Recognised Standard 24

Spontaneous combustion management in underground coal mines

Resources Safety and Health Queensland

Coal Mining Safety and Health Act 1999

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Recognised standards

This document is issued in accordance with PART 5—RECOGNISED STANDARDS and Section 37(3) of the *Coal Mining Safety and Health Act 1999*.

PART 5 - RECOGNISED STANDARDS

71 Purpose of recognised standards

A standard may be made for safety and health (a “recognised standard”) stating ways to achieve an acceptable level of risk to persons arising out of coal mining operations.

72 Recognised standards

(1) The Minister may make recognised standards.

(2) The Minister must notify the making of a recognised standard by gazette notice.

(3) The CEO must publish on a Queensland government website each recognised standard and any document applied, adopted or incorporated by the standard.

(4) In this section—

Queensland government website means a website with a URL that contains ‘qld.gov.au’, other than the website of a local government

73 Use of recognised standards in proceedings

A recognised standard is admissible in evidence in a proceeding if—

(a) the proceeding relates to a contravention of a safety and health obligation imposed on a person under part 3; and

(b) it is claimed that the person contravened the obligation by failing to achieve an acceptable level of risk; and

(c) the recognised standard is about achieving an acceptable level of risk.

PART 3 - SAFETY AND HEALTH OBLIGATIONS

37 How obligation can be discharged if regulation or recognised standard made

(3) …. if a recognised standard states a way or ways of achieving an acceptable level of risk, a person discharges the person’s safety and health obligation in relation to the risk only by—

(a) adopting and following a stated way; or

(b) adopting and following another way that achieves a level of risk that is equal to or better than the acceptable level.

Where a part of a recognised standard or other normative document referred to therein conflicts with the *Coal Mining Safety and Health Act 1999* or the Coal Mining Safety and Health Regulation 2017, the Act or Regulation takes precedence.

This recognised standard is issued under the authority of the Minister for Resources.

[Gazetted dd month year]

Contents

1 Purpose

The purpose of this recognised standard is to state ways for persons involved in underground coal mining operations to meet their safety and health obligations in relation to preparing and planning for mining (prevention), monitoring for and controlling risks associated with spontaneous combustion events in underground coal mines, to ensure risk to Coal Mine Workers (CMWs) is managed to an acceptable level.

2 Scope

This Recognised Standard applies to all underground coal mines in Queensland. All underground coal mines are subject to the risk of spontaneous combustion. The likelihood will vary from mine to mine.

All mines are required to have a Principal Hazard Management Plan (PHMP) for spontaneous combustion. The mine's PHMP must identify, analyse and assess risk associated with the principal hazard of spontaneous combustion and include standard operating procedures and other measures to control risk.

This standard prescribes ways in which an acceptable level of risk can be achieved with reference to:

- the planning and preparation, monitoring for and controlling risks associated with spontaneous combustion for underground mining activities;
- the development, implementation and review of the Spontaneous Combustion PHMP, including the development and implementation of effective standard operating procedures and control measures for spontaneous combustion events.

Technical references should be used to supplement this standard and inform risk management. This document establishes the minimum standards for the planning and preparation, monitoring, and control of spontaneous combustion in an underground coal mine and is not intended as a technical guide. A list of documents referred to in this standard and other useful material for developing a Spontaneous Combustion PHMP, guide of some reference material available at the time of writing this standard is contained in Appendix 2.

3 Definitions

Consider – Defined, documented, evaluated, and assessed.

Spontaneous Combustion is the process by which materials self-heat due to environmental conditions. This process arises due to reactions of oxygen with the material producing heat faster than it can be lost to the environment. In this document, spontaneous combustion refers to various stages of the self-heating of coal, other carbonaceous or pyritic material.

Spontaneous Combustion Risk is the set of risks to people and/or asset which may arise from spontaneous combustion where the rate of oxidation is, or is likely to, be increasing in an uncontrolled manner and result in a rapid temperature increase.

> **Note: Fire (e.g. open flame, amber coal, hot coals, smoke) or ignition of explosive gases may result from an uncontrolled spontaneous combustion.**

Increased Oxidation is an increased rate of oxidation (cause of concern event) of the coal which may lead to a heating.

> **Note: All coals react with oxygen. This is the normal oxidation process. As mining conditions have changed due to increased virgin rock temperature, gas drainage removing moisture from the coal, more coal left in the goaf, the normal/stable position of the mine readings on the oxidation curve may be higher than on previous mining areas. It is important that underground coal mines detect the change from normal and investigate the causes.**

Heating refers to a situation where the oxidation rate is increasing in a self-sustaining manner. It may also refer to an event where the temperature of the coal is substantially elevated from ambient conditions. In the context of spontaneous combustion this is due to an increase in the rate of oxidation leading to the self-heating of the coal and may become an ignition source or mine fire.

Source of Ignition refers to a heating that has progressed to the point it has the potential to ignite an explosive mixture of gases or cause a mine fire.

Ventilation Change is any change to the ventilation system, including for the purpose of gas management, that alters ventilation flows, directions and pressures, including changes to the goaf drainage system.

Critical Controls are controls crucial to preventing the event or mitigating the consequences of a spontaneous combustion event. In addition, a control that prevents one or more unwanted event, or mitigates more than one consequence is normally classified as critical. Must be determined by the Site Senior Executive (SSE) and detailed in the Spontaneous Combustion PHMP.

4 Principal Hazard Management Plan

The SSE must develop a Spontaneous Combustion PHMP through a risk management process, considering this Recognised Standard. The Spontaneous Combustion PHMP must contain critical controls for monitoring and control, for the prevention of spontaneous combustion, that are approved by the Ventilation Officer (VO) and the Underground Mine Manager (UMM).

The SSE must define the owner of the Spontaneous Combustion PHMP.

The mine shall have in place, systems and resources for the timely collection of appropriate information related to spontaneous combustion risk, prior to facilitating the spontaneous combustion risk assessment.

5 Critical Controls

Every underground coal mine must have critical controls for spontaneous combustion management. Whilst every mine will have its own unique circumstances to manage, the following critical controls must always be considered:

- Pre-drainage of working and adjacent seams impacts simultaneously, gas and spontaneous combustion risk, reducing oxygen from post-drainage.
- The ventilation system is designed and maintained to incorporate spontaneous combustion reduction principles, including Ventilation Control Devices (VCDs).
- Design and implementation of the gas sampling, analysis and monitoring system to detect increased oxidation, heatings and sources of ignition.
- Inertisation (including flooding) of active goaf and unsealed goaf areas that cannot be inspected or continually monitored to reduce oxygen levels to 5% or below, to reduce the risk of spontaneous combustion.
- Stowage underground and broken coal/spillage is managed to minimise the risk of spontaneous combustion.
- The use of polymeric chemicals and other cementitious grouts are risk assessed to consider the risk of spontaneous combustion and effective controls are implemented.
- Spontaneous Combustion Trigger Action Response Plan (TARP) identifies triggers for safe withdrawal of persons from the mine and action to take for spontaneous combustion response.
- Effective remote monitoring and sealing capability is established from the surface (a place of safety) to allow timely sealing and effective monitoring post a withdrawal. This preparation will allow for rapid sealing, sufficient data and re-entry processes to facilitate a re-entry avoiding a potential reluctance to withdraw personnel to a place of safety.

6 Risk Assessment

The risk assessment team should include workforce representation and external person(s), with ventilation engineering experience, experience in spontaneous combustion management with relevant industry experience and competency. The risk assessment should include the preparation, planning, monitoring and control of spontaneous combustion. The VO and UMM should be active participants in the risk assessment. Information to be considered in the risk assessment must include, but not be limited, to the following:

6.1 Preparation and planning

6.1.1 Characterisation

- Evaluating the spontaneous combustion related history of both the mine and any adjacent mines or prior operations in the same seams and/or coal measures.
- Natural and mining specific factors must be considered. Factors to consider include, but are not limited, to the following:
  - Coal quality and variations including pyrites.
  - Geology.
  - Geological structures.
  - Caving characteristics.
  - Roof coal that ends up in goaf.
  - Multiple seam extraction.
  - Overlaying and underlaying seams.
  - Geothermal gradient and working depth.
  - Faulting/Dykes - geological structures.
  - Proposed working methods.
  - Mine ventilation system pressures.
  - Mine cooling systems used.
  - Ambient temperatures.
  - External heat sources including polymeric chemicals, explosives, and friction.
- Evaluating propensity testing in locations relevant to current and proposed workings. Test the relevant sections of the seam for spontaneous combustion propensity.

Note: Propensity testing should not be solely relied upon as it is of limited value. History is more representative as several factors can influence propensity.

