Australian Explosives Industry and Safety Group Inc.

Code of Practice

PREVENTION AND MANAGEMENT OF BLAST GENERATED NOx GASES IN SURFACE BLASTING

Edition 1
June 2011

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ABOUT THE AEISG

The Australian Explosives Industry and Safety Group (AEISG Inc) was formed in 1994. It was originally known as the Australian Explosives Manufacturers Safety Committee and was initially comprised of representatives from Dyno Nobel Asia Pacific Ltd (previously Dyno Wesfarmers Limited), Orica Explosives (previously ICI Explosives), Union Explosives Español (UEE, previously ERT) and Total Energy Systems (TES).

Since formation, the AEISG Inc membership has expanded and broadened. Current membership includes:

- Applied Explosives Technology Pty Ltd
- Thales Australia
- Dyno Nobel Asia Pacific Limited
- Maxam Explosives (Australia) Pty Ltd
- Orica Australia Limited
- Roche Blasting Services Pty Ltd
- Johnex Explosives

The goal of the AEISG is to continuously improve the level of safety throughout our industry in the manufacture, transport, storage, handling and use of, precursors and explosives in commercial blasting throughout Australia.

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PREAMBLE

The use of explosives to break rock is an intrinsically harzardous process. These hazards have been studied over the years and modern mining methods have evolved to minimize the inherent risks of blasting under most conditions.

These guidelines have been developed to assist the safe use of explosives in situations where a specific additional hazard may arise due to the generation of nitrogen oxides (NOx) within the post-blast gases. These oxides are generally regarded as products arising from imperfect decomposition of ammonium nitrate explosives during detonation.

The purpose of these guidelines is to inform explosives users of:

- the hazards of NOx gases;
- the likely causes of their generation from blasting;
- possible measures to eliminate or minimize NOx generation; and
- to provide general management advice in the event of NOx incidents.

The information is provided in good faith and without warranty.

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1. SCOPE

Those involved in blasting operations need to be aware of the causes, risks and consequences of the oxide of nitrogen (NOx) gases that may emanate from their blasting activities. The aim of this Code of Practice is to provide information and recommended guidelines to assist in the prevention and management of blast generated NOx gases from surface blasting operations. The Code is specific to NOx gases and covers the following areas:

- the likely causes of NOx gases from blasting
- possible control measures to prevent or minimise blast generated NOx gases
- management of NOx gases from blasting should they occur

2. DEFINITIONS

ANFO:	A mixture of ammonium nitrate and fuel oil with or without a dye colouring agent (Definition from AS2187.0).
Customer:	The person with direct management responsibility for the surface blasting practices, including the selection of explosive products.
Dewatered hole:	A blast hole which has had water removed using an in-hole pump or other mechanical means
Dry hole:	A blast hole which contains no detectable water.
Dust:	Airborne particulate matter ranging in diameter from 10 to 50 microns.
Dynamic water:	Water that is in motion (i.e. flowing water)
Gas bag:	An inflatable bladder used to block off a blast hole and support explosives or stemming.
Hole liner:	A flexible plastic tube which is placed into a blast hole before product is loaded into the tube, providing protection from water or broken ground
Hole saver:	A plastic funnel which is placed in the collar of a hole, allowing product to be loaded, but preventing fallback of dirt or water ingress.
NOx:	A multiple combinations of oxides of nitrogen (N_2O, NO, NO_2, N_2O_4, N_2O_3, N_2O_5) with nitrogen dioxide (NO_2) being the principle hazardous nitrous fume.
Post-blast fume:	Gases generated by the detonation of explosives during blasting.
Precursor:	A material resulting from a chemical or physical change when two or more substances consisting of fuels and oxidisers are mixed and where the material is intended to be used exclusively in the production of an explosive. (Definition from AEMSC Code of Good Practice Precursors for Explosives.)
Recharge:	A term used to describe the re-entry of water back into a blast hole after it has been dewatered
Sleep time:	The time between explosives being loaded into a blast hole and their initiation (Definition from AS2187.0).
Wet hole:	A blast hole that contains any amount of detectable water.

3. BACKGROUND

The group of gases known as Oxides of Nitrogen or NOx, of which the most common are nitric oxide (NO) and nitrogen dioxide (NO_2), are often found as by-products in the post-blast gases of ammonium nitrate-based explosives. Together, these gases are loosely referred to as "NOx". Nitric oxide is invisible, but nitrogen dioxide ranges from yellow to dark red depending on the concentration and size of the gas cloud. These gases are toxic.

NOx from blasting constitutes only a small proportion of the total NOx emissions from human activities (primarily power generation and motor vehicles) and natural sources. However blasting produces a sudden localised release of gases with potentially high concentrations of NOx. Such gas emissions pose a health risk if people are exposed to them before the plumes can dissipate.

Despite a long history of blast-related NOx emissions, very few quantitative studies have been done under realistic field conditions. The underlying causes of high NOx are fuel-deficiency in the explosive or detonation reactions that do not continue to completion. There are many ways in which these conditions may arise.

In the absence of a single general cause or general solution, these guidelines should be viewed as an aid to identifying the local cause of NOx and as a prompt for possible ways to address those causes. It should be understood that, given the complexity of the problem and the inherent variability in the blasting environment, NOx events may still occur even after prevention and mitigating actions have been put in place. The guidelines therefore include advice on managing blasts that could produce fume and recommendations for treatment of people who may have been exposed to NOx.

As recommended in Section 7 of this code, and as outlined in Australian Standard AS2187 Part 2 - 2006, Use of Explosives (refer Appendix 7), blast sites should develop their own site specific systems and procedures for the prevention and management of blast generated gases. Such site specific systems and procedures would have more relevance and detail, focus on issues of particular importance and provide increased clarity and direction to staff in regards to expected actions and responsibilities. This code should assist in the development of such systems and procedures.

4. CAUSES OF NOX FUME IN BLASTING

Under ideal conditions, the detonation of ammonium nitrate-based explosives will produce nitrogen, carbon dioxide and water vapour according to reactions such as **(1)** (the entity CH_2 represents a typical hydrocarbon fuel).

$$\underset{\text{Ammonium nitrate}}{3\,NH_4NO_3} + \underset{\text{Fuel}}{CH_2} \rightarrow \underset{\text{Nitrogen}}{3\,N_2} + \underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{7\,H_2O} \quad \text{..........(1)}$$

None of the explosive product gases are coloured, so apart from steam and dust, there will be no visible 'fume'.

