3.4.3. Mitigating controls

A range of reactive/mitigating controls for airblast include;

- maintaining monitoring controls, including seismic system, regular cavity monitoring surveys, use of cave markers, probe drilling, mass balances of water, and reconciliation of material excavated
- limiting the number of workers in airblast prone zones
- locating infrastructure outside of airblast prone zones where possible
- use of engineered bulkheads that are designed to withstand an airblast event
- current emergency plans
- safe zones such as stockpiles that workers can retreat to if an airblast is imminent
- controlling airblast pathways
- minimising the accumulation of water
- good housekeeping
- use of personal protective equipment (PPE) and tether lines.

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[8] Fowler C Reducing the Hazard of Windblast in Underground Coal Mines ACARP NSW July 2019

[9] ACARP report C9024 – Development of Hydraulic Fracturing to Control Windblast.

3.4.4. Monitoring systems

An airblast TARP is an important administrative control in the management of airblast risk. However, for the TARP to be effective, the mine must have effective monitoring systems in place to detect any changes in any of the engineering controls used to manage airblast risk and then take the actions prescribed in the TARP.

Monitoring systems typically consist of;

- void monitoring – There are a series of tools available to industry to monitor extracted voids and mine operators should assess the systems available and their appropriateness in the risk assessment process. The monitoring system is required to monitor the size of any void
- muck pile monitoring – For block cave operations, the muck pile is a critical control in the management of airblast. Muck pile geometry, height, and porosity all have a large effect on managing airblast risk.[10] Mine operators should have appropriate systems in place to monitor these three aspects of the muck pile
- sources of potential energy – The primary source of potential energy is from unplanned rockfall. Potential energy can build up with mining extraction. Mine operators should monitor for the build-up of stress within the rock mass, which could fall in an unplanned event and displace air in the airgap. The monitoring system must incorporate the monitoring of geological conditions, and the geometry of the void to monitor that failure is occurring as planned and a stable arch is not being formed which will allow stresses to build up[11] [12] [13]. Seismic monitoring systems provide useful data to understand the void and progression.

Monitoring technologies have continued to develop over the past 20 years and mine operators should review their controls with technological developments.

3.4.5. Understanding previous airblast events

It is important to recognise the characteristics of past airblast events and investigate their relevance to a mine. Two significant airblast events that have occurred in NSW include an event in June 1995 at Endeavour Colliery and another at Northparkes Mine in 1999. Appendix B contains further information on those two events.

Some of the major lessons from those events were the need to:

- retain corporate memory around the management of airblast risk within the operation so that as staff leave, knowledge is maintained
- have a clear TARP which is understood throughout the operation and is actioned as soon as monitoring conditions identify the need to change[14].
- use incident reviews to better understand the nature of hazards
- collect and analyse data from all incidents to derive;
    - the unwanted event scenarios that will be included or excluded in the scope

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[10] Oh J, M Bahaaddini, M Sharifzadeh & Z Chen *Evaluation of airblast parameters in block cave mining using particle flow code* International Journal of Mining, Reclamation and Environment 20th June 2017

[11] Australian Centre for Geomechanics. December 2004. *Monitoring cave-related seismicity at Ridgeway Gold Mine*, ACG Newsletter, Vol. 23.

[12] Brown, E.T. 2003. *Block Caving Geomechanics*, Brisbane: Julius Kruttschnitt Mineral Research Centre.

[13] Duplancic, P. 2001. *Characterisation of caving mechanisms through analysis of stress and seismicity.* Unpublished PhD Thesis, Department of Civil and Resource Engineering, University of Western Australia.

[14] While the operation at Northparkes had documented systems in place to manage the expanding void, they were not implemented as the TARP action levels were reached.

- the initiating events scenarios that describe the point where the situation became unsafe (e.g., decrease in the muck pile). Identifying and highlighting the initiating event is fundamental as it raises awareness of the point at which operations are unsafe. It also increases the focus on what is required to keep operations safe
- the root causes of the initiating events (e.g., void increased beyond that detailed in the TARP).

3.4.6. Trigger action response plans and monitoring

TARPs summarise the overall mine environment monitoring arrangements. They include planned actions ready to implement when certain trigger or alarm points are detected by monitoring. TARPs should be established only after a risk assessment has verified the selection of the most effective control measures. There are a range of detection mechanisms for airblast, including void size, seismic responses, muck pile heights and mine geometry.

Monitoring alone is not a control. The control is the action that is triggered when the monitoring system detects a change and activates a trigger/alarm.

TARPs represent a staged response to a situation that may deteriorate, from simply being abnormal through to elevated. TARPs should specify the actions and responsibilities required by all workers at each level. Typically, there are different triggers at different modelled windspeeds using the mine's defined modelling methodology. At each point different controls are introduced which may be some or all the following;

- increasing muck pile heights
- reducing production rates in caving operation
- restricting access to airblast prone areas
- commence blasting in a caving operation
- commence hydrofracking.

Effective monitoring systems are critical to the effective management of any TARP. The airblast management plan within the PHMP for ground and strata failure must clearly define all the monitoring systems, and the relevant responsibilities for each of these monitoring systems. The interpretation and actions associated with their results also require definition.

Monitoring systems need to be maintained in their correct state. Therefore, the mine operator must maintain a clear maintenance schedule for relevant monitoring equipment.

The TARP needs to be understood across the mine workforce. When the monitoring system triggers the TARP, the TARP and its controls are immediately actioned. The first level of a TARP may not be set to detect the onset of an airblast but the deviation of operating conditions from normal that may lead to airblast (e.g., reduced muck pile).

3.4.7. Documenting the control management system in the airblast management plan

The control management system in the airblast management plan should;

- identify and describe threats, controls, and consequences
- use schematics (e.g., bowtie diagrams)
- justify the use of controls.

3.4.8. Incident management

In addition to the TARP process outlined above, the management of any airblast incident should be included within the emergency management plan. Details for emergency planning are contained within the NSW code of practice for Emergency planning for mines (NSW State Government, May 2021). A key element of the emergency response is the incident management process. The NSW

Mines Rescue Incident Command and Control Systems is an example of how to establish and operate an incident management system.[15] Other guidance can be found in AS 3745:2010 *Planning for emergencies in facilities*.

3.5. Effectiveness of controls

A critical control is a control that is crucial to preventing an event or mitigating the consequences of an event. Such a control is critical because its absence or failure would significantly increase the risk of serious injury or death despite the existence of other controls. An indicator of a control's effectiveness is whether implementing the control has introduced any new hazards. For further details see the Guide - Preparing a principal hazard management plan (NSW State Government, Sep 2022).

3.6. Documenting critical controls and how they will be measured in the airblast management plan

The International Council on Mining and Metals (ICMM) recommends a "critical control approach" to managing mine safety. Mines should identify the critical controls required at their operation to manage airblast risk and ensure they are implemented. The ICMM website provides further information on critical controls. [16]

It is imperative that critical control checklists be compiled which enable sites to confirm that they have properly implemented a control and it is functioning as designed. These checks must be carried out at a frequency sufficient to ensure the controls remain effective.

An example of a critical control could be the requirement to hydrofrack when a void reaches a certain size.

3.7. Information, training, and instruction

The mine operator must ensure that the management plan describes the arrangements for providing suitable and adequate information, training and instruction required by WHS (M&PS)R 2022 Section 28(3)(g) in relation to the principal hazard. The national training competencies outline suitable training for workers in airblast.[17]

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[15] Mines Rescue ICCS Guide, NSW Coal Industry, Coal Services, 2014.