- Evaluate gas evolution. Testing in locations relevant to current and proposed workings. Identify the relevant sections of the seam and conduct testing. Gas evolution results, whilst they provide useful information and describe the sequence of gas release, should not be solely relied upon for setting TARP values as temperature of release may vary between testing and real incidents.

Note: Gas evolution testing should not be relied solely upon for setting TARPs. History is more representative as several factors can influence gas levels observed from real events.

- Many seams that test low propensity to spontaneously combust have a history of spontaneous combustion, such as the Goonyella Middle Seam. History is more representative of a coal seam to spontaneously combust.

6.1.2 Mine design

Mine design factors to consider must include, but are not limited to, the following:

- Adequate and appropriate resources (system, people, and infrastructure) to establish and support the mine design.
- The mine operator must ensure adequate and timely pre-drainage of all relevant seams as a primary gas management control to reach the target (m3/t) to be specified in the Spontaneous Combustion PHMP. Demonstrated effective pre-drainage reduces the reliance on post-drainage and ventilation engineering dilution controls, thereby reducing the ventilation velocities and pressure differentials which impacts on oxidation and spontaneous combustion. Inadequate pre-drainage of working, lower and upper seams would later contribute to the gas management and impacting spontaneous combustion risks.

Note: Pre drainage will reduce the water content in the drained coal seam; this must be considered in managing spontaneous combustion risks.

- Mine design, sequencing and scheduling should avoid overloading sections of the ventilation system. Any change to the ventilation design that increases the spontaneous combustion risk, such as the delaying or cancelling of ventilation shafts or new access drifts, must trigger a review of the Safety and Health Management System, including change management, and a potential review of the Spontaneous Combustion PHMP.
- Major ventilation changes, as defined in the Ventilation PHMP, must consider the impact on spontaneous combustion risk and include a review of its impact on high-risk areas of the mine.
- The number of main roadways intake and return roadways should be considered. A reduced number of roadways will impact on air velocities and ventilation system pressure and must trigger a review of the spontaneous combustion risk.
- Potential areas of fluctuating pressures and resulting lower velocities, created by multiple shafts.
- The UMM must review any increase to the width of the longwall. The width impacts on geological conditions that reduces retreat rates and increases potential for stoppages. It also increases the pressure differential across the longwall face and increase the gas reservoir which increases goaf well drainage and the risk of spontaneous combustion within the goaf. Any changes to the longwall width must trigger an impact assessment and additional controls to ensure the spontaneous combustion risk is as low as reasonably achievable.
- Ventilation arrangements for longwall companion roadways, particularly where shafts are used whether upcast or down cast and the resultant pressure differentials applied to the maingate seals.
- Oxygen ingress via maingate must be controlled.
- Pillar size and potential for pillar fracture and spall.
- The mine must have a documented mine plan change procedure which assesses the impact of mine design changes on the spontaneous combustion risk. This documented change procedure must include corporate office driven change.
- Operator driven change must involve all relevant stakeholders in mine design changes to ensure the risk remains at an acceptable level.
- The mine design (including gas drainage designs) must consider minimising potential sources for oxygen ingress such as design barrier pillars, assessment of caving subsidence and borehole leakage paths.
- The mine design should consider leaving a barrier pillar between groups of panels that would improve gas management as well as minimising oxidation risks.

6.1.3 Operations

Mine operational factors to consider must include, but are not limited to, the following:

- Rate of retreat and spontaneous combustion controls during planned and unplanned stoppages.
  - Slow retreat, stoppage, or shutdown/breakdown on an active longwall face.
  - Minimising air ingress into the goaf in the maingate.
  - Strata - Managing goaf hang up and falls (flush).
  - Longwall seal (temporary) to be installed immediately.
  - Longwall seal (permanent) completed prior to the next cut through.

Note: Exception when managing windblast at panel start up.

- Avoid the stowage of carbonaceous material underground.
- Ventilation leakage, created by pressure differential (intake to return air circuit) increases the risk of spontaneous combustion. Increased inspections and monitoring must be conducted in these areas.
- Geotechnical conditions (e.g. faulting / mining direction and gradient / potential for flooding).
- Strata control methodologies.
- Impact of first goafing, barrier pillars and goaf flush.
- Evaluating external information including review of other's experience, regular review of available information, and regular review of emerging technology.

6.1.4 Supporting Procedures

The SSE must develop, document, and implement procedures to support the Spontaneous Combustion PHMP. Procedures must be backed by risk assessment and include a cross section of affected workers and content experts. Procedures must include the following:

Stowage Management

- In the first instance, take every reasonable step to avoid stowage of carbonaceous material underground.
- If stowage cannot be avoided, develop a stowage management procedure that covers:
  - A maximum time for stowage.
  - Each stowage location has a permit to authorise stowage.
  - Design of stowage, height and size, material, position.
  - Stowage rules and permits and adherence to these.
    - Consideration of Job Safety Analysis including location of high-tension cables, communication cables, services, stoppings, seals.
  - Stowage mapped/surveyed and included on the mine plan.
  - Stone dusting/use of capping material for temporary stowage.
  - Stowage inspection and confirmed removal.
  - Monitoring and inspection of stowage.
  - Actions for removal to be entered into the mines action database.

Pillar Design and Spall Management

- Pillar design and design compliance.
- Mine design variations must flag a review of the Strata Control PHMP.
- First goaf – weighting on barrier pillars.
- Age of pillars/spall.
- Managing pillar spall.
- Fractures in pillars post shot-firing.

Other Coal Spillage

- Managing coffin seal spillage.
- Preventing and managing belt spillage.
- Removal of fines build up.
- Spontaneous combustion or fire must be considered if battery operated plant and equipment is stored or used underground.

Note: Belt shavings have been identified as spillage that can be a source for spontaneous combustion.

Sealed areas

- Seal standards & maintenance:
    - Sealing to be completed as soon as practicable.
    - VCDs – surrounding strata, certified, follow design criteria, maintenance.
    - Protection of seals – strata, stowage, vehicles, water ingress and damage.
- Leakage paths into sealed and other areas:
    - Air pathways into sealed underground workings to be eliminated.
    - Sealing of boreholes/goaf well/shafts and leakage around.
    - Borehole intersection practices/design of boreholes relative to workings.
    - Multiple seam interaction.
    - Subsidence causing an airpath into a sealed area.

Ventilation and pressure

- The following must be included in the Ventilation PHMP and supporting procedures to minimise spontaneous combustion risk:
    - Ventilation and ventilation pressure design, monitoring and management.
        - Design, operate and maintain the ventilation system.
        - Manage ingress of air in the goaf. Air wash zones.
        - Maintain gas concentrations outside of flammable and explosive limits.
        - Ventilation pressure design.
        - Areas of higher-pressure differentials.
        - Pressure balancing of ventilation circuit where appropriate.
        - If booster fans are used, the risk of spontaneous combustion needs to be considered.
        - Ventilation pressure design and regulator location.
        - Auxiliary fan installations, especially when ventilating through VCDs, creating higher pressure and air paths.

Note: Highwall fan installations. High pressure and potential opencut highwall blast cracks creating air paths.

Note: Maingate back regulator – gas regulator for managing methane – this introduces a serious risk to spontaneous combustion.

Note: Any ventilation changes (e.g accessibility to tailgate), including to manage gas in an active longwall and goaf drainage changes, which impacts the oxygen content in the goaf, must consider an increase in spontaneous combustion risk and monitoring.

Gas drainage

- The essentials of pre-drainage for spontaneous combustion risk management must be considered:
    - Pre-drainage, through Surface In Seam (SIS) and Underground In Seam (UIS) holes, reduces gas content prior to and during mining and is a proactive preventative gas management control. Lower gas content leads to reduced post-drainage and a reduced risk of oxygen ingress into areas being post-drained. This

results in a reduced risk of spontaneous combustion.

Note: Less than adequate pre-drainage leads to higher volumes of post-drainage during production and increases the risk of spontaneous combustion.

- Operations must consider oxygen content in the goaf when implementing post-drainage.
  - Leakage through surrounding structure due to negative pressure.
  - Monitoring gas in gas drainage wells. Minimise oxygen in goaf by managing goaf well drainage.
  - Oxygen concentration level in the goaf hole flow must be less than 5% in goaf holes beyond 100 metres from the face line to reduce spontaneous combustion risk in the longwall goafs. Individual goaf wells are to be continuously monitored for oxygen levels and accumulated gas make by real-time monitors for trending purposes.
  - Design, specification, operation and changes to the goaf drainage system (including automated systems) to be authorised and countersigned by the VO and the UMM.