If conditions do not allow such a complete decomposition to take place, a fraction of the nitrate may only partially react to produce NOx instead of a full reaction to nitrogen. For example, nitric oxide can be generated by under-fuelled ("oxygen-positive") explosives according to reactions similar to (**2**);

$$\underset{\text{Ammonium nitrate}}{5\,NH_4NO_3} + \underset{\text{Fuel}}{CH_2} \rightarrow \underset{\text{Nitrogen}}{4\,N_2} + \underset{\text{Nitric oxide}}{2\,NO} + \underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{11\,H_2O} \quad \text{..........(2)}$$

The nitric oxide formed initially converts rapidly to orange/red plumes of nitrogen dioxide on contact with atmospheric oxygen (**3**).

$$\underset{\text{Nitric oxide}}{2\,NO} + \underset{\text{Oxygen}}{O_2} \rightarrow \underset{\text{Nitrogen dioxide}}{2\,NO_2} \quad \text{..........(3)}$$

Every kilogram of ammonium nitrate diverted along reaction paths **(2)** and then **(3)** generates over 110 litres of NOx. In the extreme worst case of no added fuel, a kilogram of ammonium nitrate can theoretically generate about 600 litres of NOx. The energy release associated with NOx-generating reactions is smaller than for the complete decomposition of ammonium nitrate as per the reaction **(1)** but, as the above calculations indicate, only a small fraction of the explosive mass reacting in the wrong way can produce noticeable volumes of NOx gases. Thus, a blast generating noticeable volumes of NOx gases will not necessarily produce a bad blasting result.

While the above example describes an under-fuelled explosive, anything that prevents the ammonium nitrate from fully decomposing through to its thermodynamically-favoured end product, nitrogen, could result in NOx. This can happen even in perfectly oxygen-balanced explosives.

The conditions leading to post-blast NOx are varied, but can be seen as cases of either fuel deficiencies or incomplete detonation of the explosive. These problems may apply to the explosive composition as a whole or to localised regions within the explosive.

In practical terms, these NOx-generating conditions might be the result of:

1. Explosive formulation and quality assurance.
2. Geological conditions.
3. Blast design.
4. Explosive product selection.
5. On-bench practices.
6. Contamination of explosive in the blast-hole.

The various ways in which the above conditions can contribute to post-blast NOx fume and the possible ways to prevent or mitigate their effects are explored in more detail in Section 5. When seeking to identify which of the above conditions are the most likely contributors to an incident where NOx gases are generated, the fault tree analysis diagram provided in Section 6 may be helpful.

5. NOX FUME CAUSES AND MITIGATION MEASURES

The following tables provide more details relating to the primary causes which may lead to the generation of NOx gases in surface blasting. The tables also include likely indicators and possible control measures that can be taken in managing surface blasts to prevent or mitigate the generation and effects of NOx. Specific blasting sites may have, or develop, other control measures.

Primary Cause 1: Explosive Formulation and Quality Assurance		
Potential Cause	**Likely indicators**	**Possible Control measures**
Explosive product incorrectly formulated	• Frequent NOx fume • All blasts and all locations utilising a specific explosive product	Explosives formulated to an appropriate oxygen balance to minimise the likelihood of post-blast fume
		Explosives product to be Authorised
		Explosives product to meet Authorised definition
		Explosives supplier to test formulations where any change in ingredients
		Explosives/Precursor supplier to provide relevant Technical Data Sheets and Manufacturing directions
Explosives product change	• Frequent NOx gases • All new blasts and locations	Supplier to notify user sites of changes to product specifications, Technical Date Sheets, recommendations for use
		Supplier to test changed product for adverse impacts
Inadequate mixing of raw materials	• Frequent NOx fume • NOx emitted from blast holes loaded from a specific delivery system • Product appearance abnormal	Visual check
		Density check
		Ensure compliance with supplier's/manufacturer's instructions

Primary Cause 1: Explosive Formulation and Quality Assurance		
Potential Cause	**Likely indicators**	**Possible Control measures**
Delivery system metering incorrectly	• Frequent NOx fume • All areas associated with loading from a specific delivery system • Product appearance abnormal	Regular calibration of metering systems
		Quality control of explosives products conducted in accordance with manufacturer's recommendations
Delivery system settings for explosive product delivery overridden		Do not override calibration settings on manufacturing systems
Explosive precursors not manufactured to specification	• Increased frequency • All blasts and all locations utilising explosive product(s) that incorporate a specific precursor	Investigate with supplier of explosive precursors
		Precursor Supplier/Owner to manage disposal or rectification
Precursor degradation during transport and storage	• Intermittent NOx gases • Traceable to a precursor which has degraded between manufacture and use	Appropriate storage location and stock rotation management (i.e. FIFO)
		Appropriate transport and transfer of precursors
		Inspection and/or testing of precursors prior to use in accordance with supplier's recommendations
		Precursor Supplier/Owner to manage disposal or rectification
Raw material changes	• Frequent NOx gases • All blasts and locations utilising explosive product(s) that incorporate a specific raw material	Change management procedures in place by suppliers
		Prior notification to suppliers from site change management systems where precursors are supplied by sites, for example customer-supplied fuels

Primary Cause 2: Geological conditions		
Potential Cause	**Likely indicators**	**Possible Control measures**
Lack of relief in weak/soft strata	• Frequent NOx gases • In specific areas known to contain weak/soft strata only	Understand geology of each shot and design blast (timing and explosive product) to ensure adequate relief in weak/soft strata, for example incorporation of a free face, reduction of powder factor, modified timing etc.
		Minimise blast size and depth
Inadequate confinement in soft ground	• Frequent NOx gases • NOx occurs in specific areas known to contain weak/soft strata only	Appropriate explosives product selection – refer to supplier
		Change design to suit conditions
		Minimise blast size
Explosive product seeping into cracks	• Intermittent NOx gases • In specific areas known to contain a high incidence of faulted/fractured ground only	Follow manufacturer's recommendations on explosive product selection
		Use blast hole liners
		Maintenance of accurate drill records which are used to map geological conditions
		Record and monitor blast holes which are slumped or require excessive explosive product to reach stemming height, but where water is not present
Dynamic water in holes	• Intermittent NOx gases • Preceded by the observation of slumped blast holes • Usually when using non water-resistant explosive products	Minimise or eliminate sleep time of shot eg load and shoot
		Follow manufacturer's recommendations on explosive product selection

Primary Cause 2: Geological conditions		
Potential Cause	**Likely indicators**	**Possible Control measures**
		Measure recharge rates if dewatering, and choose explosive products according to manufacturer's recommendations
		Record slumped holes and use this information to build understanding of pit hydrology
		Understand hydrology of pit and plan blasting to avoid interaction between explosives and dynamic water (either natural or from other pit operations)
		Use hole liners where explosive products not water resistant
Moisture in clay	• Frequent NOx gases • In clay strata only	Consider water resistant explosive products and how this may impact sleep time.
		Hole liners may be required for ANFO.
Blast hole wall deterioration between drilling and loading eg cracks, voids, hole contraction	• Intermittent NOx gases • Traceable to specific geological areas	Minimise time between drilling and loading
		Use blast hole cameras to ascertain hole condition in critical areas
		Use hole savers
		Mine planning to ensure benches are unaffected by backbreak from earlier blasts, for example presplits, buffers etc.
		Use drilling mud to stabilise hole (confirm chemical compatibility with explosives first)