[16] In 2015 the International Council on Mining and Metals (ICMM) released their good practice guide *Health and Safety Critical Control Management* that described how mining and metals industries' risk management outcomes could be improved by focussing on those controls that are most critical for health and safety. A number of subsequent ICMM documents have described the CCM framework, including the *Critical Control Management: Implementation Guide* (ICMM, 2015a) and the G*ood Practice Guidance on Occupational Health Risk Assessment* (ICMM, 2015b)

[17] Resources and Infrastructure Industry Training Package accessible at https://training.gov.au/Training/Details/RII

Appendix A - Definitions, abbreviations, and references

Definitions

In this guide, the following definitions apply:

NAME	DEFINITION
Airblast	An airblast is a rapid displacement of large quantities of air, often under pressure, in a constrained underground environment caused by a fall of ground or other material. The extent of the consequences of such an airblast depends on the amount of air that is compressed and the rate of that compression.
Bulkhead	A bulkhead is usually a solid structure built across a drive or opening that would seal the drive or opening from the effects of an airblast or mitigate the effects of such an airblast from the rest of the mine. A bulkhead can also be known as a stopping or plug.
Excursion distance	The distance that an atmosphere, expelled by airblast, may infiltrate accessible areas of a mine.
Airblast zone	That area of a mine where conservative application of experience and/or predictive modelling identifies that airblast has the potential to cause injury to people, damage equipment or seriously disrupt ventilation.
Seismogenic zone	An active seismic front caused by failure of the rock mass primarily through shearing and intact rock fracturing (Duplancic, 2001).
Muck pile	Broken material that sits above a drawpoint in an underground caving operation

Abbreviations

NAME	DEFINITION
AS	Australian Standard
AS/NZS	Australian/New Zealand Standard
BS EN	British Standard European Standard
CCM	Critical Control Management
ICMM	International Council on Mining and Metals
ISO	International Standards Organisation
PCBU	Person Conducting Aa Business or Undertaking
PCP	Principal Control Plans
PHMP	Principal hazard management plan
TARP	Trigger Action Response Plan
TRG	Technical Reference Guide

NAME	DEFINITION
WHS Act	*Work Health and Safety Act 2011*
WHS Regulation	Work Health and Safety Regulation 2017
WHS (MPS) Act	*Work Health and Safety (Mines and Petroleum Sites) Act 2013*
WHS (MPS) Regulation	Work Health and Safety (Mines and Petroleum Sites) Regulation 2022

Standards

This guide refers to the following standards, as amended from time to time:

STANDARD	TITLE
AS ISO 31000	2018 Risk Management — Guidelines
AS/NZS ISO 45001:2018	Occupational health and safety management systems: Requirements with guidance for use
AS 3745:2010	Planning for emergencies in facilities

Additional information

The following are referenced in this document or are additional resources:

ACARP report C6030 – *The Dynamics of Windblasts in Underground Coal Mines*.

ACARP report C9024 – *Development of Hydraulic Fracturing to Control Windblast*.

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NSW State Government. (Feb 2015a). *Safety management systems in mines – Code of Practice*. NSW Department of Trade and Investment, Regional Infrastructure and Services, Division of Resources and Energy. Retrieved from < https://www.resourcesregulator.nsw.gov.au/__data/assets/pdf_file/0008/543941/NSW-code-of-practice-Safety-managment-systems-in-mines.pdf >.

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Appendix B – History of Airblasts in NSW

Airblast event at Northparkes mine, 1999 – Resources Regulator case study[18]

On 24 November 1999, an airblast killed four mine workers at the Northparkes underground copper and gold mine in central NSW. Northparkes was the first mine in Australia to use the block caving method of ore extraction.

The mine was in maintenance shutdown on the day of the airblast, with approximately 65 workers underground. At approximately 2:50pm, a catastrophic event occurred over a period of four minutes. Approximately 5.5 million cubic metres of rock (14.5 megatonnes) collapsed from the roof into the void. This created an airblast which travelled throughout the underground workings of the mine.

The force of the airblast caused roof bolts and metal mesh to bend, destroyed motor vehicles and killed four workers. Two of the workers killed were contractors conducting drill and hydraulic fracturing procedures on the roof of the cave void. The other two workers killed were employees at the mine. It appears they were examining the activities taking place.

The Coroner found that the mine's production rate was the sole reason the airgap void reached the size it did on the day of the airblast event. The mine was producing far more ore than the rate at which the ore was falling from the cave roof. The Coroner found that this was because the operator prioritised production rates over adherence to maximum airgap height guidelines. These guidelines were developed by block caving experts when the mine first commenced production.

The Coroner also found that the mine operator should have been aware of the position of the bulkhead. This had been compromised and no longer served its purpose as a safeguard against airblast.

The Coroner recommended that any mine operator intending to use block cave mining methods must identify and analyse the elements of all associated risks. The Coroner also recommended that mine operators should develop and maintain hazard management procedures to manage the void above the muck pile, the height of the muck pile above the extraction level and the airblast hazard. The procedures should include all appropriate controls for the airblast at all openings or potential openings into the caving zone.

As result of the incident, there is a greater understanding of the risk involved in block cave mining in Australia and managing the risks of airblast.

Further information on this event is available at: http://mineaccidents.com.au/uploads/north-parkes-coronial(1).pdf

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[18] NSW State Government, Department of Regional NSW - 1999 Northparkes Air Blast Case Study – https://www.resourcesregulator.nsw.gov.au/safety/safety-events-and-education-programs/learning-from-disasters/learning-from-disasters/1999

Airblast event at Endeavour Colliery, 1995 – Resources Regulator case study[19]

At 9:50am on 28 June 1995, a windblast event at Endeavour Colliery created a subsequent inrush of methane from the goaf. This caused a significant explosion in the 300 Panel and substantial damage. Luckily, there were no fatalities.

The various investigations carried out by the Mine Safety and Health Administration of the US Department of Labor and the NSW Department of Mineral Resources identified several issues for which mine operators should be aware. In addition, mine operators should also note the following summary points regarding systems failures at the Endeavour mine;

- there was a failure of panel design, development, and review processes to recognise and effectively treat the hazard presented by potential accumulation of gas in the 300 Panel goaf and the possibility of windblast
- there was a failure of personnel on-shift, particularly those in supervisory roles to recognise the potential hazard represented by occurrences of gas and an imminent, large fall of roof in the goaf
- there was a failure at the mine to set and/or maintain adequate standards regarding ventilation (both practice and appliances) and the maintenance of stone dusting and barriers.

Further information on this event is available at: http://mineaccidents.com.au/uploads/endeavour-explosion-1995.pdf

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[19] NSW State Government, Department of Mineral Resources (May, 1996)

Appendix C – Guidance material for managing airblast in underground mines

This Appendix[20] may be used as fundamental input into any risk assessment process associated with identifying hazards or risk of an airblast as well as planning, designing, investigating, or maintaining control measures to prevent or mitigate airblasts underground.

This appendix is in 2 parts - Parts A and B.

Part A examines three elements which have been derived from the three key contributing factors that need to exist for an airblast to occur. These three elements are:

- *void*
- *source of potential energy*
- *openings into a void from the mine. Note: This opening into the void is one that would connect the void to the rest of the mine through which an airblast could travel.*

Conversely, if any one of these three contributing factors (or elements) in Part A is not present or is totally controlled, then an airblast would be prevented from occurring.

Part B examines issues surrounding one element only; namely *mitigating the effects of a potential airblast* or minimising the risk of exposure of persons and infrastructure to an airblast should an airblast occur.