Note: No changes to goaf drainage systems without the authorisation of the VO. Changes to be treated the same as a ventilation change. Ventilation changes should be avoided during an oxidation event.

7 Gas Monitoring

An underground coal mine must develop, document, and implement procedures that support the gas and physical indicator control mechanisms associated with monitoring for spontaneous combustion. The SSE must ensure that procedures are able to provide timely review and response to the data at the operation (physical observations and gas trends). These procedures must make the following considerations.

7.1 Resourcing (People)

SSEs must ensure appropriate personnel are available to assist the VO to manage the spontaneous combustion risks at their site.

SSEs must consider whether a specific mine based spontaneous combustion engineer or specialist needs to be appointed to assist the VO with the purpose of reviewing, trending, and analysing all spontaneous combustion monitoring gas data. This shall include, but not limited to, goaf drainage, active goaf, underground gas drainage system, surface gas drainage system, developing, implementing, monitoring and maintaining a proactive inertisation system, panel intake and return gas data, stowage management and high intake to return pressure areas.

7.2 Resourcing (Equipment)

The following equipment must be available to implement the Spontaneous Combustion PHMP:

- Gas monitoring equipment:
  - Continuous telemetric (real time) monitoring system.
  - Continual tube bundle monitoring system.
  - Gas bag sampling equipment (type of handheld pump, type and size of bags and covers).
  - Gas chromatograph (GC).
  - Stain tubes (often known as Draeger tubes).
  - Personal / handheld gas detectors.
  - Collar static pressure measurement measuring in real time at all major intake and return shafts.
  - Longwall, tailgate and maingate seals differential pressure monitors.
- Thermal imaging cameras.

- Ventilation pressure measuring devices:
    - Water manometer.
    - Digital manometer.
    - Real time flow monitors on inertisation injection points.
    - Fixed underground continuous pressure monitors that forms part of telemetric monitoring system.

7.3 Physical Inspections

The following inspections must be developed to address the spontaneous combustion risks identified in the Spontaneous Combustion PHMP:

- Explosion Risk Zone Controller inspections.
- VO inspections of gas monitoring equipment to ensure they are in the correct location for spontaneous combustion management.
- Inspection of inertisation points and flows.
- Physical indicator observation and reporting.

Note: CMWs play an important role in reporting abnormal conditions by identifying physical indicators such as smell, smoke, heat, haze, sweating and fire.

7.4 Gas Monitoring Systems

The following section is based on well-established, current technology at the time of publication and should not limit the implementation of new and improved technology or techniques.

- Multiple systems are required for the monitoring of spontaneous combustion:Tube bundle.
- GC.
- Real time sensors.
- Physical inspections including with handheld portable monitors.

For each technique and sensor, users must understand and apply the requirements of AS2290.3 *(Electrical equipment for coal mines – Introduction, inspection and maintenance. Part 3: Gas detecting and monitoring equipment*) and the Original Equipment Manufacturer (OEM) accuracy specifications, capabilities and range of the instrument.

Gases measured for each analytical technique (minimum)

Component	Hand Held (General Body)	Hand Held (Goaf well analysis)	Tube Bundle	Goaf skid continuous monitoring	GC
Carbon Monoxide	X	X	X	X	X
Oxygen	X	X	X	X	X
Methane	X	X	X	X	X
Carbon Dioxide	X	X	X	X	X
Hydrogen					X
Nitrogen			Calculated	Calculated	X
Ethylene					X
Ethane					X

7.5 Gas Monitoring Locations, Techniques and Triggers

The VO must identify areas of higher risk potential for spontaneous combustion through risk assessment. Once the higher risk areas have been identified the VO must determine the monitoring strategy and frequency to manage the risk of spontaneous combustion. This must be authorised by the UMM and captured in the work management process.

Note: Triggers are minimum parameters to consider for relevant TARP.

Note: Frequency is minimum frequency to be considered for routine sampling.

Note: Tube bundle sampling time must be set to avoid the carryover of gases from previous sample.

Monitoring locations as a minimum (but not limited to) are detailed below:

7.5.1 Reference Tube (fresh air from surface)

This location is to provide a reference for fresh air and a reference for initial conditions for Graham's Ratio (GR) calculated by tube bundle analysis. At least one reference tube per tube bundle system is required.

Technique	Frequency	Trigger*
Tube Bundle analysis	As per sampling sequence.	• Low oxygen • Negative or positive CH_4, CO_2 and CO

*Alarms set to identify analyser drift to prompt troubleshooting/calibration

7.5.2 Longwall Return

- Outbye tube to capture influence from leakage from adjacent seals.
- Inbye tube, located close to the Tailgate 150 metre sensor, to monitor the mixed airflow from goaf and longwall face.

Technique	Frequency	Trigger
Tube Bundle analysis	As per tube sequence	• CO Make • GR • CO/CO_2
Continuous monitoring	Continuous	• CO Make

7.5.3 Goaf Stream – Active Longwall Goaf

Technique	Frequency	Trigger
GC analysis	Daily at barometer low Day shift preferred (2pm – 5pm)	• CO • Ethylene • GR • Hydrogen
Handheld monitor	Readings taken at time of GC bag sample and recorded on bag tag.	• CO • Temperature

7.5.4 Active Longwall Goaf Seals

Tube bundle continuous monitoring at locations must be determined by the second workings risk assessment. The following factors must be considered when determining the location of tube bundle monitoring points for the active goaf (not limited to):

- High risk areas
- Fault zones
- Stress notches
- Proximity to active face
- UIS holes
- Squaring off
- Validation of proactive inertisation
- Longwall recovery
- Tube to be located no further than two seals back from the face on the maingate side to monitor the air-wash zone.
- The spacing and number of maingate tubes must be based on risk assessment, re-entry monitoring requirements and leading practice.
- Where companion roadways are able to be accessed in the first longwall, tailgate tube bundle monitoring should be conducted.

Note: Tube bundle locations must be identified for remote monitoring requirements for mine re-entry following an event.

Technique	Frequency	Trigger
GC Bag sample	Each seal sampled fortnightly at barometer low – Day shift preferred. (Increased sampling regime in slow retreat)	• CO • Ethylene • GR
Tube Bundle analysis	As per tube sequence	• CO • GR • CO/CO_2

7.5.5 Longwall post-drainage goaf well / UIS riser in active goaf

- Automated monitoring must be confirmed with handheld monitor daily until confidence in the monitoring system is achieved.
- GC bag samples to be taken as per the second workings risk assessment (ie. when a well is opened after purging, slow retreat, closest active wells to face - within 200m - to be done more frequently).
- Sensor installation and maintenance must comply with AS2290.3.

Technique	Frequency	Trigger
Handheld Confirmation	Daily at barometer low	• CO • Oxygen • Methane
Continuous real-time monitoring*	Continuous	• CO • Oxygen • Methane • Combined CO make for tailgate and goaf drainage
GC Bag sample	Daily	• CO • Oxygen • Methane • Ethylene

		• Hydrogen
Tube Bundle analysis* (best practice)	As per tube sequence. Eliminates the need for handheld confirmation checks.	• CO • Oxygen • Methane • GR

*Where available

7.5.6 Newly identified areas of interest

The **goaf stream TARP and sampling schedule** will be applied to any unspecified location within an active goaf where it is deemed sampling is required. This includes samples taken from between or behind longwall shields.

Technique	Frequency	Trigger
GC analysis	Daily at barometer low Day shift preferred	• CO • Ethylene • GR • Hydrogen
Handheld monitor	Readings taken at time of GC bag sample and recorded on bag tag.	• CO

7.5.7 Sealed Goaf

Technique	Frequency	Trigger
GC Bag sample	As per mine's risk assessment or Recognised Standard 9	• Oxygen or explosibility • CO • Ethylene
Tube Bundle analysis *for selected panels based on risk assessment*	As per tube sequence	• Oxygen or explosibility • CO

7.5.8 Place change panel / Working panel main return

- Monitor CO make in the return side of the panel and the return side of inaccessible, unsealed areas.

Technique	Frequency	Trigger
Tube Bundle analysis *for selected panels based on risk assessment*	As per tube sequence determined in the Gas Management PHMP	• CO • CO Make • GR • CO/CO_2
Continuous monitoring	Continuous	• CO • CO Make • GR • CO/CO_2
GC analysis	As per TARP	• CO • Ethylene • Hydrogen • GR • CO/CO_2

8 Control

An underground coal mine must develop, document, and implement procedures to control a known or suspected cause of concern event relating to spontaneous combustion.

The mine's controls need to include measures so that in the event where the mine has to respond to an event the preventative measures employed underground can be managed from the surface.

8.1 Response

The mine must have in place response plans for the mitigation and control strategies for the effects of spontaneous combustion, including means for the protection of personnel and the mine.