Primary Cause 2: Geological conditions		
Potential Cause	**Likely indicators**	**Possible Control measures**
Chemistry of rock type e.g. limestone	• Frequent NOx gases • Traceable to specific geological areas	Appropriate explosive product as per manufacturer recommendations
		Use hole liners

Primary Cause 3: Blast Design		
Potential Cause	**Likely indicators**	**Possible Control measures**
Explosive desensitisation due to the blast hole depth	• Frequent NOx gases • In deep holes only	Reduce bench height
		Ensure adequate relief in deep holes
		Follow manufacturer's recommendations on explosive product selection and blast design for deep holes, for example decking where appropriate.
Inappropriate priming and/or placement	• Intermittent NOx gases • Residue product	Follow manufacturer's recommendations on explosive product initiation.
		Review of the site approved blast design to improve priming.
Mismatch of explosives and rock type	• Frequent NOx gases	Appropriate blast design/approval process for site.
		Communication between user and supplier to determine product suitability for application

Primary Cause 3: Blast Design		
Potential Cause	**Likely indicators**	**Possible Control measures**
Inter-hole explosive desensitisation	• Frequent NOx gases • Blast holes drilled too close together • Blast hole deviations	Change blast design and timing.
		Product and initiation selection – consult manufacturer/supplier
		Increased control on drilling with deeper designs
Intra-hole explosive desensitisation in decked blast holes	• Frequent NOx gases • When using decks only	Appropriate separation of explosive decks eg distance, initiation timing.
		Change design
Initiation of significant explosive quantities in a single blast event	• Intensity of post-blast gases proportional to explosives quantity used	Reduce blast size in order to reduce total explosive quantity being initiated in the one blast event
		Reduce powder factor

Primary Cause 4: Explosive product selection		
Potential Cause	**Likely indicators**	**Possible Control measures**
Non water-resistant explosive products loaded into wet or dewatered holes	• Intermittent NOx gases • Blasts containing wet/dewatered blast holes only	Follow manufacturer's recommendations on explosive product selection
		Regular education of bench crew on explosive product recommendations from current supplier
		Discipline in on-bench practices (refer also to Primary Cause 5)
		Weather forecasts to be obtained and considered
		Bench design for effective water run-off
Excessive energy in weak/soft strata desensitising adjacent explosive product columns	• Frequent NOx gases • In specific areas known to contain weak/soft strata only	Understand geology of each shot and design blast (timing and explosive product) to match, for example reduction of powder factor.
		Follow manufacturer's recommendations on explosive product selection
		Obtain appropriate technical assistance if required to ensure optimal result
Primer of insufficient strength to initiate explosive column	• Frequent NOx gases • All blasts using a particular primer type / size	Follow manufacturer's recommendations on compatibility of initiating systems with explosives

Primary Cause 4: Explosive product selection		
Potential Cause	**Likely indicators**	**Possible Control measures**
Desensitisation of explosive column from in-hole cord initiation	• Frequent NOx gases • Only in areas where in-hole cord initiation is used	Follow manufacturer's recommendations on compatibility of initiating systems with explosives
		Minimise use of detonating cord for down the hole initiation wherever possible
Inappropriate explosive product for application	• Frequent NOx gases • In specific applications	Communication between user and supplier to determine product suitability for application
		User to follow supplier's Technical Data Sheets
		Appropriate blast design/approval process for site.

Primary Cause 5: On bench practices		
Potential Cause	**Likely indicators**	**Possible Control measures**
Hole condition incorrectly identified	• Intermittent NOx gases • Only when using non water-resistant explosive products	Dip all holes prior to loading
		Record wet, dewatered and dry holes on blast plan and use this information as a basis for explosive product selection
		Measure recharge rate of dewatered holes and choose explosive products according to manufacturer's recommendations
		Record actual load sheets for each hole
		Minimise time between dipping and loading, especially in soft and clay strata. Note: Enough time should be allowed for any dynamic water in the hole to be identified
		Use blast hole cameras to ascertain hole condition in critical areas
		Minimise sleep time
		Training/competence of blast crew
Blast not drilled as per plan	• Intermittent NOx gases • Can be correlated with inaccurately drilled patterns	Maintenance of accurate drilling records and review of blast design if required to compensate for inaccuracies.
Dewatering of holes diverts water into holes previously loaded with dry hole explosive products	• Intermittent NOx gases • Only when using non water-resistant explosive products	Load wet holes first and dip remaining holes prior to loading. Adjust explosive product selection according to manufacturer's recommendations.
		Bench design for effective water run-off
		Training/competence of blast crew

Primary Cause 5: On bench practices		
Potential Cause	**Likely indicators**	**Possible Control measures**
Blast not loaded as per blast plan	• Intermittent NOx gases • Localised or general occurrence	Training/competence of blast crew
		Effective supervision
		Communication of loading requirements
		Record actual loadings eg product, quantity, height

Primary Cause 6: Contamination of explosives in the blast hole		
Potential Cause	**Likely indicators**	**Possible Control measures**
Explosive product mixes with mud/sediment at bottom of hole.	• Intermittent NOx gases • Blasts containing wet/dewatered blast holes only	Optimise drilling practices to minimise blast hole damage
		Ensure appropriate loading practices are followed during charging
		Ensure primer is positioned in undiluted explosive product
		Insert gas bag to separate mud/sediment from explosive product
		Use blast hole savers
		Use end of loading hose dispersers to minimise contamination
		Training/competence of blast crew
Interaction of explosive product with drilling muds.	• Frequent NOx gases • Blasts where drilling mud is used in conjunction with a given explosive product	Confirm compatibility of drilling mud with explosive products before use
		Ensure that drilling muds and other chemicals used on bench are managed through change management systems