Parts A and B include suggestions on issues that may warrant consideration. These may include:

- general issues to consider
- investigation work that may be necessary
- planning or design suggestions
- controls that may be put in place
- monitoring suggestions that may help to indicate if further action is necessary

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[20] Appendix C is an unedited extract from MDG 1031 TR June 2006

PART A	ELEMENT	
	(1) VOID	A void needs to be present for an airblast to occur. Therefore, the risk of an airblast is lowered if the dimensions of a void are minimised. However, if a medium to large void ispart of the mine design or there is a potential for a larger void to be created then the following should be considered.
Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Geometry	1. Volume of void	*General* There needs to be in place a system to measure or accurately estimate the changing dimensions of a void so that the risk of an airblast can be estimated. *Coal or tabular deposits* In tabular deposits, especially coal mines, the presence of a massive stratum in the immediate roof area is critical to estimating the potential for an airblast. Factors to consider could include the following: ● Where a massive stratum lies within the caving height of a goaf, a void or air gap may develop. The size of the void can be very difficult to estimate. ● Where a massive stratum lies directly on top of the seam the volume of the open goaf is criticalin estimating the potential for an airblast. In this case the total dimensions of the uncollapsed goaf or void would be important to readily estimate the risk. *Caving operations* An airblast can be substantially prevented in a caving operation by designing the void geometry to provide for continuous caving. Planning and designing for a minimal air gap and void throughout acaving operation is an important design objective.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring (cont.)
Geometry (cont.)	1. Volume of void (cont.)	*Caving operations* A primary control in preventing an airblast from occurring is to inhibit or minimise the development ofan air gap. Consider only pulling the swell until the cave back has broken through to its limit to prevent a significant void being developed. Also, to minimise an air gap one could consider blasting or hydrofracturing the stope or cave back to induce a fall of ground. Where inducement of the back isnot practical then a muckpile of broken material below the cave back and in the potential fall area could be provided. This muckpile should be kept as large as possible to reduce the volume of the void and cushion the energy from any fall of ground. This stockpile of material could also reduce the air pressure should an airblast occur as air flows through it, thus minimising the effects of an airblast to the rest of the mine. *Monitoring controls* Consider establishing a void monitoring system to monitor the void's dimensions and any changes to those dimensions. Some monitoring systems have included: ● time domain reflectometers (TDR's), ● mass balance calculations, ● open hole cameras, ● cavity monitoring systems, ● depth plumbing via drill holes, and ● microseismic sensors (at various depths) to identify seismogenic zones. Information, such as above, should be obtained from several sources to cross check the data. Ifsafe access exists to the void and information can be obtained on its dimensions, then it can be compared to the void design and an additional assessment of the risk of airblast could be made.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Geometry (cont.)	2. Plan area of void	*Coal or tabular deposits* Where a goaf is overlain by a massive stratum the plan area of an open goaf void and in particular the width of the goaf would be important in determining the risk of an airblast occurring. *Controls* A primary control to prevent airblast is to minimise the plan area of a void thus minimising a fall of ground. It may be appropriate following a geotechnical assessment to induce a fall of ground and manage the fall. This may be appropriate in caving operations and could be achieved by increasing the area of the footprint. However, consideration should be given for additional controls to minimise the effects of an airblast if one did occur. *Planning and monitoring* ● The void plan area should not exceed engineering design specifications. If the risk is high of this happening due to geotechnical or other reasons, then a monitoring system should be in place. Cavity monitoring system (CMS) or survey pickups may facilitate the identification of over-breaks within a stope or mined out void. If an increase in the plan area is detected it may contribute to an uncontrolledfailure of ground and therefore an airblast. Further control measures may be considered to reduce this risk

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Geometry (cont.)	3. Height of void	*General* It would appear that the potential energy and therefore the magnitude of the consequence of an airblast increases proportionally with the height of the void. *Coal or tabular deposits* The height of an open goaf void, overlain by a massive stratum, would be important in assessing the consequence of an airblast should it occur. *Controls* A primary control is to leave blasted or fallen material in the mined-out area to reduce the height of the void to cushion or dissipate the energy from an airblast should it occur. If there is potential for the void height to increase in time, then a monitoring system could be set up to monitor changes in height. Planned responses could then be established when certain trigger points are reached that would minimise the risk of an airblast from occurring. A Trigger Action Response Plan (TARP) can be arranged in a table form to summarize this response plan, refer to Appendix I for an example. Planned responses to consider include: • initially more regular monitoring of the void height, • adopting a very strict draw control strategy, • increasing the stockpile of rock material below the void, • securing escape pathways, • establishing controls, such as safe havens and partly or fully restricting an airblast pathway. For details see Part B *Mitigating the potential effects of an airblast.*

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Geometry (cont.)	4. Shape of void opening and hydraulic radius	*General* Shape can influence the stability of a void. Hydraulic radius (area divided by perimeter) is a commonly used measure of the geometry of the undercut in caving operations. Both Laubscher'sStability Graph and the Extended Matthew's method use hydraulic radius of the undercut for determining whether a rock mass will cave. *Planning and controls* The stope shape design process should take into consideration the stability of all stope surfaces, not only the stability of the backs. Hanging wall and rib pillar failures in steep to moderately dipping orebodies should be considered. Empirical design methods may be used to determine the maximum stable hydraulic radius for each surface. The principal controls include: • mine design (taking into account the footprint shape and hydraulic radius), • variations in the draw of material below and • understanding the ground’s caveability through geotechnical data.
Geometry	5. Changes in geometry ofvoid	*Planning and monitoring* The potential for an airblast to occur increases if any unplanned over-break of ground occurs in any mined-out areas or stope. A geotechnical assessment should be carried out to determine the level of risk should any over-break occur. If considered necessary, monitoring of the void and surrounding ground may be required, which may then trigger the need for further control measures to minimise therisk of an airblast. See controls mentioned above under Part A, (1) Void, Geometry, 3. Height of void.

<u>Sub-element</u>	<u>Issues to be considered</u>	<u>Additional notes, controls, and monitoring</u>
Content	1. Gas Note: Coal Mines – the risk level significantly increases with the presence of flammable gases should an airblast occur	*Coal –General* An airblast in a coal mine will expel a mixture of methane, coal dust and air from the goaf. This expelled mixture may also raise deposited coal dust, in the active workings, into suspension. Ignitionof this gas and dust cloud is likely to result in a major explosion. *Coal – Controls* It is worth noting that in coal mines the lower explosive limit (LEL) for methane gas and suspended coal dust air cloud is lower than the LEL for separately. Therefore, serious consideration needsto be given to effectively ventilate the void area or goaf to eliminate explosive methane levels if the potential for an airblast develops. *Coal – Monitoring* Gas detection equipment may need to be installed to monitor for changes in methane levels. Further planning may be necessary to have the ability to provide additional ventilation to dilute air or to prevent gas from accumulating.
Content	2. Dust Note: Coal Mines – the risk significantly increaseswith the presence of flammable dust should an airblast occur	*Coal - Minimise risk with controls* In coal mines the real lower explosive limit (LEL) for methane gas and suspended coal dust air cloud is lower than the LEL for separately. Consideration needs to be given to the application of stonedust into the void or goaf area to reduce the coal dust explosion hazard.