8.2 TARPs

The mine must determine indicators for the earliest detection of spontaneous combustion, including gaseous & physical indicators (such as smell, smoke, heat, haze, sweating and fire).

TARPs must be developed with responses to indicators with levels ranging from early detection through to withdrawal and identifying re-entry limits for the mine.

In the development of TARPs, TARP development forms (see example in Appendix 1) must be kept recording the TARP development process and data used to develop the TARP. To develop the response to TARPs the following information must be considered:

- Gas data analysis (includes the analysing of gas trends)
  - Internal mine-based expertise undertaking gas analysis, trending and interpretation.
  - Access to external experts with ventilation competencies to assist with gas analysis.
- Use of historical data from the mine, mines operating in the same seam and from real events, external technical expert advice and assistance.
  - Mine site to document and review technical reports.
    - Not to be taken at face value
    - What has been adopted and why?
    - What has not been adopted and why?

TARP controls and TARP triggers should be road tested to ensure it is sustainable, achievable and effective.

8.2.1 TARP Response Levels

The following is to be considered when setting response levels.

No Cause for Concern

<u>No indication of elevated / accelerated oxidation activity</u>

- Represents background conditions which are not at a substantially elevated temperature from ambient/ground (virgin rock) temperature.
- This must be determined by examining the gas profile of the monitoring locations over an extended timeframe. For example at periods when the longwall / bord and pillar panel is operating successfully (not stood or prolonged slow retreat rate) and are not preceded or followed by a suspected elevated temperature or heating event.

Level 1 – Investigate and prepare for mitigative action

<u>Level 1 TARP trigger – Indications of increased oxidation activity</u>

- Investigate TARP level represents a deviation from expected background conditions which must be investigated for the potential of increased oxidation activity. Review TARP Triggers against oxidation activity (e.g. elevated trends).

- Implement suitable control strategies.
- Review prevention infrastructure.
  - Additional inertisation points.
  - Additional monitoring points.
  - Additional resources.

Level 2 – Take action and prepare for withdrawal

Level 2 TARP Trigger – Indications of substantial heating and not being able to control requiring immediate action

- Review TARP Triggers against oxidation activity (e.g. elevated trends).
- Review effectiveness of the prevention strategies.
- Implement the control strategies.
- Deploy appropriate resources to assist with the implementation.
- Prepare for withdrawal from the mine to manage the incident from the surface.
- Ensure infrastructure is in place that can be managed from the surface.

Level 3 – Withdraw

Level 3 TARP Trigger – Indications of advanced heating requiring withdrawal

- Review TARP Triggers against oxidation activity.
- Review effectiveness of the control strategies.
- Develop and implement the extinguishing strategies.
- Remove CMWs from risk of uncontrolled fire/explosion.

The VO must ensure there is effective remote monitoring and sealing capability established from the surface (a place of safety) to allow timely sealing and effective monitoring post a withdrawal.

Note: Preparation allowing rapid sealing, sufficient data and re-entry process to facilitate a re-entry. This aims to avoid a potential reluctance to withdraw personnel to a place of safety.

8.2.2 Actions to be considered for re-entry following a withdrawal

The UMM must have protocols in place for the re-entry decision following a withdrawal from the mine or part of the mine. Re-entry should:

- only be considered when conditions are in TARP Level 2, trending towards conditions giving no cause for concern, with adequate and effective monitoring, determined by risk assessment, in place.
- identify whether there is a risk of an explosive mixture of gas.
- identify whether there is a risk of an ignition source.

8.2.3 Considerations for triggers

- TARP Creation – Must ensure that the TARPs are reviewed periodically by a review team with the VO and approved by the UMM. The aim is to ensure that the data they are based on is still relevant.
- Deeper coal operations with steep geothermal gradient must have greater spontaneous combustion controls and a quicker response to triggers.
- ‘And’ statements or qualifying statements can only apply to a single sample from the same technique.
- ‘And’ statements must only be used when conditions give no cause for concern or the Level 3 withdrawal TARP.
- ‘But’ statements must not be used.
- It is reasonable and encouraged for GC samples to be **immediately** reanalysed (same sample) for confirmation of an unexpected trigger.

Note: it is appropriate to use a trigger of hydrogen and carbon monoxide, if both readings are taken from the exact same sample and analysis.

Note: Trigger values in TARPS are intended to be inherent, non-emotional guides for mine operators.

Considerations for ethylene (C_2H_4) triggers

- A standalone measured ethylene response at any location underground, set to a threshold no higher than 0.3 ppm (this value may be lower based on instrument response and historic data), must trigger an investigate (level 1) TARP level by the VO.
- Samples containing unexpected ethylene should be immediately re-analysed for confirmation (using the same bag and GC).
- It is appropriate to include a conservative (100:1) carbon monoxide / ethylene ratio (from the same bag sample as the ethylene) as a qualifying condition for ethylene samples at withdrawal (level 3) TARP.
- Laboratory testing demonstrates that ethylene at 1ppm or higher combined with elevated carbon monoxide indicates an increased likelihood of a coal heating existing at a temperature of over 100 degrees Celsius. A measured response for ethylene no higher than 1ppm must be considered for a withdrawal (level 3) TARP.

Typical GC response for ethylene (C_2H_4) in the Queensland mining industry

- 0.1 ppm – 0.2 ppm: Response may be inconsistent and variable due to noise/ interpretation of baseline.
- 0.3 ppm – 0.5 ppm: Peaks are typically integrated more reliably at these measured concentrations and more consistency with trending is possible.
- 0.5 ppm – 1ppm: It is unusual to measure a response of 0.5 ppm which has been incorrectly integrated, it is often associated with a problem or other substantially elevated indictors.
- 1 ppm. This is a high concentration of ethylene, often associated with a serious event when combined with elevated carbon monoxide.
- Carbon Dioxide over 5% will reduce ethylene sensitivity.

Considerations for hydrogen (H_2) triggers

- Doubling of the normal goaf stream hydrogen value associated with increase CO and detection of ethylene indicates the commencement of increased oxidation activity.
- Substantially elevated levels of hydrogen combined with elevated carbon monoxide and ethylene may indicate an advanced heating or fire.
- Elevated hydrogen combined with carbon monoxide where there is substantial movement of atmosphere i.e., the goaf stream or tailgate is of particular concern.
- TARP actions should consider the hydrogen concentration to be included in interpretation if they are not used as triggers.
- The Queensland Industry GC (Agilent 490/990) can easily detect hydrogen sub ppm levels.
- Fresh air may contain small amounts of hydrogen (1-2 ppm) but elevated levels must raise concerns.

Quality control process for processing and reviewing gas results

TARPs checklist and signoff

- Operators must check for triggers at time of analysis / alarm and record.
- Develop a process for testing bag samples and tube bundles and goaf well analysis to allow for comparative testing and trending.
- Bag samples must be reviewed by the VO daily.

- Alarms must be flagged for review by the UMM daily for triggers.
- The daily alarm log must be signed by the CRO, undermanager, oncoming CRO, oncoming undermanager, VO and UMM.

8.3 Incident Management Team (IMT)

If the mine needs to respond to an event, where TARP triggers have been activated, the mine forms the IMT to manage the response. The response must be managed by site personnel not at a corporate level.

The TARPs must define the trigger which will invoke the operation of the IMT to respond to spontaneous combustion triggers. The IMT must include persons with sufficient authority to implement decisions, together with appropriate knowledge and experience.

The control measures implemented must be risk-based.

The IMT must maintain an event log to record issues, decisions, actions and resulting events. The IMT must not be disbanded until a controlled and stable condition exists at the mine with respect to the risk of spontaneous combustion.

Any IMT formed from other principal hazard triggers and/or incidents must consider spontaneous combustion risk.

8.4 Emergency Sealing

The mine must develop and implement a process for the rapid sealing of specific areas of risk in response to TARPs supported by sealing procedures and seal design together with a minimum inventory of materials to be maintained on-site, or to have guaranteed ready availability, at all times.

Preparatory seals should be considered at the start of each extraction panel (to seal off panels) and in selected areas in the mains (to seal off areas inbye and keep the outbye areas of the mains open).

Other areas that must be considered include but are not limited to:

- Remote sealing of the mine or parts of the mine.
- Inertisation isolation and activation.
- Borehole setup at panel entrances for the use of Inertisation.
- Continued operation of the real time gas monitoring system (underground).
- Real time gas monitoring from the surface.
- Continued operation of the tube bundle gas monitoring system.
- Borehole tube bundle monitoring.
- Develop exclusion zones from the portals, shafts and boreholes.
- Operation of the mine from the surface outside of the exclusion zones from portals.
- Conduct emergency exercises to demonstrate effectiveness of the system.
- Closing seals is a major ventilation change and its impact must be considered.