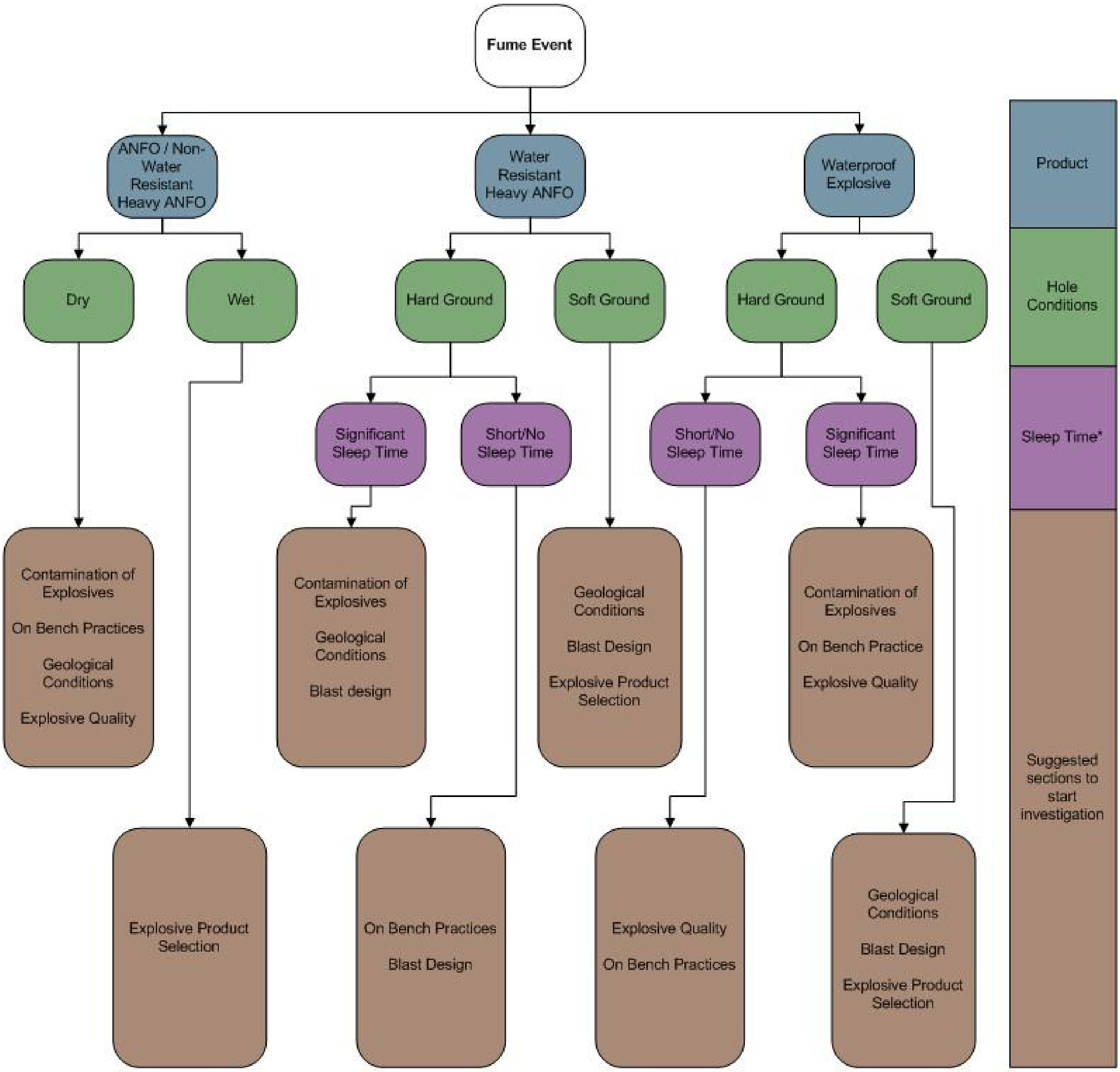
Primary Cause 6: Contamination of explosives in the blast hole		
Potential Cause	**Likely indicators**	**Possible Control measures**
Penetration of stemming material into top of explosive column (fluid/pumpable explosive products only)	• Intermittent NOx gases • Blasts charged with fluid/pumpable explosive products only	Use appropriate stemming material
		Ensure explosive product is gassed to manufacture to specifications before stemming
		Seal top of explosives column prior to stemming e.g. gas bag
Water entrainment in explosive product	• Intermittent NOx gases • Blasts containing wet/dewatered blast holes only	Training/competence of blast crew
		Eliminate top loading into wet blast holes
		Ensure all primers are positioned in undiluted explosive product. Increase number of primers in explosives column
		Use of gas bags in dewatered blast holes
		Seal top of explosives column to prevent water ingress eg gas bag
		Use hole liners
		Minimise hose lubrication during charging
		Measure water recharge rate after dewatering and adjust explosive product selection according to manufacturer's recommendations.
		Select explosive products for wet blast holes according to manufacturer's recommendations.

Primary Cause 6: Contamination of explosives in the blast hole		
Potential Cause	**Likely indicators**	**Possible Control measures**
		Verify correct hose handling practices are in place eg operator competence, procedures, use explosives supplier's personnel
		Load low blast holes last where practical
		Use suitable, safe dewatering techniques
		Minimize sleep time
Moisture in ground attacking explosive product	• Frequent NOx gases • Wet ground occurrence	Explosives product selection
		Use hole liners where product not water resistant
		Minimise or eliminate sleep time eg load and shoot
		Load wet holes first and dip remaining holes prior to loading. Adjust explosive product selection according to manufacturer's/supplier's recommendations.
Contamination of explosives column by drill cuttings during loading	• Intermittent NOx gases	Verify correct hose handling practices are in place eg operator competence, procedures, use explosives supplier's personnel
		Training/competence of blast crew
		Minimise vehicle contact near blast holes
		Use hole savers

Primary Cause 6: Contamination of explosives in the blast hole		
Potential Cause	**Likely indicators**	**Possible Control measures**
Rainfall on a sleeping shot.	• Intermittent NOx gases • Occurs following rainfall • Usually when using non water-resistant explosive products • May be preceded by the observation of slumped blast holes	Review rainfall forecasts for planned sleep time of shot and select explosive products according to manufacturer's recommendations.
		Minimise sleep time for non-wet blast hole explosive products if rain is predicted. Consider early firing of blast.
		Bench design for effective water runoff
		Seal top of blast holes to prevent water ingress e.g. with gas bag
		Consider removing affected product
		Use hole savers

6. FAULT TREE ANALYSIS OF BLAST GENERATED NOX GASES INCIDENTS

Should NOx be produced in a surface blast the following fault tree can be used to identify which of the fundamental causes (see Section 5) was the significant contributor to the generation of NOx. Once the likely causes have been identified appropriate action plans can then be put in place to mitigate and reduce the generation of NOx from future surface blasts. The fault tree can also be used to educate those responsible for surface blasts as to their responsibilities in ensuring appropriate steps are taken in the design, loading and firing of the blast to minimise the likelihood of generating NOx from the blast.



*Reference to short sleep or significant sleep in this Fault Tree does not refer to the explosives manufacturer's recommended sleep time, but rather is a subjective term aimed at differentiating between a load and shoot blast and one which is designed to sleep for a period of time. It recognises that there is a correlation between increased sleep time and the generation of NOx gases from blasting. As a guide for this Fault Tree Analysis only, a time of less than 3 days is considered a short sleep time, however conditions vary from site to site and consideration should be given to the adverse impacts longer sleep times can have on loaded blast holes.

