Code of Practice

Elevated Temperature and Reactive Ground

Edition 3
June 2012
About the AEISG
The Australian Explosives Industry and Safety Group (AEISG) is an incorporated association of Australian explosives manufacturers and suppliers originally formed in 1994. Since then, AEISG membership has grown and currently includes:

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

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

One of the strategies adopted by AEISG in this regard is to identify areas where improved standards of operation need to be consistently applied and then develop and issue appropriate codes of practice which capture industry best practice in these areas.

AEISG codes of practice are adopted by members for the benefit of their employees, their customers and the general community. They are also made available free of charge on the AEISG website, www.aeisg.org.au, for use by any interested parties.

To keep abreast of technological advancements, industry progress and regulatory changes, AEISG Codes of Practice are subject to regular review and updated through the issue of amendments or revised editions as necessary. It is important that users ensure they are in possession of the latest edition and any amendments. References to superseded versions should be updated accordingly.

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PREAMBLE

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

This Code has been developed to assist the safe use of explosives in situations where a specific additional hazard may exist due to the possible unwanted reaction between an explosive and the rock being blasted. In such situations the unwanted reactions may result in premature detonations with potentially fatal results. The reactions can be caused by rock chemistry, temperature or a combination of both.

The purpose of this Code is to provide a scientific and objective basis for predicting the potential unwanted explosive/rock reaction and to provide practical advice on preventive mechanisms available.

The information is provided in good faith and without warranty.
Scope and Definitions

Section 1

1.1 Scope and Interpretation of the Code

The aim of this Code is to enhance the safety of AEISG Inc members and their customers when handling explosives and charging in elevated temperature and/or reactive ground conditions.

The Code covers the following areas:

- Outlines the nature of elevated temperature and reactivity, and the current understanding on the mechanisms of elevated temperature and reactive ground chemistry.
- Summarises the hazards and risks associated with blasting in elevated temperature and/or reactive ground.
- Provides recommended risk assessment methods including sampling and testing for reactivity and measuring elevated temperature conditions at new and existing sites.
- Provides guidelines for the risk management of operations at an elevated temperature and/or reactive ground sites including blasting methods and systems.
- Provides guidelines for managing misfires and premature detonations in elevated temperature and/or reactive ground.

The customer must establish whether there is elevated temperature and/or reactive ground, as detailed in the Code, on their site. In so doing the customer should request assistance from explosives suppliers to conduct appropriate risk assessments and to make recommendations as to the appropriate risk management procedures for the handling of explosives on the site to ensure the safety and well being of all working on the site. The responsibility for implementing these procedures will always remain with the customer, and explosives suppliers should not supply product for use in situations where the risk assessments undertaken based on the guidelines of this Code indicate that the risks are unacceptable. The customer has the responsibility of disclosing to explosive suppliers any history or suspected history of elevated temperature and/or reactive ground on the site, and must reveal to explosive suppliers any changes in geological conditions that may indicate the presence of elevated temperature and/or reactive ground.

Should a customer carry out his own assessment of elevated temperature and/or reactive ground explosive suppliers will always have the right to review this assessment or to carry out their own assessment based on this Code, and decide whether there are appropriate controls in place by the customer to ensure that the supply of explosive products can be made to an acceptable and agreed level of risk. Explosive suppliers have a responsibility to ensure that employees are always offered a safe place of work to carry out their defined duties.

It is the 'duty of care' of explosive suppliers to advise customers of the risks associated with elevated temperature and/or reactive ground and to offer products appropriate to the site application. If the customer chooses to operate contrary to this advice, explosive suppliers reserve the right to withdraw their products and services. If a request is received by an explosive supplier from a regulator, the supplier will inform the regulator of sites that have elevated temperature and/or reactive ground conditions as assessed by this Code.

1.2 Definitions

“Customer” – the person with direct management responsibility for the design of blasting practices in any blasting situation including the selection of explosive products.

“Elevated temperature” – material that is above 55°C and includes both hot ground and high temperature ground conditions as defined in AS2187.2-2006.

“Elevated temperature products” – explosive products that have been formulated and/or packaged and tested to withstand a nominated higher than ambient temperature for a recommended period of time before they will deteriorate or become unstable and possibly decompose violently or explode.

“High temperature ground” – High temperature blasting is defined as the blasting of material at 100°C or greater [AS 2187.2-2006 – Section 12.7]
“Hot ground” – material shall be defined as hot if its temperature is 55°C or more but less than 100°C [AS 2187.2-2006 – Section 12.6.1]

“Inhibited product” – explosive product that chemically suppresses the reaction between nitrates and sulphides.