PART A	ELEMENT	
	(2) A SOURCE OF POTENTIAL ENERGY	There needs to be a source of potential energy or "piston" for an airblast to occur. Rock or other material above or adjacent to a void has potential energy to fall. If this source of potential energy is minimised, then the risk of an airblast is also minimised. The followingissues may be considered when a source of potential energy that could contribute to an airblast occurring in an underground mine.
Sub-element	Issues to be considered	
Potential for instability of in-situ rock	1. Span	Additional notes, controls, and monitoring *Assessment, planning and design* It is generally accepted that larger spans expose a greater number of joints in a rock mass than smaller spans. Consider identifying dominant joint sets and controlling structures such as faults or geological contact zones. Stope designs may need modification or require additional ground support prior to mining and as part of the ongoing mining method. Empirical design methods may be used to estimate maximum stable spans and stand-up times. Detailed geotechnical assessment may be necessary to assist in estimating the ground's caveability with its hydraulic radius. Openings may then need to be carefully designed to minimise the risk of unplanned ground movement. A potential large scale massive failure would pose a greater risk than a progressive failure in sheared rock material. *Planning - Coal* In coal mines planning of the goaf width could be critical to ensure either: - 1. Caving will not occur, or 2. Regular systemic caving is controlled leaving limited goaf hang-up.

<u>Sub-element</u>	<u>Issues to be considered</u>	<u>Additional notes, controls, and monitoring</u>
Potential for instability of in-situ rock (cont.)	2. Shape	*Planning and design* The design shape may influence the stability of an open void. For example, arched stope backs may exhibit better stability than the equivalent span of a flat back. Consideration should be given to mining only inherently stable shapes following geotechnical assessment. Consider alternate stope designs and apply risk assessment principles to potential failure mechanisms.
Potential for instability of in-situ rock	3. Mass	*General* Consider induced stresses that could cause rock mass to shear. For example, an excavated stope may affect the stability of crown pillars. *Monitoring* Consider monitoring the loading in the backs or roof of the open void. And, if applicable, monitor the effects of static loading on bridge or crown pillars by the filling of stopes at levels above especially but also any adjacent stope. Recognise that arching can develop in a fill mass such that some of the vertical load is transferred to surrounding walls.
Potential for instability of in-situ rock	4. Height	*General* The higher the potential fall the greater the potential energy and its consequences even within a small area. For instance, an airblast could occur at a drawpoint ifthere is sufficient height and a plug or slab of material falls.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability of in-situ rock (cont.)	5. Proximity to the surface	*Coal and all other shallow mines* In coal mines and or other shallow mines at depths of 50m or less, a plug failure may occur in the strata above the goaf or stope to the surface, creating a risk of an airblast by a mass fall of ground in otherwise readily caving strata. Under these conditions the entire goaf area formed can suddenly collapse resulting in a massive airblast. The term 'suddenly' means with no practical warning. Experience has been that a goaf can collapse with no warning in less than two seconds. However, in 1999, a large plug failure occurred at Parkes (NSW) at about 110m from the surface in weaker layers of rock. When this plug failure occurred, it resulted in a massive airblast travelling through some of the underground workings. *Investigation* Rock masses close to surface can have varied properties due to weathering, oxidation, geological structure, and the presence of aquifers. A pre-strip as part of open pit development may be necessary. And this may provide an opportunityto investigate near-surface geotechnical conditions. Also, there may be the potential for migration of a stope through or into a crown pillar by unraveling of weathered zones in proximity to the surface. Exposure of the stope back in a rockmass with different engineering qualities to the design may potentially acceleratefailure as the rock mass conditions change. Monitoring may therefore be considered, and changes reviewed against the design criteria.
Potential for instability of in-situ rock	6. Proximity to other voids	*Planning and design* Consider design stoping sequences and the location of excavations in relation to other openings with a view to minimising ground stresses to the other openings. If for instance a pillar was designed between two open stopes, it can result in the creation of a very large void volume and span should the pillar collapse. This emphasizes the importance of adequate pillar design.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability ofin-situ rock (cont.)	7. Geotechnical conditions (a) General	*Investigation* Consider using appropriate site investigation techniques based on the topographical, geological, geotechnical, and hydro-geological conditions of the area and its surroundings. Also consider geophysical techniques being applied to investigate and understand the regional geology of the mine and its surroundings. Experience has shown that understanding the ground conditions and identifying changes can greatly assist in developing predictive methods. In particular, major geological structures need to be identified and taken into account. Other geotechnical information could include stress modelling and stress measurement. *Monitoring* Identifying and monitoring geotechnical conditions can provide systematic measurements and new knowledge regarding void changes and rock movement on various geological structures. Monitoring of changes can include the use of microseismic monitoring, extensometers, and open borehole plumbing.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability ofin-situ rock (cont.)	7. Geotechnical conditions (cont.) (b) Rock Mass Quality	*Investigation* Rock Mass Quality data may be used as a basis for empirical design of stable stopes or mined areas. Having accurate and extensive rock mass quality data can lead to enough understanding to be able to reduce the possibility of failure due to unidentified structures. As stated previously, rock masses close to the surface can have variable properties due to weathering, oxidation, geological structures, and the presence of aquifers. *General* According to Brown (2003:32-125), rock mass quality is primarily determined by (1) Geotechnical diamond drilling and core logging, and (2) Geotechnical exposure mapping of the rock mass. (1) Geotechnical diamond drilling and core logging. Consider the following: • Representative sampling of the rock mass conditions – minimum of 25% of all resource drilled meters being logged for geotechnical information. • Driller’s remuneration to include a component which is based on the percentage of core recovered and not just the metres drilled. • Multi-directional hole orientations. • Hole size being NQ triple tube core barrels or larger. • Holes surveyed with multi-shot equipment over the full depth of the hole. • Orientation of drill core using a suitable core orientation device with every core barrel run. • Prompt and detailed geotechnical logging of drill core in a dedicated core logging, layout, preparation, handling, and storage area.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring (cont.)
Potential for instability ofin-situ rock (cont.)	7. Geotechnical conditions (cont.) (b) Rock Mass Quality (cont.)	• All geotechnical cores being logged before any sampling or splitting isdone. • Selected geotechnical core kept intact with the complete hole length. • Sections of low strength core (e.g., high clay content) to be sealed to preserve in-situ conditions including moisture content immediately on recovery. • Colour photography of all drill core under controlled conditions. • Logging of core to follow discontinuity parameters, such as orientation, spacing, roughness, wall strength, filling, and number of sets. • All logging data is recorded promptly into a suitable geotechnical databaseusing appropriate manual or electronic techniques, recognizing the potential for data loss. • Full extent and location of core loss is to be represented in core trays. • Down hole rock mass permeability testing may be necessary in water bearing or highly broken ground. • Groundwater levels being monitored in “observation” bore holes. • Down hole geophysical methods are useful to determine discontinuity, such as orientation, spacing, aperture and filling.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring (cont.)
Potential for instability of in-situ rock (cont.)	7. Geotechnical conditions (cont.) (b) Rock Mass Quality (cont.)	(2) Geotechnical exposure mapping of the rock mass For both underground and open pit mines consider the following: • Mapping representative samples of the rock mass conditions. • Appropriate mix of spot mapping, scan line mapping and area mapping. • Recording coordinates of area being mapped. • Collecting discontinuity data; namely distance along tape, number of endpoints, discontinuity type, orientation, roughness, planarity, trace length and termination types. • All logging data is recorded promptly into a suitable geotechnical databaseusing appropriate manual or electronic techniques, recognizing the potential for data loss. Data gathered from geotechnical diamond drilling and exposure mapping can be used to establish an appropriately detailed three-dimensional model of the rock mass geotechnical and hydrogeological conditions. Data from the three-dimensional geotechnical model can be used as input for rock mass classification systems, etc. Appropriate rock mass classification systems can be applied. Techniques often used include RMR system, Q system and MRMR system as detailed in Brown (2003:100-116).