Note: Where there is a risk of an explosive mixture of gas and an ignition source, sealing must be done remotely.

9 Document and Data Control

The Spontaneous Combustion PHMP and related documents must be managed by the mine's document control system and be in a form which is easily accessible, easy to use and understand and able to be updated. All obsolete documents are to be removed from circulation.

Records related to the Spontaneous Combustion PHMP that must be retained include, but not limited to:

- Spontaneous combustion events.
- Ventilation and gas monitoring and spontaneous combustion control data.
- Mine specific spontaneous combustion characteristics.
- TARPs.
- Non-conformances - corrective action.
- Spontaneous combustion training.
- Audits and reviews.

10 Training and competency

Persons with responsibilities under the Spontaneous Combustion PHMP must have the following competencies.

- The senior person in the organisation structure, with the relevant competency, to establish and maintain the Spontaneous Combustion PHMP.
- GC operators must have a certified competency from the supplier.
- Control Room Operators must have a demonstrated competency in using the automated gas monitoring system and acknowledging alarms.
    - A mine managers representative must; be appointed as per section 60(8) of the *Coal Mining Safety and Health Act 1999*; and
    - have AQF 5 qualifications or higher in spontaneous combustion, ventilation and gas management or a second-class certificate of competency. Persons with responsibilities under the Spontaneous Combustion PHMP must undergo training including:
- the relevant sections of the Spontaneous Combustion PHMP and the importance of adherence.
- the roles and responsibilities of persons in relation to the operation of the Spontaneous Combustion PHMP.
- spontaneous combustion indicators.
- reporting and recording the observation of spontaneous combustion related indicators.
- relevant standards and procedures associated with the Spontaneous Combustion PHMP.

11 Roles and responsibilities

The Spontaneous Combustion PHMP must define the authorities and duties of all persons who have responsibilities under the plan. In fulfilling these requirements such devices as organisation charts, job, or position descriptions in relation to the spontaneous combustion management plan, or statements of duties with respect to the spontaneous combustion management plan will assist.

The Spontaneous Combustion PHMP must be adequately resourced in terms of resources for the development of the plan for the prevention, monitoring and control of spontaneous combustion, for the implementation of the plan, and for ongoing maintenance.

A senior position in the management structure with the relevant competency must be responsible for the Spontaneous Combustion PHMP.

The VO must be involved, and appropriate dedicated resources should be assigned to assist in the prevention management and control of spontaneous combustion. Additional resources must be assigned when workload increase: increasing bag sampling, conducting inertisation, installing additional tube bundle, during an event etc.

All operational changes to design and process with potential to have an impact on the risk of spontaneous combustion should be counter signed and approved by the UMM and VO.

12 Audit

Effective and timely audits and reviews are a valuable means to give management and CMWs assurance that requirements of the spontaneous combustion principal management plan are being adhered to in practice.

Spontaneous combustion critical controls must be established by risk assessment and form part of the critical control auditing process.

A schedule of both internal reviews and external audits must be prepared to ensure the verification of the Spontaneous Combustion PHMP operation.

Internal reviews must be conducted by persons independent of those with direct responsibility for the aspect of spontaneous combustion principal management plan which is subject to the review.

External audits must be conducted by persons independent of the mine's operations and must be done by persons that have knowledge, relevant ventilation competencies and experience in prevention, monitoring and control of spontaneous combustion.

Records of all audits and reviews must be maintained in the mine record. Audit and review actions must be communicated to the senior person responsible for the Spontaneous Combustion PHMP. All actions must be considered for implementation.

13 Review

The timely and effective review of the content and operation of the Spontaneous Combustion PHMP will assess its continued suitability and effectiveness in managing spontaneous combustion related risks at the mine.

The mine must prepare a review protocol conforming to the following requirements:

- Define time based and event-based review triggers.
    - Event based review triggers must include, as a minimum requirement:
    - failure or ineffective control to manage spontaneous combustion.
    - significant change in mining systems.
    - when information of an event at another mine becomes available.
- A re-evaluation of the spontaneous combustion related risks and all aspects of the Spontaneous Combustion PHMP.
- Identification of persons to participate in reviews (indicate who should decide if significant change has occurred, and to what criteria that decision is to be made).

Where the conduct of any review indicates that the Spontaneous Combustion PHMP is no longer suitable and effective in managing spontaneous combustion related risks then management should implement corrective action to amend the Spontaneous Combustion PHMP.

Appendix 1: Example of TARP Development Form

TARP DEVELOPMENT - TRIGGER LEVELS			
Name of Reviewer		**Date**	Date
TARP NAME		**Signature**	Signed
NORMAL CONDITIONS	Legislative Requirement.		
	Circumstance or Condition.		
	Historical Data.		
	Best Practice.		
	Supporting RA or documentation.		
	Consider any conflict or interaction between next trigger point.		
	Consider logical progression of the trigger response relative to supporting information used to determine trigger level.		
LEVEL 1 INVESTIGATION REQUIRED	Legislative Requirement.		
	Circumstance or Condition.		
	Historical Data.		
	Best Practice.		
	Supporting RA or documentation.		
	Consider any conflict or interaction between next trigger point.		
	Consider logical progression of the trigger response relative to supporting information used to determine trigger level.		
LEVEL 2 ACTION REQUIRED	Legislative Requirement.		
	Circumstance or Condition.		
	Historical Data.		
	Best Practice.		
	Supporting RA or documentation.		
	Consider any conflict or interaction between next trigger point.		
	Consider logical progression of the trigger response relative to supporting information being used to determine trigger level.		
LEVEL 3 URGENT ACTION REQUIRED	Legislative Requirement.		
	Circumstance or Condition.		
	Historical Data.		
	Best Practice.		
	Supporting RA or documentation.		
	Consider any conflict or interaction between next trigger point.		

Appendix 2- Reference standards

List of documents referred to in this standard and other useful material for developing a Spontaneous Combustion PHMP:

ACARP

- 19010 Emergency Response: Mine Entry Data Management July 2015
- C29024 Contamination – Ethylene from Timber Supports March 2023
- ACARP website related to sponcom and gas management work

Australian/New Zealand Standard – *Electrical equipment for coal mines – Introduction, inspection and maintenance. Part 3: Gas detecting and monitoring equipment* (AS/NZS 2290.3:2018)

Balusu, R, Deguchi G, Holland, R, Moreby, R, Xue, S, Wendt, M and Mallett, C 2001. *Goaf Gas Flow Mechanics and Development Of Gas and Sponcom Control Strategies At A Highly Gassy Coal Mine.* Australia-Japan Technology Exchange Workshop 2001, 2nd – 4th December, Hunter Valley, Australia.

Balusu, R, Tuffs, N, White, D, Harvey, T and Xue, S 2006. *Surface Goaf Gas Drainage Strategies for Highly Gassy Longwall Mines.* Journal of The Mine Ventilation Society of South Africa, Volume 59, Number 3, Jul/Sep 2006, pp 78 – 84.

Belle, B., Cliff, D., Improved TARP development based upon mine specific data, International Journal of Mining Science and Technology, Volume 28, Issue 3, May 2018, Pages 477-481

Basil Beamish CB3 web site

Caley, D. 2023. *Broadmeadow Mine Solid Coal Oxidation Event 18-19ct, South Mains* ERZ forums and ventilation officers workshop March 2023;

Cliff, D, Beamish, B and Cuddihy, P, 2009. Explosions, fires and spontaneous combustion,

in *Monograph 12, Australasian Coal Mining Practice – Third Edition*, pp 800-814 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Cliff, D, Brady, D & Watkinson, M 2018 2nd ed, *Spontaneous combustion in Australian coal mines*, referred to as 'The Green Book', Simtars, Redbank, Australia.

Coal Mining Safety and Health Regulation 2017 (Queensland, Australia)

ICMM: Health and Safety Critical Control Management: Good Practice Guide

Muller, S, Bartrop, L and Dhyon, S. 2023 *Detection of ethylene by micro gas chromatograph and associated evolution temperatures for gas evolution testing.* World Mining Congress Brisbane Qld Australia 26-29 June 2023.

National Coal Board 1977, *The Tube Bundle Technique for the Continuous Monitoring of Mine Air*, National Coal Board, London.