“Reactive ground” – ground that undergoes a spontaneous exothermic reaction after it comes into contact with nitrates. The reaction of concern involves the chemical oxidation of sulphides (usually of iron or copper) by nitrates and the liberation of potentially large amounts of heat. The process is unpredictable and can be so violent that it results in premature or unplanned initiation of explosives.

“Reactivity” – this term may be defined in two ways:

- The induction time for the sulphide/nitrate reaction in a constant temperature situation (i.e. a short induction time indicates a higher level of reactivity);

or

- The onset temperature for the sulphide/nitrate exotherm in a temperature ramping situation (i.e. a lower onset temperature indicates a higher level of reactivity).

“Shall/should” - For the purpose of this Code “shall” is understood as mandatory and the word ‘should’ is advisory.

“Site Operator” – definition as for “Customer”.

“Sleep time” – the period of time that an explosive is left in a blast hole until it is fired. The time is measured from the time of loading until the time of firing.

“Start-up product” – explosive product that is produced in the change-over from manufacturing non-reactive and reactive ground explosive products or precursors.

1.3 List of Standards, and References

In the development of this Code a number of relevant references were consulted and are listed. These references may be useful to the reader in gaining a further understanding of the issues associated with the use of explosives in elevated temperature and/or reactive ground situations.

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- AS 4360 – Risk Management

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- P Bellairs, “Explosive Ground Reactivity Indicators And Strategies To Overcome This Phenomena”, International Society Of Explosives Engineers, 1997


SECTION 2  Regulatory Requirements

The Regulatory requirements for blasting in elevated temperature and/or reactive ground vary significantly from state to state. Some guidance is given in Sections 12.7 to 12.9, AS2187.2 but this does not adequately address how elevated temperature and reactive ground are determined and the precautions that need to be taken in the use of explosives in such ground. This Code attempts to address these shortcomings.

With this Code elevated temperature ground conditions will be covered first, followed by reactive ground conditions. For the case of both elevated temperature and reactive ground conditions, the risks associated with both conditions need to be considered during product selection and in determining operational requirements.
SECTION 3. Background

When dealing with the issue of elevated temperature ground and reactive ground, there are four main ground conditions that can apply:

With this Code elevated temperature ground conditions will be covered first, followed by reactive ground conditions. For the case of both elevated temperature and reactive ground conditions, the risks associated with both conditions need to be considered during product selection and in determining operational requirements.

3.1 Case Histories

There have been a number of incidents that have occurred across the mining industry that have been associated with elevated temperature and/or reactive ground. Some examples are listed below:

Table 1 Examples of known incidents caused by elevated temperature and/or reactive Ground