7. MANAGEMENT

7.1 Explosives/Precursor Manufacturer/Supplier

The manufacturer and/or supplier of the precursors or bulk explosives must ensure products are formulated appropriately to prevent/minimise the generation of NOx gases during blasting. The products should be authorised, with quality control systems in place to ensure that the manufactured/supplied products meet specifications

The explosives manufacturer/supplier must have documented change management procedures for modification and alterations to explosive and/or precursor formulations. The procedures must provide for:

1. assessing and managing risk associated with the modification/alteration of the formulation through the use of documented hazard review assessments;
2. recording any modification/alteration and updating relevant authorisations, Technical Data Sheets, Material Safety Data Sheets, work procedures, and training programs as and where relevant;
3. ensuring changes continue to meet the requirements of this Code;
4. ensuring that any modification or alteration does not affect the validity of an authorisation issued by the relevant authority; and
5. notifying the user sites of changes to authorisations, Technical Data Sheets, Material Safety Data Sheets or recommendations in relation to proper use of the explosives or precursor products.

In cases where there is a recognised potential for the generation of post-blast NOx gases, or where historical experience indicates such a potential, management systems need to be in place to effectively manage the risks posed by the presence of such emissions. These management systems need to be risk based to minimise the impact on site operators and equipment, and on the public and the environment.

Consideration of post-blast gases, including NOx, should be included in the development of the Blast Management Plan for any specific site as outlined in Australian Standard AS2187 Part 2: Use of Explosives (refer Section 4 and Appendix A). The Blast Management Plan includes the details and records of any blast that are taken and maintained, which would have provision for the detection, assessment and reporting of any blast generated NOx gas event. It is considered good practice to record any significant blasting activities for possible future examination.

7.2 Risk Assessment

7.2.1 Initial

Prior to any blasting operation, a risk assessment should be undertaken to investigate the potential for post-blast NOx generation at a particular site and, where necessary, to identify the appropriate control measures which need to be put in place to minimise the likelihood and/or extent of any post-blast gases produced, and to determine the appropriate measures necessary to ensure safety for all on-site and off-site personnel eg effective exclusion zones and other identified management zones.

The risk assessment should be undertaken by a competent person or team. Representatives of any such team may include:

- the blast site management
- the explosive supplier
- the drillers
- the shotfiring crew
- other relevant contractors involved in the blasting operations.

The potential causal factors and relevant control measures outlined in Section 5 should be used in conducting the risk assessment to ensure all factors have been considered and adequately addressed where considered necessary.

While the risk assessment will lead to the development of an effective exclusion zone as a response to any proposed blast, it must also consider the implications of any potential post-blast gases and the risks posed to areas/directions where such gas plumes might drift, even outside the determined exclusion zone for the blast. The risk assessment will consider what steps need to be taken, if any, in these management zones to minimise risk to any persons, on-site or off-site.

7.2.2 Post Loading/Pre Firing Reassessment

Following the loading of any shot, and immediately prior to firing, a reassessment of the risks posed by the blast should be undertaken with due consideration given to the relevant factors applying at the time eg rain events, wind direction and speed, inversions, operational factors on site.

Following the reassessment it may be necessary to apply additional risk control measures, or defer the blast, to ensure appropriate safety levels are achieved.

7.3 Risk Management

Blast sites with the potential for post-blast NOx gases, or which are experiencing such gas generation, must have systems in place to effectively manage the risks posed. These management systems would normally include the following:

7.3.1 Training

Training of all employees and contractors involved in the blasting process, and those involved in the management of these personnel, should be undertaken to ensure the relevant risk are understood and managed.

Training should include at least the following:

- the identification and rating of post-blast NOx gases
- the toxicology of such gas emissions
- potential causal factors
- appropriate control measures
- site specific blasting operation procedures
- reporting procedures for post-blast NOx gases
- emergency response procedures for post-blast NOx gases.

7.3.2 Post-blast Fume Identification, Reporting and Recording.

Post-blast NOx gases should be identified and rated by blast site personnel using the rating scale outlined in Appendix 2 and 3. Such events should be reported to the blast site management and to the explosives supplier, who should maintain records of such events.

Note: In some jurisdictions, post-blast NOx events of a particular significance may be required to be reported to the relevant statutory authority. Applicable legislation should be referenced to determine requirements.

It should be noted that the visual appearance of a post-blast NOx gas plume will depend both on the concentration of NO_2 and on the size of the plume. It will change with time as NO is converted to NO_2 and as the wind disperses the plume. Therefore the visual rating is approximate at best, but gives some indication of the severity of the event, so is worth recording. This and other factors worth recording in the report of post-blast NOx gas events are listed in Appendix 1.

Blast site personnel, including Blast Guards should report any noticeable post-blast NOx gases including the extent and direction of such plumes.

7.3.3 Blast Management Plan

The following areas should be considered for inclusion in any specific site Blast Management Plan (refer also AS2187 Part 2 Appendix A):

- training
- drill report assessment
- hole monitoring prior to loading
- explosive selection
- explosive loading procedures, including primer placement
- hole loading sequence
- hole stemming
- sleep time
- exclusion zone determination
- any additional management zone
- blast guard posting

- PPE, including personnel monitors and/or gas masks
- changes to conditions after explosives loading
- post-blast gases identification, rating and reporting
- meteorology eg rain, wind
- emergency response for persons exposed to NOx fumes
- communication with neighbours and other potentially impacted parties

7.3.4 Investigation of Post-blast NOx Events

As indicated earlier any reported significant NOx event or trends should be investigated to minimize the potential for ongoing generation of NOx gases and to mitigate the potential impacts of any such event. Such investigation should involve the explosives manufacturer and/or supplier.

The fault tree (see Section 6) and the control measures for any potential causal factors outlined in this Code should assist any investigation and ensure all relevant factors are considered and adequately addressed. The results of any investigation of post-blast NOx gases should then be factored into the site specific procedures to minimize fume production and to mitigate impacts.

7.3.5 Weather Conditions

Rain, wind speed and direction can significantly alter the impact and severity of a post-blast gas event. Weather forecast knowledge regarding wind direction and speed can be exploited when blast scheduling in order to maximize dissipation of post-blast gases and to direct them away from sensitive areas. Temperature inversions can also be tracked and considered when determining when best to schedule the firing of an affected blast.

7.3.6 Exclusion Zones

For blasting operations exclusion zones are established to minimize risks to personnel. Post-blast NOx gases need to be considered when establishing such zones and placement of blast guards.