Sub-element	Issues to be considered	Additional notes, controls, and monitoring (cont.)
Potential for instability of in-situ rock	7. Geotechnical conditions (cont.) (b) Rock Mass Quality (cont.)	*Caving methods* Rock mass classification systems and undercut geometry can form the input to caveability assessment methods, sometimes referred to as “Laubscher’s caving chart” and “Mathew’s stability graph approach,” see Brown (2003:126-155). *Planning* Consider the orientation of stopes to main geological structures with a view to minimising the potential instability of any span. *Geotechnical assessment* Geotechnical data from a three-dimensional geotechnical model could be analysed using recognized analytical methods (possibly software) to determine

(cont.)	(c) Structures	geological structures, such as planes of weakness found in the rock mass. Variability of the rock mass geotechnical conditions, including geologicalstructure, is an inherent feature that needs to be quantified. Note: Rock mass classification schemes do not explicitly take into account the full range of geological structures found in the rock mass. Rock mass behaviouris usually controlled by geological structures in most mining environments, particularly low and moderate rock stress levels. The division of the rock mass into geotechnical domains of broadly similar characteristics may be useful. Domains may be based on geological structure, rock mass classification systemsor preferably a combination of both. Rock within a given geotechnical domain will generally exhibit similar behaviour, failure mechanisms, ground support requirements, etc.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability of in-situ rock (cont.)	7. Geotechnical conditions (cont.) (d) Pre-mining stress	*General* Consideration should be given to an adequate number of pre-mining rock stress measurements taken to estimate the rock stress field magnitude and orientation in three dimensions and the rate of stress increase with depth. Also consider various measurement techniques such as hydraulic fracturing and those based on acoustic emission. These offer the advantage of being able to remotely determine the rock stress field using bore holes and drill core, respectively. Over-coring techniques have been used for some time in the mining industry andare widely recognized as being able to provide reliable “point” estimates of the rock stress field in three dimensions. However, consideration should include several rock stress measurement techniques to ensure that there is sufficient independence in the results. Then consider interpreting results of rock stress measurements having regard for • the geology of the deposit, • its geological structure (including shear strength of discontinuities), • the physical properties of the rock mass (e.g., strength and deformability), and • The portion of rock measured is representative of rocks in the rock mass.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability of in-situ rock (cont.)	7. Geotechnical conditions (cont.) (e) Induced stress and regional stress	*General* Induced stress around openings is a complex issue and relating a modeled induced stress to the possibility of any rapid failure is inherently difficult. Induced stresses are created in the rock mass by the presence of excavations. The induced stress surrounding an excavation can be greater than or less than thepre-mining rock stress field. The combination of adversely oriented geological structure and induced rock stresses can result in failure of the rock mass, for example, by slip on geological structures. Regional stresses may be affected by the presence of large-scale geological structures that lie outside the immediate mine area. Regional scale mapping is required to gain a good understanding of the regional geological structures. Geophysical methods, such as seismic may be useful in determining large scale geological structures. Estimates of the rock stress field remote from the mine could be undertaken using hydraulic fracturing or methods based on acoustic emission.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring (cont.)
Potential for instability of in-situ rock (cont.)	7. Geotechnical conditions (cont.) (e) Induced stress and regional stress (cont.)	However, modelling changes to the rock stress field may identify areas prone to stress damage. Stress model results may be calibrated by physically measuring stress changes as mining occurs or by visual inspections of areas predicted to be prone to stress damage. Consideration should be given to calibrating models by conducting a back-analysis of any known failure events.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability of in-situ rock (cont.)	8. Potential for caveability	*Coal* The caveability of roof strata in coal mines is a critical issue. Further, airblasts have occurred from violent pillar failure. It is critical to design pillars either not to fail or to yield in a controlled manner. Whilst several airblasts have occurredas a result of pillar collapse most events have been associated with goaf caving events in longwall and pillar extraction panels. *Metal mines and pillar design* In metal mines an airblast is often associated with caving and sub-level caving operations. But an airblast has also been known to occur from crown or rib pillar failure with open stoping. Thus, pillar design and extraction sequence are critical for the prevention of an airblast from occurring. *Investigation and design* It is important to realize the huge variation in caveability properties between material that is solid, broken, finely fragmented, partially weathered, totally weathered, clay-rich or other types of material. The likelihood of uncontrolled failure resulting in an airblast may be a function of the ease with which the rock mass breaks up. Consideration should also be given to failure occurring due to dominant structures in the rock mass that couldresult in rapid plug failure.
Potential for instability of	9. Designed ground failure	If appropriate, consideration is given to planning and design, ground failure may be induced so that the fall of ground is managed safely. This induced failure may