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Type1</th>
<th>Details of Incident</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Drayton</td>
<td>HR</td>
<td>Premature detonation</td>
</tr>
<tr>
<td>2010</td>
<td>South Africa</td>
<td>H</td>
<td>Fatality Premature detonation caused by explosive column slumping into an underground combustion zone after an airbag failure</td>
</tr>
<tr>
<td>2008</td>
<td>Mt Gordon</td>
<td>R</td>
<td>Two hole deflagration</td>
</tr>
<tr>
<td>2009</td>
<td>Gaisky (Russia)</td>
<td>R</td>
<td>NOx fume emanating from blasthole soon after charging</td>
</tr>
<tr>
<td>2007</td>
<td>Donaldson Coal</td>
<td>R</td>
<td>Spillage fire</td>
</tr>
<tr>
<td>2006</td>
<td>Curragh</td>
<td>H</td>
<td>Two blastholes detonated due to slumped hot material that was undetected when drilled.</td>
</tr>
<tr>
<td>2005</td>
<td>Black Star</td>
<td>HR</td>
<td>Premature detonation</td>
</tr>
<tr>
<td>2005</td>
<td>Moura</td>
<td>H</td>
<td>Melted primer</td>
</tr>
<tr>
<td>2003</td>
<td>Ernest Henry</td>
<td>R</td>
<td>Melted lead lines (2 leads in one hole).</td>
</tr>
<tr>
<td>2003</td>
<td>Drayton</td>
<td>H</td>
<td>Detonating cord caught fire on bench surface.</td>
</tr>
<tr>
<td>2002</td>
<td>Collinsville</td>
<td>R</td>
<td>Melted primer</td>
</tr>
<tr>
<td>2006</td>
<td>Gadjinsky</td>
<td>R</td>
<td>Premature detonation 3 hr after loading</td>
</tr>
<tr>
<td>2000</td>
<td>Parkes</td>
<td>R</td>
<td>Spillage fire</td>
</tr>
<tr>
<td>1998</td>
<td>Century</td>
<td>R</td>
<td>AN spilt on the bench started to burn several days after the shot was fired.</td>
</tr>
<tr>
<td>Date</td>
<td>Location</td>
<td>Type</td>
<td>Details of Incident</td>
</tr>
<tr>
<td>--------</td>
<td>---------------</td>
<td>-------</td>
<td>-------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1998</td>
<td>Ok Tedi</td>
<td>HR</td>
<td>Drill cuttings caught fire.</td>
</tr>
<tr>
<td>1998</td>
<td>Sons of Gwalia</td>
<td>R</td>
<td>Several holes at Jacoletti pit started smoking within 20 minutes of being loaded with heavy ANFO.</td>
</tr>
<tr>
<td>1998</td>
<td>Southern Cross</td>
<td>R</td>
<td>ANFO spillage fire.</td>
</tr>
<tr>
<td>1998</td>
<td>Collinsville</td>
<td>R</td>
<td>A hole loaded with sawdust/ANFO detonated prematurely.</td>
</tr>
<tr>
<td>1997</td>
<td>Minahasa</td>
<td>U</td>
<td>Premature detonation.</td>
</tr>
<tr>
<td>1995</td>
<td>Saraji</td>
<td>R</td>
<td>Spillage on bench reacted with drill cuttings from sulphide band above K seam.</td>
</tr>
<tr>
<td>1995</td>
<td>Collinsville</td>
<td>R</td>
<td>Holes containing emulsion (heavy ANFO) caught fire.</td>
</tr>
<tr>
<td>1994</td>
<td>New Hope</td>
<td>H</td>
<td>Blasthole detonated while blast crew and drill on shot due to burning of stringer coal seams.</td>
</tr>
<tr>
<td>1992</td>
<td>Mt Leyshon</td>
<td>R</td>
<td>Emulsion in a shot which had been sleeping for several months detonated.</td>
</tr>
<tr>
<td>1991</td>
<td>USA</td>
<td>U</td>
<td>Paradise Peak Gold – premature detonations with ANFO.</td>
</tr>
<tr>
<td>1990</td>
<td>Dominican Republic</td>
<td>U</td>
<td>Heavy ANFO caused burning and premature detonation.</td>
</tr>
<tr>
<td>1989</td>
<td>Mt Lyell</td>
<td>U</td>
<td>Explosive ejection – premature detonation of AN emulsion within 10 hours of loading.</td>
</tr>
<tr>
<td>1989</td>
<td>USA</td>
<td>U</td>
<td>Battle Mountain Gold – premature detonations with ANFO.</td>
</tr>
<tr>
<td>1989/90</td>
<td>Faro, Canada</td>
<td>U</td>
<td>Premature detonation.</td>
</tr>
<tr>
<td>1987</td>
<td>Mt Whaleback</td>
<td>R</td>
<td>A hole which was lined and loaded with ANFO detonated when the hole liner split.</td>
</tr>
<tr>
<td>1983</td>
<td>Mt Whaleback</td>
<td>R</td>
<td>A hole loaded with ANFO detonated prematurely.</td>
</tr>
<tr>
<td>1968</td>
<td>Russia</td>
<td>R</td>
<td>Gaiskii Combine copper, spontaneous detonation with AN explosives.</td>
</tr>
<tr>
<td>1963/65</td>
<td>Mount Isa</td>
<td>R</td>
<td>Holes in 500 ore body became incandescent on contact with ANFO. Premature detonations.</td>
</tr>
</tbody>
</table>

Note 1:  
H = Elevated temperature ground only.  
R = Reactive ground only.  
HR = Elevated temperature AND reactive ground.  
U = Information unavailable.
SECTION 4  Risk Assessment

Due to the serious nature and high risk of premature detonations associated with the use of explosives in elevated temperature and/or reactive ground there are a number of strong indicators that mine and quarry operators (at both proposed and existing sites) should monitor. If any of these indicators are found then a detailed risk assessment of the use of explosives on the sites should be carried out (including sampling and screen testing refer Sections 7 & 8) and, as the site develops, the risk assessment should be regularly reviewed with due consideration given to all the indicators.