The following personnel have been identified as those generally at the greatest risk of exposure to post-blast NOx gases during blasting operations. Consideration should be given to minimizing the numbers of personnel exposed to these situations:

- shotfirers and support personnel may be exposed during the post-blast period by moving back into the general blast area prior to dispersion of the gases;
- shotfirers and support personnel may be exposed during the post-blast inspection of the blast area as the dispersion of the gases can be very localized and continue to leak from under the ground for some time after the blast;
- shotfirers and support personnel may be exposed during the blast guarding process;
- general blast site personnel may be exposed during the dispersion of the NOx gases across a site;
- personnel that gather at areas such as blast guard positions and crib huts, close to the edge of the exclusion zone.

The extent and direction of any post-blast NOx gas plumes should be closely monitored to minimize any adverse impacts and to facilitate appropriate emergency response. It may be useful to increase the size and/or the duration of the exclusion zones in some cases to provide maximum opportunity for any NOx formed to dissipate to normal background levels eg downwind of blasting operations.

Where potential for significant post-blast NOx gases exists, consideration needs to be given to personnel monitors, or gas masks, as an additional safety measure for persons conducting higher risk activities eg post-blast inspections.

7.3.7 Management Zones

While steps should be taken to eliminate or minimise the generation of blast generated NOx gases, there will be occasions where potential risk remains.

Both the initial risk assessment and the post-loading/pre-firing risk assessment must include consideration of areas of risk outside the developed exclusion zone. Such areas will normally be downwind of blasting operations where post-blast gases may drift in concentrations yet to be effectively dissipated.

Following such assessments, additional risk control measures may be considered necessary to ensure risk minimisation eg temporary evacuation of such management zones, deferral of blasting until climate conditions are more favourable.

7.3.8 Communication

While persons off site are unlikely to be significantly affected by blast generated NOx gases, communication with neighbours and other potentially impacted parties should be managed to alert them to possible post-blast gas events and to the steps being taken to prevent/minimise any risks presented. Some safety recommendations and guidance to such parties should also be considered.

7.3.9 Emergency Response

While it is unlikely that exposure to post-blast NOx gases will result in a fatality due to the concentration of the gases in an outdoor, well ventilated surface blasting site, NOx gases must be recognized as a potential health threat and managed accordingly. Generally, NOx plumes generated during blasting will dissipate to background levels in a relatively short time. Dissipation is highly dependent on local atmospheric conditions. However, in cases where a NOx plume does not dissipate and has the potential to result in the exposure to people the following steps must be undertaken:

Persons in the path of a NOx gas plume should

- not enter the plume
- move away from the path of the plume
- if indoors, close all windows and doors and stay inside
- if in a car, stay inside and use recirculated air conditioning if possible

If a person has been exposed to NOx gases medical attention must be sought as soon as it is safe to do so. The possibility of delayed and life-threatening pulmonary oedema dictates that:

- any person exposed to a visible plume of NOx, and/or any person experiencing sudden acute effects of coughing, shortness of breath or irritation of the mucous membranes of the eyes, nose or throat following post-blast NOx events must be examined by a medical practitioner without delay, even if no NOx smell was noticed or symptoms are mild
- the treating medical practitioner must be informed of the potential NOx exposure. The material included in Appendix 4 should be provided to assist in the conveying of such NOx exposure information to the treating medical practitioners.

APPENDIX 1 - FACTORS TO BE CONSIDERED FOR INCLUSION IN REPORT OF POST-BLAST NOX GAS EVENT

The following factors should be considered for inclusion in any post-blast report:

- date and time of blast;
- presence of noticeable post-blast NOx gases;
- post-blast NOx gas rating, eg 0 - 5 (refer Appendix 2);
- extent of post-blast NOx gas event, eg A,B or C (refer Appendix 2);
- duration of any post-blast NOx gas event (measure of time to disperse);
- direction of movement of any post-blast NOx plume;
- movement of any post-blast NOx gas plume relative to the established exclusion zone and any established management zone (ie maintained within, exceeded);
- climate conditions, including temperature, humidity, wind speed and direction, cloud cover, rain;
- results/readings of any NOx monitoring equipment employed for the blast
- video results of blast where relevant.

APPENDIX 2 - VISUAL NOX FUME RATING SCALE

The following table, together with the Field Colour Chart in Appendix 3, details how NOx gases from a surface blast can be assessed.

Level	Typical Appearance
Level 0 No NOx gas	
Level 1 Slight NOx gas 1A Localised	
1B Medium	
1C Extensive	
Level 2 Minor yellow/orange gas 2A Localised	
2B Medium	
2C Extensive	
Level 3 Orange gas 3A Localised	
3B Medium	
3C Extensive	
Level 4 Orange/red gas 4A Localised	
4B Medium	
4C Extensive	
Level 5 Red/purple gas 5A Localised	
5B Medium	
5C Extensive	

Assessing the amount of NOx gases produced from a blast will depend on the distance the observer is from the blast and the prevailing weather conditions. The intensity of the fume produced in a blast should be measured on a simple scale from 0 to 5 based on the table above. The extent of the fume also needs to be assessed and this should be done on a simple scale from A to C where:-

A = Localised (ie Fume localised across only a few blast holes)

B = Medium (ie Fume from up to 50% of blast holes in the shot)

C = Extensive (ie Extensive generation of fume across the whole blast)

APPENDIX 3 - FIELD COLOUR CHART.

Pantone colour numbers have been included in the following Field Colour Chart to ensure colours will be produced correctly thereby ensuring a reasonable level of standardisation in reporting fume events across the blasting industry.

Level	Colour	Pantone Number
Level 0 No NOx gas		Warm Grey 1C (RGB 244, 222, 217)
Level 1 Slight NOx gas		Pantone 155C (RGB 244, 219, 170)
Level 2 Minor yellow/orange gas		Pantone 157C (RGB 237, 160, 79)
Level 3 Orange gas		Pantone 158C (RGB 232, 117, 17)
Level 4 Orange/red gas		Pantone 1525C (RGB 181, 84, 0)
Level 5 Red/purple fume		Pantone 161C (RGB 99, 58, 17)

APPENDIX 4 - INFORMATION FOR TREATING MEDICAL STAFF.

Those exposed to NOx gases should seek immediate medical treatment and consideration should be given to placing those exposed under observation for at least 24 hours after exposure.

To assist medical staff the following guide should be provided.

Advice to Medical Staff

in the Treatment of Those Who Have Been Exposed to NOx Gases.

The patient may have been exposed to NOx. This is a gas usually produced on mines after the use of explosives. NOx consists of multiple combinations of nitrogen and oxygen (N_2O, NO, NO_2, N_2O_4, N_2O_3, N_2O_5). Nitrogen dioxide (NO_2) is the principle hazardous nitrous fume. NOx irritates the eyes and mucous membranes primarily by dissolving on contact with moisture and forming a mixture of nitric and nitrous acids. But this is not the only mechanism by which injury may occur. Inhalation results in both respiratory tract irritation and pulmonary oedema. High level exposure can cause methhaemoglobinaemia. Some people, particularly asthmatics, can experience significant broncospasm at very low concentrations.