in-situ rock		reduce the risk of an airblast occurring. Ground failures could be induced or controlled. Blasting or hydrofracturing to increase the base area have been usedto induce and control ground failures.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability ofin-situ rock (cont.)	10. Potential for ground failure which is notdesigned	*General* Consider the possibility of an airblast occurring as a result of rapid unravelling of strata or sudden mass failure due to unstable structures or lithology. *Investigation (modelling)* In mines where the possibility of an airblast is ongoing, wind gust models can be developed for various scenarios corresponding to various void heights and spans. Potential maximum velocities can then be determined should an airblast occur. *Monitoring using TARPs* Consider summarizing this monitoring process in a Trigger Action Response Plan (TARP) which would become a key component of a mine's safety management plan. A TARP system of risk management can be developed to continually evaluate and act on various levels of risk of an airblast. This involvescontrols to reduce the risk to an acceptable level and procedures to monitor the effectiveness and integrity of those controls. Experience has shown that a TARP document can be a very useful tool to regularly review the integrity of controls and help identify and act on early warning signs when the risk of an airblast is increasing. A TARP is a useful system to ensure actions are pre-planned and have been well thought through. The TARP's results and monitoring process could be reviewed on a regular basis by independent persons sourced internally and/or externally. This will ensure "group thinking" does not develop and issues are dealt with objectively and with good tangible reasons for any decisions made. *Review possible changed conditions* Consider examining scenarios for various changed conditions that may occur and then affect airblast controls could be reviewed. A trigger levels identified from monitoring could then be established to cover possible situations that have been identified and to maintain the integrity of those controls.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability of in-situ rock (cont.)	11. Status of mine openings	*Monitoring* Consider monitoring for early warning signs any large mine openings or openings that have a potential for wall(s) to be unstable and create larger openings. Monitoring the size of openings should be considered with open stopes and large excavations particularly if there are any geotechnical considerations that could lead to scale strata instability. An airblast could resultfrom such instability with any mine opening with such strata. *Block caving and sub-level caving* Monitoring is particularly important in block caving and sub-level caving operations to detect and monitor the creation of any void being formed in the mined-out areas. In these cases, if any void develops and enlarges further plannedmeasures should be considered to minimise the risk of an airblast. In such situations in caving operations consideration should be given to inducing caving to minimise such a void. Also consider using a TARP management system to determine planned responses at an early stage of the operation with an ongoing review process and monitoring results should changes be detected.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability of in-situ rock (cont.)	12. Trigger mechanisms (a) Blasting influences	An airblast could occur following blasting if particular circumstances exist. For example, in areas where blast vibration could induce a failure of the ground, the use of electronic 'icon' detonators to accurately control initiation sequences maybe appropriate. Particular consideration should be given to this possibility with mass blasts underground using programmable initiators. If there is a likelihood of induced failure, then changes in the blast design and method of initiation may assist in controlling the outcome. Experience has shown that investigating and then monitoring for this possibility has been critical in preventing an airblast from occurring.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability of in-situ rock (cont.)	12. Trigger mechanisms (cont.) (b) Seismic influences	*Monitoring* Consider microseismic monitoring as a tool for identifying seismic events. If microseismic monitoring is used then typically three predominant groups of events are recorded. They are: • events above mined out areas • footwall events, and • structural events Each group of events are recorded to provide: • distinct location, • timing and • seismic characteristics To clearly identify seismogenic zones a complete record of all events over magnitude –2 has been found to be generally appropriate. Seismic events cannotbe monitored at a sensor station if a void exists between the event and the sensor station. There is a need to monitor from different sides to get accurate measurements. Some mines have used a minimum of four sensor stations. Even though three are required to establish the location, a fourth sensor station gives management more confidence in the accuracy of the results. Also, microseismic monitoring has been found to be appropriate in monitoring pillar degradation and particularly if such instability has been ongoing.
	(c) Water accumulation influences	*Investigation* Consider rainfall events and the risk of sudden water inflow and/or the susceptibility of material to absorb water and becoming fluidised and create an unstable body of material. The use of a water balance model may assist in determining water inflows and outflows from a mine.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability of in-situ rock (cont.)	12. Trigger mechanisms (cont.) (d) The influence of changed ground conditions	*General* As a mine develops conditions will change. These conditions could be plannedor unplanned and could trigger a situation of unstable ground conditions. For example, a simple change in the shape of openings or a more gradual change of ground conditions in time, may all have an influence in increasing the risk of ground instability and the possibility of an airblast occurring. *Coal* In coal mines the most likely change is in the nature of the stratigraphy above the seam. In pillar extraction operations, a changing goaf width and/or coal left unmined in the goaf may increase the risk of an airblast. *Monitoring* If there is any possibility of conditions changing that could be critical, then monitoring should be considered. Also appropriately planned responses can beready to be implemented in a timely manner. This monitoring and their corresponding planned responses could be summarized in a TARP table (see Appendix I). *Examples* Changed conditions in the following could create the likelihood for an airblast to occur. (1) A cumulative effect of small failures could create potentially unstable spans. (2) A mine opening that could potentially create a large fall of ground may, with additional wall failures, affect the integrity of bulkheads, drives or even monitoring stations themselves.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability of in-situ rock (cont.)	13. Effectiveness of ground support	*General* The effectiveness and continued integrity of ground support is essential to maintaining control of potential instability of in situ rock. Some support can reduce its effectiveness over time. Therefore, a monitoring program of their continued effectiveness should be considered. *Monitoring* To ensure the integrity that ground support is maintained consider developing a plan to schedule regular reviews of ground control measures with observation, testing and evaluation. The scope of this should be defined in a ground support management plan that is specific to the mine. This plan may assist in identifying poorly installed ground support or other weaknesses in the ground support regime. Also, back analysis of failures may assist in identifying design criteria that should be modified or improved.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability of backfill material.	1. General	Consider referring to the *Handbook on Mine Fill* as a guide when using mine fill. Consideration should always be given to the possibility of mobilization of fill material if fill material is being used in a mine. Backfilling can create its own potential to produce an airblast if not managed and controlled effectively. Amongst other considerations the following issues are suggested: • The mined areas or stopes to be surveyed in three dimensions prior to filling to record their geometry. • The amount of fill material being placed in mined areas or stopes to be documented on a daily basis as filling takes place. • Monitor pulp density, adequate drainage, water balance, design pressure for bulkheads, water not ponding on top of fill, adequate fill pour and resttimes to ensure drainage • The engineering properties of the fill to be known. • The number of exposed fill surfaces to be known. • The height of the exposure of fill surfaces to be known. • Schedule backfilling to prioritize the filling of potentially unstable voids first as well as having a regard for secondary stope mining requirements. • Consider reviewing the backfilling schedule as further information is obtained. *Planning* The location of stopes and mined out areas can be important in relation to already filled stopes or stopes ready for fill placement. It is worth considering the possibility of various scenarios if fill material becomes mobilized and enters nearby mined out areas or stopes as well as any effect this scenario may have on surrounding ground stability. It is also worth considering the pathway of any likely airblast which may actuallybe different to the direction that mobilized fill may travel.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for instability of backfill material. (cont.)	2. Quality and moisture content of fill material	*Quality of fill* The quality of fill material being placed underground is of vital significance. If the fill material is of poor quality it could have little strength. Poor quality fill material includes weathered material, high clay content material, poor quality control or chemically reactive material. In general terms the strength and binder content of the fill material are the most critical in preventing failure that could lead to an airblast. Therefore, laboratory tests to determine the fill's physical properties and strength should be part of the mine fill management system. *Moisture content* Control of the moisture content within backfill material is also of vital significance in maintaining its stability. Further detail can be obtained from the*Handbook on Mine Fill*.
Potential for instability of backfill material.	3. Mass failure of fill	*Experience* Massive failure of fill material into adjacent voids has occurred which resulted in an airblast in the mine. This possibility should always be considered in a stoping risk assessment. However, the risk assessment should consider the possibility of a domino effect in that if there is a massive fill failure what is the possibility of a second failure of ground as a consequence, which could then also result in an airblast occurring.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for uncontrolled water flow	1. General	To understand and to control the potential for the inflow of water, it is generally worth considering as a minimum the following: • obtaining hydrological, hydrogeological as well as geotechnical reports, • studies on the potential for rapid inflow and ongoing inflow of ground water, and • the various monitoring systems available. It is good practice to be sure water is not channelled into mined out areas or potentially unsafe areas, such as stopes or the cave (in caving operations).
Potential for Uncontrolled water flow	2. Induced water flow	*Investigation* Before development openings are excavated consider: (1) if nearby voids have the potential to hold water. Nearby voids could include: • aquifers, • old workings, • drill holes, • stopes, and • water drainage into stopes via intersecting drill holes (2) the existence of any surface infrastructure or natural features such as dams, lakes, or rivers. Consider estimating water inflow rates from aquifers using a researched groundwater model and appropriate numerical model. *Monitoring* Consider monitoring for controlling induced water flow by using: • dewatering boreholes, • piezometers, • diversion or relocation of flow.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Potential for uncontrolled water flow (cont.)	3. Mudflows	*General* There is a real potential for a mudflow if a mine has stopes being filled with hydraulic fill material or a mine uses a caving method of mining. The risk of a mudflow greatly increases if the material within these stopes or caved areas become saturated. Water should be channelled so that it does not enter a stope orcave and creates a potential for mudflow to occur. For a mudflow to occur it generally requires a trigger to set it off such as a blastor when loading material both of which disturb the moist material enough to cause it to flow. *Caving mines* In caving mines hydrological studies have been completed to determine: ● the size of particles within the material in the cave area, ● the cave material's absorbent qualities, and ● the cave material's susceptibility to flow. Once hydrological studies have been completed a monitoring program can be developed with trigger values and planned responses. This could be tabled in a TARP document to continually manage and control the level of risk of a mudflow.