NSW Resources Regulator

- *MDG 1006 Spontaneous Combustion Management Guideline*
- *MDG 1006 Technical Reference for Spontaneous Combustion Management Guideline*

Queensland Coal Mining Board of Inquiry Part II Report – May 2021

Resources Safety and Health Queensland (RSHQ)

- *Recognised Standard 09 The monitoring of Sealed Areas*
- *Recognised Standard 16 the use and control of polymeric chemicals at underground coal mines*
- Safety Bulletin 204 Spontaneous combustion monitoring and response systems

Simtars.1999, *Interpretation of Mine Atmospheres* referred to as ‘The Grey Book’, Simtars, Redbank, Australia.

Simtars.1997, Spontaneous Combustion in Underground Coal Mines *“Red book”* (for coal mine workers)

Simtars.1997, Spontaneous Combustion in Underground Coal Mines *“Blue book”* (for coal mine officials)

Simtars website

- Gas monitoring and consulting services
- Spontaneous combustion testing services
- Resource Library

Windridge, F. W., Parkin, R.J., Neilson, P.J., Roxborough, F.F. & Ellicott, C.W. 1996, *Report on an Accident at Moura No. 2 Underground Mine* on Saturday, 7 August, 1994: Wardens Inquiry, Queensland Government, and Brisbane, Australia.

Appendix 3: Background to active longwall gas and spontaneous combustion management strategies

Gassy and known sponcom prone GM seam longwall operations require a greater understanding the goaf gas behaviour, post gas drainage control strategies for TG gas management, and well balanced gas and sponcom management strategies of highly gassy seams. Following paragraphs below highlight the spectrum of scientific research based engineering controls and monitoring systems developed and improved over the last two decades in underground longwall operations and details are described elsewhere (Belle and Balusu, 2023, Qld Safety Conference).

The evolution of major coal oxidation and resulting sponcom incidents are sudden and may result in catastrophic negative safety outcome or result in the withdrawal of persons and closure of longwall panels/mines. Historically, gassy longwall workings in Australian Goonyella Middle (GM) seam (late-1990's to mid-2010's), experienced increasing trend in CO levels associated with coal oxidation and sponcom indicator gases and major safety incidents were due to oxygen ingress on the maingate side. The original Australian active longwall goaf gas drainage system designs are based on the past work of the CSIRO, supported by the operational experiences. The CSIRO based studies in gassy and hot coal mines had carried out numerical and field data investigations on goaf hole gas flow mechanisms and proactive inertisation strategies for preventative spontaneous combustion and goaf gas management. This critical foundational knowledge work contributed to the original goaf gas drainage and sponcom management strategies in other Australian longwall mines and potentially extended to rest of the world. Considering the risks associated with sponcom, GM seam operations were the first operations in Australia to introduce proactive N2 injection along the MG in mid-to-late-2000's, to manage sponcom fire and explosion risks in an active goaf, despite not having field data readily available to calibrate the models prior to its implementation.

Over two decades ago, active goaf gas drainage flow rates were moderate (2,000 l/s to 3,000 l/s) and the oxygen ingress on TG side was not a major concern. However, with increasing goaf gas drainages rates and manual or automated mode operation of goaf wells to extreme flow rates to address higher longwall goaf gas emissions, TG oxygen ingress and air wash zones became a major issue recently, necessitating the introduction of TG inertisation strategies now to address this emerging issue. Introduction of MG proactive inertisation strategy had ultimately reduced the number of high CO or intensive oxidation incidents over two decades. The following paragraphs provide practical safety benefits of longwall tail gate (TG) inertisation supported by the original computational fluid dynamics (CFD) modelling studies carried out by the CSIRO. The field verification with both MG and TG inertisation using proactive N_2 injection during various phases of longwall production and stoppages in an active longwall provides reasonable technical and operational justifications on gas and sponcom management strategy for worker's safety.

The original and modified longwall seam gas drainage system design evolutions are essentially based on the joint industry led historic initiatives and work of CSIRO, supported by the GM seam operations (Balusu et al., 2001, 2002, 2004, 2014, 2019). The historic review of goaf drainage introduction in Australia and the rest of the world, drainage design and operational practices are summarised elsewhere (Belle, 2014). In addition, the impact of longwall and TG hole positioning study by the CSIRO for the GM seam operations recently is summarised elsewhere (Khanal et al., 2021). The science-based CSIRO studies in gassy, sponcom prone hot coal mines had been carried out numerical and field data investigations on goaf hole gas flow mechanisms and proactive inertisation strategies for preventative spontaneous combustion management. This critical operational knowledge contributed significantly to the original goaf gas drainage and sponcom management strategies in Australian underground longwall mines and potentially extended to rest of the coal mining world. The contradictory nature of the GM seam sponcom led fire and gassy mine requiring maximised goaf drainage capacity systems and the need to reduce oxygen ingress into the MG and TG active goaf requires careful operational strategies. The term 'sponcom' is used below to discuss the various stages of coal oxidation to the development of fully uncontrollable combustion when large quantities of coal left in the goaf due to geo-technical safety considerations. In this context, it is important to note that use of ventilation driven dilution controls for longwall tailgate gas management that are practiced elsewhere in Australia or the world, are not necessarily appropriate for gassy, steep geo-thermal gradient and known sponcom prone GM seam mines.

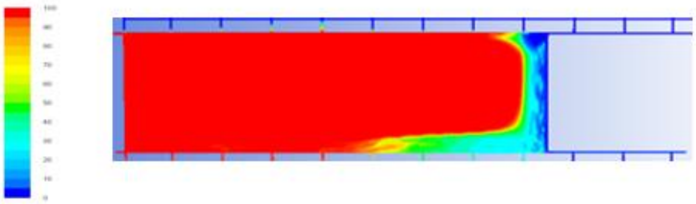
Goaf Gas Management Strategies

Traditionally, highly gassy mines are to be managed through extensive pre-drainage techniques long before the actual longwall mining to take place. During the active longwall mining, goaf drainage systems are used as the primary control for gas management with adequate drainage capacity for maximized drainage along with ventilation as the secondary control for gas management as a dilution control. Longwall gas emissions have increased significantly in recent years in some of the Australian longwall mines due to increased seam gas reservoir size with multiple upper and lower seams, higher production rates and increase in mining depths. In addition, there have been mines, that had previously deployed 3 gateroad systems in their longwall panels for continued access to diesel vehicles during maintenance periods. With the greater understanding with extensive and flexible goaf drainage systems, Australian coal mines use 2 gateroad ventilation system for longwall panel development and extraction. Extensive scientific and field work has been carried out previously to develop optimum gas and spontaneous combustion control strategies for 2 gateroad longwall panels [Balusu and Tanguturi, 2019], [Balusu, Belle, and Tanguturi, 2017], [Belle, 2015], [Balusu, Schiefelbein, Ren, O'Grady, Harvey, 2011].

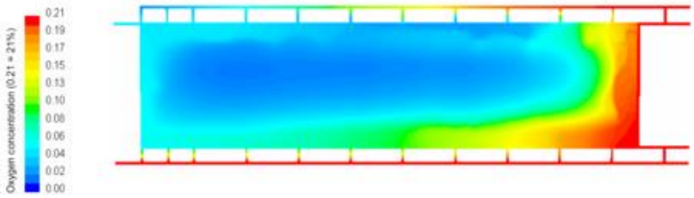
Although 3 gateroad system provides more ventilation capacity during gateroad development and assists in providing more ventilation dilution capacity in tailgate during longwall extraction, its effect on goaf gas distribution and explosive fringe gas profiles in the longwall goaf areas was historically unknown. There is a continued perception that as the 3 gateroad system provides more ventilation capacity for gas dilution in the longwall tailgate return, it would also reduce the explosive fringe gas distribution profile near the tailgate area in the longwall goaf to manage the explosion risk. The results of the CFD modelling simulations indicate that there is a significant difference in the spread of explosive fringe gas distribution profiles in the longwall goaf under 2 gateroad and 3 gateroad conditions, i.e. a significant increase in the spread of explosive fringe (or close to explosive range) zone in the goaf under 3 gateroad conditions. Based on the results of these investigations, appropriate strategies have been developed for gas control and minimization of the spread of explosive fringe gas distribution in the longwall goaf under field site conditions (Balusu, Belle, Tangutiri, 2019). Therefore, based on the extensive operational gas management experience, it is pre-drainage and goaf gas drainage management is the primary control rather than ventilation engineering to manage the gas hazard.