The following effects are commonly encountered after NOx exposure:

ACUTE

- Cough
- Shortness of breath
- Irritations of the mucous membranes of the eyes, nose and throat

SHORT TERM

- Pulmonary oedema which may be delayed for up to 4-12 hours

MEDIUM TERM

- R.A.D.S. (Reactive Airways Dysfunction Syndrome
- In rare cases bronchiolitis obliterans which may take from 2-6 weeks to appear

LONG TERM

- Chronic respiratory insufficiency

High level exposure particularly associated with methhaemoglobinaemia can cause chest pain, cyanosis, and shortness of breath, tachapnea, and tachycardia. Deaths have been reported after exposure and are usually delayed. Even non irritant concentrations of NOx may cause pulmonary oedema. Symptoms of pulmonary oedema often don't become manifest until a few hours after exposure and are aggravated by physical effort. Prior to transfer to you the patient should have been advised to rest and if any respiratory symptoms were present should have been administered oxygen. The patient will need to be treated symptomatically but as a base line it is suggested that the following investigations are required:

- Spirometry
- Chest x-ray
- Methheamoglobin estimation

Because of the risk of delayed onset pulmonary edema it is recommended that as a precaution the patient be observed for up to 12 hours. As no specific antidote for NOx exists, symptoms will have to be treated on their merits.

APPENDIX 5 - TOXICOLOGY OF NOx

Only one study (CSIRO Australia, 2007) has been found which attempts to quantify the size, concentration and longevity of post-blast gas plumes under realistic conditions pertaining to open cut mining [1].

However, the toxicology of NOx is well understood from controlled medical studies and this knowledge is embodied in exposure limits defined by organisations such as the US Environmental Protection Agency (EPA) and US National Institute for Occupational Safety and Health (NIOSH).

The US EPA has compiled sets of Acute Exposure Guideline Levels (AEGLs*)* which represent threshold exposure limits for the general public and are applicable to emergency exposure periods ranging from 10 minutes to 8 hours [2].

The other relevant standards are known as IDLH levels (Immediately Dangerous to Life and Health) which have been determined by NIOSH [3]. These exposure limits are not considered relevant for public health scenarios, but are generally applied when selecting respirators in an industrial situation.

The toxicology of NOx is summarised below, but more information including detailed definitions of AEGL's and IDLH is contained in Appendix 6.

Nitric Oxide (NO)
Under normal conditions, NO is actually formed at low levels in the body and it serves as an important regulator molecule for the human cardiovascular, immune and nervous systems [4]. NO is even used therapeutically for the treatment of several conditions (for example: adult respiratory distress syndrome and frequent pulmonary hypertension in newborns). However nitric oxide can be toxic in larger amounts because it combines with haemoglobin in the blood and prevents its normal oxygen-absorbing function. The toxicology of NO is complicated by the spontaneous formation of NO_2 which has its own adverse effects on the body. As a consequence, the toxicity of NOx is guided by the levels set for NO_2.

Nitrogen Dioxide (NO_2)
The first toxic effects observed with NO_2 exposure [5] are related to irritation of the airways and eyes. These effects have been studied many times with human volunteers in control environments. Because NO_2 is not very soluble in the moist airways, some gas can reach deep into lungs, causing delayed effects, notably pulmonary oedema (fluid in the lung), which can cause death. Normally, asthmatics or people with chronic lung conditions (eg bronchitis) are considered to be the individuals most 'at risk' in the general population. As with many toxic substances, the observed effects depend on both the concentrations and duration of exposure (Table 1).

Table 1. Summary of toxic effects verses NO_2 levels

NO2 (ppm)	Exposure period	Response in Health Adults
0.04-5		Odour threshold
0.3-0.5	2 hr	Decreased lung function, cough and dry throat and mouth.
20	30 min	IDLH level (Immediately Dangerous to Life or Health)*
30	40 min	Tickling sensation in nose and throat
30	70 min	Burning sensations and cough
30	2 hr	Deep chest burning sensations, shortness of breath
80	3-5 min	Chest tightness
90	40 min	Fluid in the lung

* IDLH is defined by the US National Institute for Occupational Safety and Health (NIOSH) as the exposure that is "likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment". The IDLH standard was developed to assist in selecting respirators in a work situation. It should be noted that delayed pulmonary oedema may not be accompanied by any other significant symptoms. This has been considered in the Acute Exposure Guideline Levels (AEGL) (see Appendix 6). It is recommended to consult other authorities (medical) for further advice.

APPENDIX 6 - EXPOSURE STANDARDS

The toxic effect of any substance depends on the agent, the agent concentration, duration of exposure and the age and health status of the exposed individuals. The health effects of these components has been well studied in both workplace and community situations.

There are many different exposure standards in general use, the question of which exposure standard should be applied to the expose of both workers and the general population to post blast fumes should be considered. The most frequently applied reference standards for occupational exposures are the Occupational Exposure Limits as published by Safe Work Australia [6]. These exposure standards have been prepared for work situations and to be applied for daily exposure of workers. Additionally these standards have been derived from studies of a predominantly health, male workers, therefore since there is the potential for general public to be exposed to post blast fume it is believed these standards are not appropriate.

It is believed the most appropriate reference standards are the US EPA Acute Exposure Guideline Levels (AEGLS). These have been prepared after extensive consultation between public, private and community sectors and AEGLs are intended to describe the risk to humans resulting from once-in-a-lifetime, or rare, exposure to airborne chemicals [2]. Other community guidelines, such as National Research Council's Short-term Public Emergency Guidance Levels (SPEGLs) have been superseded by the AEGLs [7].

Included in the information below are the IDLH levels (Immediately Dangerous to Life and Health) [3]. These exposure limits are generally applied when selecting respirators in an industrial situation and not considered relevant for public health scenarios.

AEGLs (Acute Exposure Guideline Levels)

AEGLs represent threshold exposure limits for the general public and are applicable to emergency exposure periods ranging from 10 minutes to 8 hours. AEGL-2 and AEGL-3, and AEGL-1 values as appropriate will be developed for each of five exposure periods (10 and 30 minutes, 1 hour, 4 hours, and 8 hours) and will be distinguished by varying degrees of severity of toxic effects. It is believed that the recommended exposure levels are applicable to the general population including infants and children, and other individuals who may be susceptible. The three AEGLs have been defined as follows:

AEGL-1 is the airborne concentration, expressed as parts per million or milligrams per cubic meter (ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

AEGL-2 is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

AEGL-3 is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

Airborne concentrations below the AEGL-1 represent exposure levels that can produce mild and progressively increasing but transient and non-disabling odour, taste, and sensory irritation or certain asymptomatic, non-sensory effects. With increasing airborne concentrations above each AEGL, there is a progressive increase in the likelihood of occurrence and the severity of effects described for each corresponding AEGL.