	ELEMENT	
PART A	(3) OPENINGS INTO A VOID FROMTHE MINE	There needs to be at least one opening into a void which may be thesource of an airblast to create the possibility of a pathway for an airblast to affect a mine. That is, an airblast through a mine wouldnot occur: ● If there are no openings connecting a void which may be a sourceof an airblast, or ● If there is sufficient distance of solid ground from such a void tothe mine so that any potential over-break of ground cannot thenconnect the void to the mine.
Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Planned openings connecting a void to the mine	1. Number of openings	*Mine planning* When planning a mine consider minimising the number of mine openings thatmay connect a mined-out area or a potentially large void with the rest of the mine. *Preliminary bulk sampling* If bulk sampling of an orebody is to be carried out, then there is a need to carefully consider its location in relation to the long term mine design so that the potential risk of an airblast is taken into account. The worst case would be to locate it with the highest potential energy situated above it with a potential for an airblast. If block or sub-level caving is being considered, then consider planning the location of the bulk sample so that there will be no way it will create a connection of the cave with the rest of the mine for the full duration ofthe mine’s life.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring (cont.)
Planned openings connecting a void to the mine (cont.)	1. Number of openings (cont.)	A bulk sample could be taken in a location which would not connect a void to the rest of the mine. This could be a location where future development is likely to be positioned, such as where a drill drive or extraction level will exist.
Planned openings connecting a void to the mine	2. Location of openings	*Mine planning* Planning should consider minimising the risk of a potential airblast at all phases of mining. Consider the location of openings so that any potential airblast is not going to enter the rest of the mine workings. Then if an airblast should occur its pathway will simply go to unmanned areas of the mine such as ventilation shafts or other areas where persons are not located. Planning could also consider the proximity of mine workings to any potentially large mined out area or possible void. If, for instance over-breaking of ground occurred in a mined area then the resulting large void could inadvertently connect the void to the rest of the mine and an airblast could then potentially travel through the mine. If there is a possibility of a potential airblast then further consideration could be given to planning safe havens, remote loading areas and locations along drives for engineered bulkheads or stoppings.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Planned openings connecting a void to the mine (cont.)	3. Cross-sectional area of openings	*General* The larger the cross-sectional area of openings or drives the easier an airblast will travel through those drives. Conversely, the smaller the cross-sectional area of drives the more pressure that is built up and the higher the velocity of airflow. By reducing the cross-sectional area of some drives and an airblast goes through then the air pressure will increase. But beyond that point the pressure will drop, and the velocity of air reduces, and the energy is dissipated. Other practical measures to mitigate the effects of an airblast with respect to different cross-sectional areas, refer to *Part B Mitigating the potential effects of an airblast Element 5. Control of airblast pathways*.
Planned openings connecting a void to the mine	4. Path of least resistance and concentration effect	*General* If there is a potential source for an airblast then consider the pathways of least resistance through the mine that an airblast may follow to vent to the atmosphere. Return airways are likely paths as they offer negative pressure. Also, it is worth considering the potential air velocities taking into account the cross-sectional areas of the drives and the airblast could concentrate through certain sized openings. Again, planning for stoppings or bulkheads may be considered. *Coal* In coal mines, longwall maingate and tailgate roads represent a high potential exit path for airblast. These roads are likely to contain workers and have critical infrastructure.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Unplanned openings connecting a void to the mine	Proximity of mine workings to a void	*General* The proximity of mine workings to a void which has a potentially unstable back (or roof) can be a significant factor in increasing the risk of an airblast to potentially pass through the mine. Considerations may include: • proximity of openings to a void or to regional openings • interaction of ground stress between mine openings and the void • instability or potential failure of ground in the openings and the void • ground conditions that may change as further openings are excavated • proximity of old workings • ore-passes that may have been worn to a larger area or have the potential to be worn away and become unstable • stability of bulkheads if an unstable void is nearby or has the potential to increase in volume • instability of fill if fill material is being used. *Planning* Consider during the mine planning phase the separation distances of openings into a void or potential voids that may create an unplanned connection. Other considerations include: • the number of openings • the location of openings • the size of openings • the cross-sectional area of openings • the path of least resistance should an airblast occur.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring (cont.)
Unplanned openings connecting a void to the mine (cont.)	Proximity of mine workings to a void (cont.)	• any concentrated effect along its pathway should an airblast occur • location of bulkheads and their design and specifications • access to a void • potential connections to the surface • old plans and what has been done historically that could affect planning. One cannot always rely on existing data. Experience has shown to be so. *Monitoring* Consider a regular review of the proximity of openings to a void and the suitability of bulkheads as mining progresses. Take into account potential changes in ground conditions and how this may impact on the potential risk ofan airblast occurring or affect the capability of bulkheads to remain functional.Consider monitoring the rock noise and movement by using microseismic monitoring, extensometers, depth plumbing via drill holes and visible inspections.

PART B	ELEMENT MITIGATING THE POTENTIALEFFECTS OF AN AIRBLAST	**The following examines various situations and issues in the case whenthere is a potential risk of exposure of persons and/or infrastructure to a potential airblast.**
Sub-element Planning and monitoring	Issues to be considered 1. Zones of influence of a potential airblast	Additional notes, controls, and monitoring *General* Identify zones of influence of a potential airblast which could affect personnel and/or infrastructure. *Investigation* Consider investigating and determining the potential pathways, air velocity and secondary effects (debris becoming airborne) in the vicinity of persons or infrastructure should an airblast occur. Velocities of up to 15m / sec. have been accepted by the coal industry as a minimum threshold above which an airblast is likely to have a marked effect on either persons or infrastructure.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring (cont.)