One of the major difficulties in the ventilation and gas flow dynamics is our inability to visualize the complex likely gas concentration profiles in the active goaf with time and non-constant retreating longwall. The advances in the CFD numerical calculations have enabled the industry by providing an understanding of gas management or the extent of 'air wash zone' that is often used colloquially during risk assessment or emergency situations. In this paper, air wash zone is typically referred to as the concentration of relative oxygen in the goaf atmosphere aiding the left over coal oxidation, and typically referred to oxygen concentration values of 3 % to 21%. Fresh air is the concentration that is representative of longwall fresh air intake. It is to be noted that due to almost no relative airflow movement that can be measured in the goaf may also mean the presence of oxygen even at levels of 2 to 3%. The CSIRO studies (Balusus, 2002) provided a visual scenario of potential oxygen distribution in an active LW goaf and goaf well nearer to the LW face. The field studies have noted that (Balusu et al, 2006) the oxygen concentration was above 19% for up to 100 m behind the longwall face and reduced to 6% at 250 m behind the face in the absence of any inertisation control. This air penetration distances of 250 to 350 m may be attributed due to poor MG brattice control practices along with the increased longwall airflow rates for gas dilution purposes. The tracer gas studies have revealed that the goaf at 300 m behind the face is highly consolidated and does not allow direct travel of air fom the intake side to return side of the TG.

Methane and oxygen gas distributions patterns in longwall goafs under two different conditions by means of CFD simulations using operational longwall panel gas emissions and goaf gas drainage conditions with total gas emissions into the longwall goaf were around 9,000 l/s with 98% methane (CH4) is shown Figure 1. The total goaf gas drainage rate was around 8,000 l/s, with gas concentration in different vertical goaf holes varying between 80% and 95% with adjacent sealed panel goaf drainage of 800 l/s for a typical U ventilation system in a 2 gateroad panels. In the methane and oxygen gas distribution color contours below, the red colour indicates higher gas concentration and the blue colour indicates lower methane or oxygen gas concentration. As noted herein, the presence of oxygen and continued methane emissions are contradictory controls requiring finer balance and continued vigilance in goaf drainage operations and highly reliable gas trend monitoring.



(a) CH4 profile in U ventilation



(b) Oxygen profile in U ventilation

Figure 1: Methane and oxygen gas distributions patterns in longwall goafs under two different conditions

Sponcom management strategies

Based on the two decades of close collaboration between the industry, ACARP and CSIRO, extensive scientific and field-based studies have been carried out. The learning from these studies, have resulted in the following summary and context behind the proactive preventative sponcom management goaf inertisation strategy:

1. Major events in Queensland demonstrates the critical importance of proactive sponcom management for underground coal mines extracting/working in known sponcom prone Moranbah region GM seams.
2. Widely referred low sponcom propensity (R70) of coal risk ratings in Principal Hazard Management Plan (PHMP) documents and frequency of their testing may be misleading the likely initiation or risk frequency estimations. For example, both German Creek and Goonyella Middle Seam R70 levels are similar but the left-over roof coal in GM seam workings increase the oxidation risk with increasing depth due to geo-thermal gradient.
3. Historically, experiences of workings in GM seam (late-1990's to mid-2020's), high and increased CO trends and sponcom incidents due to oxygen ingress on maingate (MG) side was the major issue for safe operation of LW panels. To address this issue, MG proactive inertisation strategy was introduced at GM seam operations mid-to-late-2000's, which ultimately reduced the number of high CO incidents over the next decade.
4. When MG proactive inertisation strategy at MNM was introduced, there was no precedence in Australia and there was no field data to prove its effectiveness (prior to its implementation). However, it is to be noted that during longwall operations of GM seams, it's the additional proactive N2 inertisation strategy that was essential to successfully manage the sponcom and resulting major fire risks.
5. The evolution of major coal oxidation and sponcom incidents are sudden and may result in catastrophic negative safety outcome or result in the withdrawal of persons and closure of panels/mines.
6. In view of the recent incidents in a number of mines working in GM seam (irrespective of the cause of the incidents), elevated oxidation may potentially become an ignition source and inadequate control may result in the undesirable safety outcome.

Maximised goaf drainage Strategies -Lessons Learned

To develop optimum and effective goaf gas drainage strategies for any new or operating mine, an extensive goaf gas monitoring scheme should be implemented in at least one or two panels to obtain detailed information on gas flow patterns and goaf gas distribution under various operating circumstances for the site conditions and geometry. In many cases, the recent standard practice of draining gas from 2 to 4 goaf holes near the face operating its peak capacity would not solve the tailgate gas problems, but exasperate the oxygen ingress into the deeper portion of tailgate area of an active LW goaf. A number of factors including goaf gas emission flow rates and composition, panel ventilation, coal seam gradients, overlying and underlying coal seams, face retreat rates, caving characteristics, and goaf gas flow patterns need to be considered during development of goaf gas drainage operations.

Based on the results of various CSIRO studies and investigations supported by the industry over the last two decades, the following guidelines are recommended for optimum maximized goaf gas drainage strategies at highly gassy mines:

- Surface goaf holes for gas drainage provide the highest capacity and lowest cost option for goaf gas drainage under most circumstances.
- Goaf holes should be drilled on return side of the goaf, preferably at 20 to 70 m from gateroad depending on the longwall caving conditions.
- Goaf holes are to be drilled 80 m to 100 m away from faults/dyke areas.
- Uniform and continuous operation of goaf holes (sudden peaks and lows in goaf drainage flow rate increases the coal oxidation resulting in spontaneous combustion risk).
- Goaf gas drainage hole diameter should be in the range of 250 to 400 mm for optimum flow rates and the goaf holes may be drilled at 100 to 300 m spacing depending on the goaf gas emissions and other conditions.
- The total capacity of the goaf gas drainage plants should be around 2 to 3 times the expected goaf gas emissions to cater for deep goaf holes gas drainage, shifting of goaf plants or goaf hole connection changes and reduced plant efficiencies due to high pressure losses. Provision of a high-capacity and flexible gas drainage system allows optimisation of goaf gas drainage strategies, flexibility, improves the overall efficiency and provides better gas control on the face.
- The goaf gas drainage system should include a combination of goaf holes near the face and deep goaf holes in the panel in order to improve the overall gas drainage efficiency and to reduce the effects of barometric pressure changes on tailgate gas levels.
- The strategy of continuous operation of deep goaf holes at moderate capacity should be implemented i.e., intermittent operation of deep goaf holes at high capacity may not improve the overall efficiency and may lead to problems.
- Goaf gas drainage should be carried out from around maximised number of goaf holes with the retreating longwall goaf in the panel (including deep holes), instead of the standard practice of gas drainage from just few goaf holes closest to the face.
- Application of increased suction pressure to drain more gas from goaf holes closest to the face might result in increased air dilution, without any net increase in gas drainage flow rates.
- The ventilation system in the panel should be designed to minimise oxygen ingress into the goaf, including immediate sealing-off all the cut-throughs behind the face, in order to improve overall gas drainage efficiency.
- Oxygen concentration level in the goaf hole flow should be less than 5% in goaf holes beyond 100 m from the face line to reduce spontaneous combustion risk in the longwall goafs.
- Gas drainage from adjacent old goafs should also be carried out wherever possible, depending on the goaf gas emission flow rates and adjacent seal strengths.

Discussions of MG and TG inertisation and gas management strategy

Presence of oxygen in the active goaf is unavoidable when carrying out goaf drainage activities to manage tail gate gas levels of an active longwall. Extensive monitoring activities of goaf dynamcs and goaf gas composition studies have been carried out by the industry for over two decades. Figure 2 shows one such historic work of impact of oxygen profile as a result of proactive N2 injection on both TG and MG areas. The reduced air wash zone is clearly evident in the active goaf thus minimising the conducive environment for any elevated oxidation events (Balusu, 2005). Figure 3 provides the latest CSIRO study using calibrated CFD model of MG and TG inertisation strategy for an operating high gassy longwall mine.

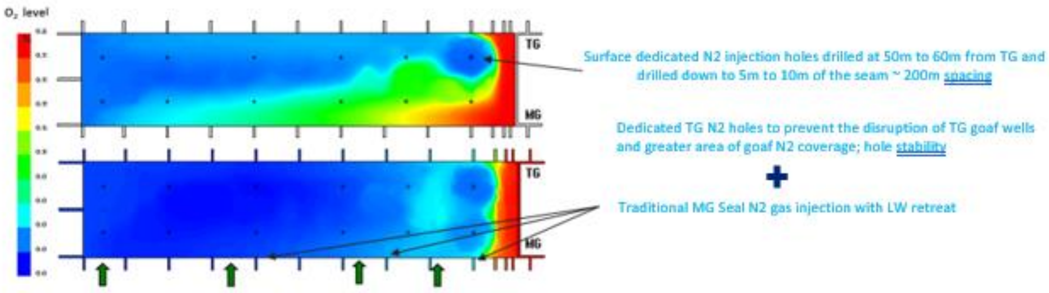


Figure 2: MG and TG inertisation conceptual strategy for gassy longwall mines.