Although the AEGL values represent threshold levels for the general public, including susceptible subpopulations, such as infants, children, the elderly, persons with asthma, and those with other illnesses, it is recognized that individuals, subject to unique or idiosyncratic responses, could experience the effects described at concentrations below the corresponding AEGL.

Nitric oxide (NO) * AEGL (Interim 13/Dec/2004)					
ppm					
	10 min	30 min	60 min	4 hr	8 hr
AEGL 1	NR	NR	NR	NR	NR
AEGL 2	NR	NR	NR	NR	NR
AEGL 3	NR	NR	NR	NR	NR

NR = Not recommended due to insufficient data
Short-term exposures to below 80 ppm NO should not constitute a health hazard
* AEGL values for nitrogen dioxide (see table below) should be used for emergency planning.

Nitrogen dioxide (NO_2) AEGL (Interim 13/Dec/2004)					
ppm					
	10 min	30 min	60 min	4 hr	8 hr
AEGL 1	0.50	0.50	0.50	0.50	0.50
AEGL 2	20	15	12	8.2	6.7
AEGL 3	34	25	20	14	11

Some effects may be delayed

IDLH (Immediately Dangerous to Life and Health) exposure limits.

The following is an extract from the NIOSH (US National Institute for Occupational Safety and Health) publication on the IDLH standard setting methodology and process [3]:

"The current NIOSH definition for an IDLH condition, as given in the NIOSH Respirator Selection Logic, is one that poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment [NIOSH 2004]. The purpose of establishing an IDLH value is

(1) to ensure that the worker can escape from a given contaminated environment in the event of failure of the respiratory protection equipment and,

(2) is considered a maximum level above which only a highly reliable breathing apparatus providing maximum worker protection is permitted [NIOSH 2004]. In establishing the IDLH value, the following conditions must be assured:

A. The ability to escape without loss of life or immediate or delayed irreversible health effects. (Thirty minutes is considered the maximum time for escape so as to provide some margin of safety in calculating an IDLH value.)

B. The prevention of severe eye or respiratory irritation or other reactions that would hinder escape".

NIOSH [2004]. NIOSH respirator selection logic. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH). Publication No. 2005-100.

APPENDIX 7 - REGULATORY REQUIREMENTS

A number of mining and non-mining regulators reference the 'Australian Standard AS2187.2-2006. Explosives – Storage and use. Part2: Use of explosives' in relation to safe blasting requirements. This standard outlines the need to consider post-blast fumes and manage the associated risks accordingly (refer Sections 4.8 and 9.4).

4.8 ENVIRONMENTAL IMPACTS

The area surrounding the blast site should be inspected and assessed to determine appropriate means of minimizing environmental impacts. Regulatory limits may apply.

In conducting the risk management, foreseeable factors should be considered, including, but not limited to the following:

(a) Distances to buildings, structures, and other environmental effects.
NOTE: See Appendix J for guidance.

(b) Identification of monitoring requirements and the requirement for monitoring locations, systems and instruments.

(c) Ground vibration and airblast overpressure.
NOTE: See Appendix J for information and guidance on the environmental effects of ground vibration and airblast overpressure.

(d) Effects of various weather patterns and wind directions.

(e) Effects of dust, fume, sediment run-off, noise.

Any of the above factors can be expected to have an impact on the blast design. It should also be noted that significant lead times may apply to any required interruption to utilities, e.g., gas, water, electricity.

9.4 POST-BLAST INSPECTION

The purpose of a post-blast inspection is to ascertain if it is safe for personnel to return to the blast site and for routine operations to resume.

The extensive variables associated with not only the type of blasting operation but also the location of the operations would necessitate specific rather than general post-blast procedures to be included in the blast management plan. The procedures for consideration should include but not be limited to the following:

(a) Whether there is a need for more than one person to return to the shot for the inspection.

(b) Procedures to be adopted if the inspection reveals that the 'all clear' into the exclusion zone cannot be given, including the communications mechanism of the 'all clear' or otherwise.

(c) Determination that oxygen, fumes and dust are at acceptable levels.

(d) Continuous inspection procedures during the approach to the post-blast site that might identify unusual or abnormal results indicating possible hazards.

(e) Whether there is a need to wash down/or scale (bar down), especially in underground workings.

(f) Identifying a misfire or butt and the means of clearly marking misfires or butts.

APPENDIX 8 - REFERENCES

1. CSIRO 2007, NO_x Emissions from Blasting Operations in Open Cut Coal Mining in the Hunter Valley; ACARP Project C14054.

2. Acute Exposure Guideline Levels (AEGLs) Definitions: http://www.epa.gov/opptintr/aegl/pubs/define.htm

3. US NIOSH IDLHs: http://www.cdc.gov/niosh/idlh/intridl4.html

4. Acute Exposure Guideline Levels (AEGLs) for nitric oxide (CAS Reg. No. 10102-43-9) October 2006. http://www.epa.gov/oppt/aegl/pubs/tsd309.pdf

5. Acute Exposure Guideline Levels (AEGLs) for nitrogen dioxide (CAS Reg. No. 10102-44-0) nitrogen tetroxide (CAS Reg. No. 10544-72-6) December 2008. http://www.epa.gov/oppt/aegl/pubs/nitrogen_dioxide_interim_nitrogen_tetroxide_proposed_dec_2008.v1.pdf

6. Safe Work Australia: Occupational Exposure Levels, http://hsis.ascc.gov.au/

7. National Research Council: Protecting the Public and Emergency Workers from Releases of Chemical Hazards: http://dels.nas.edu/resources/static-assets/best/miscellaneous/AEGLS%20Marketing%20Brochure%202008.pdf

8. Australian Standard as2187 Part 2-2006, Use of Explosives

About the AEISG

The Australian Explosives Industry and Safety Group (AEISG), originally known as the Australian Explosives Manufacturers' Safety Committee, was initially comprised of representatives from Dyno Nobel Asia Pacific Pty Limited (previously Dyno Wesfarmers Limited), Orica Explosives (previously ICI Explosives), Union Explosives Espãnol (UEE, previously ERT), and Total Energy Systems (TES), was formed in 1994. Since then, the AEISG membership has expanded and broadened.

Current (June 2011) membership includes:

- Applied Explosives Technology
- Downer EDI – Blasting Services Pty Ltd
- Dyno Nobel Asia Pacific Pty Limited
- Johnex Explosives
- Maxam Australia Pty Ltd
- Orica Australia Limited
- Thales Australia