Planning and monitoring (cont.)	1. Zones of influence of a potential airblast(cont.)	*Mine design and planning*
		If there is any potential for an airblast to occur, consider the:
		• pathways of a potential airblast.
		• areas of highest resistance and therefore potentially highest velocity. However, this could be deliberately planned to reduce resistance beyond that point to help dissipate an airblast's energy.
		• location and impact of potential airblasts on:
		  ◦ areas where people have access,
		  ◦ the surface should a collapse of ground occur due to a breakthroughto the surface. A surface exclusion zone could be considered.
		  ◦ the ingress and egress drives and the effects on egress from the mine should it be blocked after an airblast has occurred,
		  ◦ effects on ventilation fans, and
		  ◦ all other infrastructure
		• there is sufficient distance between drives and mined out areas that could become a potential source for an airblast. This distance may allow for establishing safe havens and/or stockpile locations for rock material to be stored and/or bulkheads to restrict or stop the flow of air should an airblast occur.
		• suitable locations for seismic and/or other monitoring provisions to gather accurate data on any changed conditions that may occur and increase the risk of an airblast occurring.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring (cont.)
Planning and monitoring (cont.)	2. Restricting access	*Investigation* When reviewing access ways when there is a potential for an airblast, considerthe following • develop an airblast model and predicted pathways and any associated issues that may occur if an airblast did occur • restrict access to certain areas where the risk is too great • place rock material (either permanently or temporarily) as well as bulkheads between where the potential airblast source exists and where people are likely to be located. Even a temporary barrier of rock could greatly restrict the flow of air should an airblast occur or if the risk of one has increased to an unacceptable level. *Monitoring* Regularly monitor any changes in ground stability and review restricted access areas if results indicate the risk has changed. Consider adding this issue to a TARP management system so there are regular and systematic reviews carried out.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Planning and monitoring (cont.)	3. Provision of safe havens	*General* Establish safe havens so that personnel can escape to a safe location if the risk of an airblast appears imminent. However, often there can be no warning. Also securing safe access to areas of the mine and egress out of the mine need to be considered if they could be affected by an airblast. Experience from airblasts has indicated that if persons go into a nearby dead-end crosscut (or dead-end heading) then they would be kept safe from the effects of an airblast should one occur. The pathway of an airblast would not flow through a dead end crosscut. *Procedures and training* Procedures should be developed for people to follow should an airblast appearto be potentially imminent. This should include communication with mine control. Protocols should be developed, and training of personnel should be given on procedures to follow if the potential for an airblast appears to becomeimminent. *Monitoring by personnel* A procedure for people to go to a safe haven would not be practical unless there is sufficient warning so that people can get to a safe haven in time. Thesewarnings could be from people being aware of severe ground vibration or constant noise. These warnings may be coming from the initial breaking up of large blocks of ground. An alarm system also may be installed near potential airblast sources using geophones or seismic monitoring systems.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Planning and monitoring (cont.)	4. Location of contaminants Note: In coal mines – the risk level can significantly increase with the presence of flammable dust and gases	*Coal* In coal mines airblast excursion distances have been measured to be hundreds of metres from the source of the airblast. Areas which are generally considered outside the Hazardous Zone (HZ) can be inundated with explosive atmospheres.It should be remembered that electrical equipment in non HZ's may not be protected from an explosion nor be regarded as intrinsically safe. The risk of anexplosion can increase should an airblast occur in a coal mine.
Planning and monitoring	5. Control of airblast pathways	*Planning and control* Consider planning a separate pathway where persons would not be located should there be a potential for an airblast to occur. An airblast would follow thepathway of least resistance and this pathway may take most of the airblast flow.Planning considerations could take this into account for the worst-case scenario if there is a risk of an airblast occurring. Consider planning drives with larger cross-sectional area to take an airblast away from where personnel or infrastructure are located. *Control* Broken rock material may be placed in drives between the source of an airblast and the mine to minimise the cross-sectional area of the drives. A series of broken rock placed along drives can progressively de-energise an airblast as it passes over the series of rock piles and no piles and then further rock piles. Enough material strategically placed within particular drives can greatly reduce the velocity and the energy as an airblast travels before it continues its pathwayto the rest of the mine where people or infrastructure are located. These temporary series of rock piles could greatly mitigate the effects of an airblast.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring (cont.)
Planning and monitoring (cont.)	5. Control of airblast pathways (cont.)	However, important considerations would be to ensure that there is sufficient volume and size of material and consider its porosity and permeability so that the rock or material restricts airflow as planned and does not travel with an airblastthrough the mine. This may require establishing additional drives so that it ispossible to place temporary stoppings in appropriate locations. *Monitoring* Consider monitoring for changes in conditions that may indicate the risk of an airblast has increased. Then establish a trigger measure that would bring about actions such as the control measure above.
Planning and monitoring	6. Plan for monitoring the risk of exposure to a possible airblast	*General* Consider monitoring the risk of exposure of an airblast to people and infrastructure by using a TARP. This is a management system to manage and review all monitoring of any changed conditions, the effectiveness of controls and planned responses to any changes in the risk of exposure to an airblast. See*Appendix 1* for an example of a TARP, and Part A *Source of Potential Energy, Potential for instability of in situ rock, Potential for ground failure which is notdesigned.*

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Mitigating the effects of a possible airblast in existing mines	1. Control airflow	*General* Consider controlling airflow by: • restricting the airflow of a potential airblast by placing sufficient volumeof broken rock along drives. • determining the porosity and permeability of broken rock to an airblast if this is acting as a barrier. • erecting engineered bulkheads in drives to stop an airblast airflow completely. *Bulkheads (or Stoppings) design* There is no generally recognized design for bulkheads. However structural engineering considerations are recommended. Each bulkhead should be assessedfor its capacity to withstand an airblast on a case-by-case basis. However, the design may consider: • potential velocities of air and rock material, • pore pressure on the bulkhead, • bulkhead dimensions, • bulkhead load capacity, • material properties, • three-dimensional numerical stress analysis, • V or arched shape with the apex facing the potential airblast source, • located in a drive with minimal cross-sectional area, • located in solid ground free from major planes of weakness, and • construction practicalities of the bulkhead design

Sub-element	Issues to be considered	Additional notes, controls, and monitoring (cont.)
Mitigating the effects of a possible airblast in existing mines (cont.)	1. Control airflow (cont.)	*Planning* The objective may not necessarily be to totally withstand an airblast. But it couldbe designed to redirect airflow or even to fail at a certain point. And then there may be additional means to de-energise an airblast after that point by placing material placed along drives to continue the de-energising process. *Fill behind the bulkhead* If fill material is to be used behind the bulkhead consideration should be given to design considerations that affect the stability of the fill material also. Reference could be made to the *Handbook on Mine Fill*. Also, see additional considerations regarding fill behind a bulkhead in Part A (2) Potential Energy Source, Element 'Potential for instability when backfilling'. *Experience* Experience has led to one site designing a bulkhead to 770kPa ultimate pressure capacity after research had shown that airblast pressures in that mine could reach 500kPa in the worst-case scenario. This design included using four layers of eleven solid 27 mm rebar rockbolts extending into the walls as well as into a shotcrete filled bulkhead with reinforcing mesh which is V shaped with the apexof the V facing the airblast source. Two pipes were placed through the bulkhead at the base to allow water to drain.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Mitigating the effects of a possible airblast in existing mines (cont.)	2. Debris and housekeeping	*General* Consider secondary impacts of an airblast. Material may get picked up by an airblast which could then impact on persons or infrastructure if an airblast occurs.Consider where electrical installations, fans, vent tubing, ducting, pipes, and other infrastructure is located to minimise this risk. Explosion doors could be installedon main fan cowlings to vent the blast and take the forces away from the fan itself. General housekeeping and the selection of appropriate locations for infrastructure may also reduce the potential risk of secondary impacts.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring
Mitigating the effects of a possible airblast in existing mines (cont.)	3. Develop an airblast model	Consider developing an airblast model to determine potential pressures and velocities if there is a potential for an airblast to occur. *Wind velocities* Logan (2004) suggests that there are limited international guidelines available to define tolerable wind velocities. Most meteorological scales are not applicable as they measure gust velocities 10m above the ground. However, Logan (2004) states that the Saffir-Simpson Hurricane scale is one that may be more applicableas it measures velocities at ground level. This classification is supported by the Australian Coal Association Research Program (ACARP) work which indicates that laceration injuries of uncovered skin would occur for wind velocities exceeding 15 m/s with projectiles weighing 10 grams or less. Logan also suggests that a theoretical formula and parameters can be established for determining wind velocities in a model. The parameters will however vary for each mine site. He states that a credible peak wind velocity due to air inrush is a function of several key variables, such as: • the expansion void, • the thickness and permeability of broken rock if wind passes through a broken rock, • the number of exit pathways, and • measurement errors can occur because interpretations and estimations have to be made. Wind velocities can be assessed from overpressures using air flow principles.A model can be developed using a “leaky piston” model to assess the overpressure.

Sub-element	Issues to be considered	Additional notes, controls, and monitoring (cont.)
		This overpressure could be modelled for a range of air gap heights, broken rock heights, and broken rock fragmentation types following a collapse of ground. Principal unknowns include the degree to which a fall of rock breaks up, vertical height of fall, the plan area of the fall and the air flow resistance of the connected openings. Several assumptions must be made, such as the fall is uniform. Calculated overpressures applying to different broken rock resistances (if it passes through such broken rock) to enable calculations to be made of variousflow rates. Wind velocities can be assessed for a series of voids or air gaps and broken rock heights for different rock porosities. *Charts* According to Logan (2004) a series of charts can then be developed in the modelto form a nomogram that links the void height to variable broken rock heights togive separate wind velocity assessments through a single exit tunnel. The nomogram can also show reduced wind velocities for multiple exit paths. Separate nomograms can be produced for different broken rock fragmentations and permeabilities.