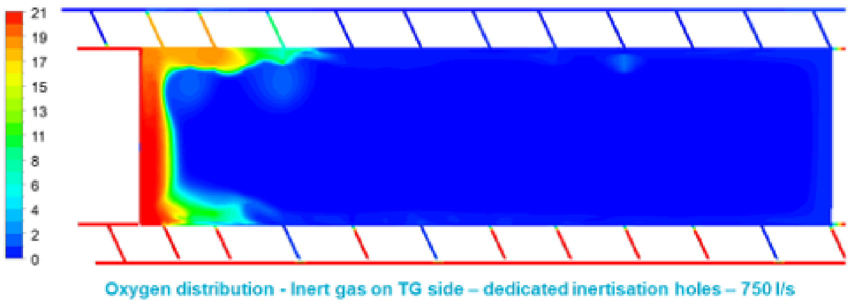


Figure 3: Calibrated MG and TG inertisation strategy for an operating high gassy longwall mine.

Summary of Optimum Gas and Sponcom Management Strategies

Conjointly managing the gas and sponcom risk is fundamental to securing a safe underground place of work at GM GM seam longwall operations. With the increasing gassy and known sponcom prone coal seams and a working depth with steep geothermal gradient is contributing towards the step changes in goaf drainage managements for gas and sponcom management in order to be compliant with legislative safe TG gas limits as well as greenhouse gas management with reduced ventilation air methane (VAM) emissions. This strategy reinforces the fundamental importance of the pre-drainage systems with long lead time prior to longwall mining. Over two decades ago in Australia, goaf gas drainage rates in Qld and NSW were low to moderate (1,000 l/s to 3,000 l/s) and the ingress of airwash zone on longwall TG side was not a major concern. However, with increasing goaf gas drainages rates upto 6,000 l/s 10,000 l/s and manual or automatic mode operation of goaf wells to the extremes to address higher goaf gas emissions, TG oxygen ingress deeper in the goaf has become a major issue in recent years, necessitating the introduction of both TG and MG inertisation strategies now to address this emerging coal oxidation issue. Furthermore, contrary to the views in relation to elevated coal oxidation and sponcom events related to goaf hole spacing and maximized goaf drainage practices, it is prudent to note that there have been historic cases of sponcom events with 400 m to 200 m goaf hole spacing, and even with no goaf drainage practices.

Following safety benefits reasoned with adequate technical and operational justifications are made for an active longwall panel for gas and sponcom management strategy aided with both MG and TG inertisation using proactive N2 injection during various phases of longwall production and stoppages:

1. In the absence of active and continuous proactive N2 inertisation, maintaining 5 % to 8 % O_2 levels in the active goaf would be very difficult and may exasperate the oxidation in active goaf when the longwall retreat rates slows down or stops for weeks and months, but reduction goaf drainage to minimise the O_2 ingress in deep goaf area of TG region will significantly increase the longwall TG gas levels. This approach would put operations in a dangerous

position from gas management perspective.

2. It is the operational management of goaf wells (not sudden or automatic operation of the goaf wells to the extreme flow rates, rather stepwise increase) with proactive LW active goaf inertisation for sponcom management that will enable the appropriate maximised goaf drainage gas management to manage the longwall return gas levels.
3. The introduction of TG inertisation assists in reducing the airwash zone. In addition, longwall operations need to continue with the leapfrogging of the well-established MG seal inertisation strategy [including quicker and timely MG seal build, and tight MG brattice control], along with the dedicated tube bundle monitoring points for goaf gas monitoring to understand the goaf flow dynamics and sponcom management.
4. As a general long-term strategy, known sponcom prone longwall operations to ensure flexible and contingency inertisation infrastructure is readily available and to remain in a state that it is able to be recommissioned within a single shift at any time during the monitoring period.
5. The association of slow retreat due to known or unknown geological structures in the longwall hazard plan and known historic oxidation related incidents, have further reinforced the active inertisation system maintaining at least 2,200 l/s of inert flow into the active panel [around 1200 l/s on the MG side and 1000 l/s on the TG side using dedicated vertical N_2 holes drilled 5 to 10 m from the working seam height].
6. Considering the various uncertainties associated with the LW operations in sponcom prone seams, recommendation of inertisation holes at 200 m spacing on TG side is essential and appropriate for long term risk management planning and design purposes. If the evidence suggests otherwise, i.e., constant increased retreat or no stoppages, then TG proactive inertisation may be carried out through inertisation holes at increased spacing (i.e. alternate inertisation holes) in those areas. This would mean that the intermediate dedicated holes and other old/deep inertisation holes can be equally used for oxygen ingress or airwash zone monitoring and sponcom monitoring on the TG side of the goaf as per the oxygen limit recommendations of an active goaf.
7. It is to be noted that these gas and sponcom management strategies are not merely based on the LW retreat rate, but also includes the inherent nature of seam propensity for sponcom despite it being equally rated as “low” risk sometimes, geo-thermal gradient, existence of faults and structures, amount of coal left behind, changes to the goaf hole designs, delay in operational related building of MG seals, inadequate MG brattice leakage control for long periods. other engineering related uncertainties associated with the LW equipment, strata control uncertainties associated with moisture/water in TG roadways, and uncertainties associated with cavity control measures.
8. The implemented TG and MG proactive N2 inertisation strategy of active longwall goaf at the Sponcom prone seam has resulted in the new technical/empirical data generation in verifying the fundamental understanding of goaf gas drainage maximization and sponcom management.
9. Finally, strengthening the proactive inertisation strategy on both MG and TG with flexible inertisation capacity and responding to the up to date trigger response values of the oxidation scenario rapidly developing into an advanced stage using appropriate early monitoring strategy is essential in the future proofing of the sponcom risk.

Appendix 4: General Layout of Goaf Monitoring and MG Inertisation Locations

Active goaf continuous monitoring is paramount to the proatcive inertisation for spontaneous combustion management. Where an opportunity is possible whereby goaf gas monitoring is possible on both sides f the LW panel, inertisation effectiveness can be assessed. This would enable, detailed goaf gas distribution on both sides of these initial longwall panel or extended LW panel from the previous panel. It is very rare to have access to such valuable data for multi-hazard Longwall ventilation, gas and spontaneous combustion management to understand the goaf dynamics.

In remaining longwall panels, one can only monitor on the maingate side of the panel due to access issues and potentially consider the manual goaf hole samples. Since the suggestions below provide a general layout, operations may amend the monitoring point locations, with qualified reasons that would provide sufficient data in formulating/reviewing the Spontaneous combustion indicator gas levels for appropriate responses and inertisation effectiveness.

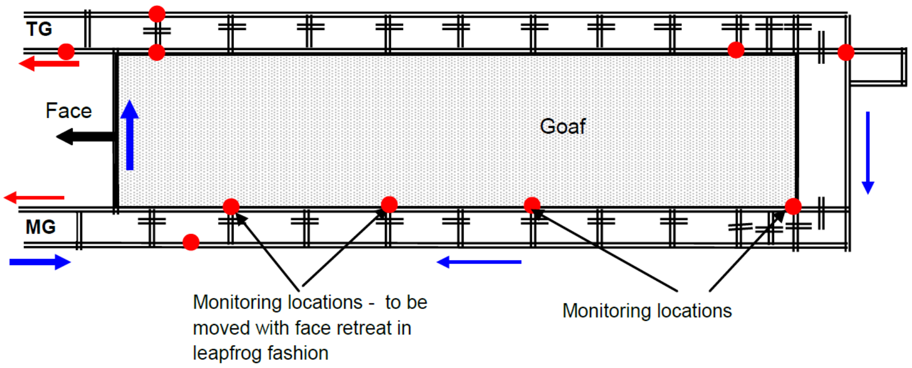


Figure 1: General Layout of Monitoring locations with access to TG seals

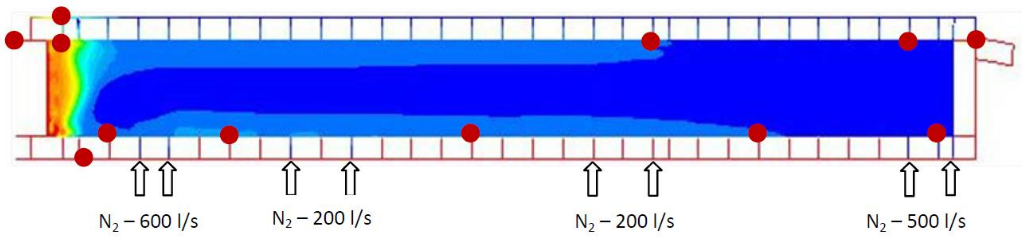


Figure 2: Generalised layout of monitoring and MG inert gas injection locations of a 3.0 km goaf