As well as historical data, indicators for the presence of reactive ground are:-

- the presence of sulphides (normally greater than 1%);
- the presence of black sulphide bearing sediments;
- sulphides within mineralised rock;
- the presence of white or yellow salts on rock. This is an indication that oxidation is taking place;
- acidic conditions (generally resulting from oxidation) as indicated by the colour of run off water, usually yellow-red brown in colour;
- significant corrosion of rock bolts, safety meshing and fixed equipment associated with the mining operation;
- the spontaneous combustion of overburden or waste rock/ore either in dumps or in the pit, especially as it is exposed to the air;
- the acrid smell of sulphur dioxide caused by the naturally occurring sulphide oxidation reaction;
- elevated blast hole temperatures;
- elevated ground temperatures.
SECTION 5 Elevated Temperature Blasting

5.1 Principles for Elevated Temperature Management

The preferred approach to elevated temperature ground management is to mitigate the risks highlighted in the risk assessment process by quantifying the hazards and selecting the most appropriate mitigation measures. This will be achieved through a combination of suitable procedures and product selection.

Elevated temperature may be caused by reactive ground, however this section deals with ground that is at an elevated temperature but is NOT reactive.

5.2 Causes of Elevated Temperature Ground

Elevated temperature ground can exist due to one of the following conditions:

- geothermal heating – e.g. volcanic activity;
- geothermal gradients;
- burning coal seams;
- sulphide oxidation – reactive ground is a special case of elevated temperature ground;
- cement fills in stopes;
- thermal heating of ground surfaces by solar radiation.

5.3 Risks and Hazards of Blasting in Elevated Temperature Ground

Elevated temperatures (i.e., temperatures above 55°C) will affect bulk, packaged and initiating explosives products over time, increasing the rate of degradation and potential failure which may lead to an explosion. Some of the major hazards associated with elevated temperature ground can be summarised as follows:

- exposure of operators to high temperatures;
- exposure of operators to toxic vapours;
- ignition of vapours associated with emulsion and ANFO type products;
- softening of plastic components of initiating products;
- melting and decomposition of bulk, packaged and initiating products;
- detonation following decomposition.

5.4 Risk Management through Operating Practices

Once a site has been identified as having elevated temperature ground conditions, the operating procedures and on-bench practices need to be adjusted accordingly to minimise the hazards outlined above. These should include:

5.4.1 Site Specific Operating Procedures

Site specific operating procedures need to be developed involving all key stakeholders based on a risk assessment and including all appropriate control measures. Document control and change management procedures must be put in place to ensure all key stakeholders are formally notified of any intention to change these procedures and agreement reached on the changes.

Areas to be included in site specific operating procedures include:

- training;
- sleep time;
- hole temperature monitoring;
- hole loading sequence;
- delineation of zones;
- product selection;
- spillages.
5.4.2 Training
The customer is responsible for ensuring that training in these procedures occurs. Training is to extend to all personnel operating on the bench or involved in the management of these personnel. Training shall also include regular reassessment. (See also Section 13.)

5.4.3 Sleep Time
The sleep time of product in elevated temperature ground shall be minimised to prevent unnecessary heating of products, which may lead to product deterioration and a possible unplanned event. Reference should be made to the Technical Data Sheet for the explosive product, or to a technical representative of the explosives provider.

Note: Hole temperature is often linked with the recommended sleep times (the higher the temperature, the shorter the sleep time).

5.4.4 Hole Temperature Monitoring
Hole temperature monitoring is a critical part of the risk management process for the following reasons:

- allows for hole-by-hole classification of temperature – not all holes may be hot and hence different products may be suitable for different areas;
- identifies if hole temperature is changing with time;
- allows holes that are too hot to be charged to be left uncharged or backfilled.

The temperature logging procedure, including the frequency of measurement, shall be recorded in the site-specific procedures generated. Key principles for effective temperature logging include:

- selection of a measurement device with a suitable temperature range and a measuring system suitable to the conditions (e.g. infra-red may not be effective in wet holes or steaming holes);
- hole-by-hole logging;
- recording maximum hole temperature;
- frequency of measurement;
- recommendations on how to act on the temperature information.

5.4.5 Hole Loading Sequence
When working in elevated temperature areas, it is preferable that loading occur near the initiation point first (i.e. load in the sequence in which the blast will be fired). This is to allow the pattern to be quickly tied up and fired in the event of a change in conditions (e.g. weather or approaching maximum allowable sleep time). Where practical, allow for the hottest holes to be loaded last.

5.4.6 Occupational Health and Safety Considerations
Areas of elevated temperature ground may lead to exposure of personnel to scalding from steam and hot water. Toxic gas such as hydrogen sulphide and carbon monoxide may also be generated under these conditions.

5.4.7 Delineation of Zones
Delineation of ground into elevated temperature and non-elevated temperature zones can occur as it is possible to take multiple hole-by-hole measurements. Delineation allows for the choice of different explosive products, the use of physical barriers, the setting of sleep time and if necessary the backfill of holes on a hole-by-hole basis.

5.4.8 Spillages
During charging of blast holes there is a possibility that spilt explosives may react where benches are at an elevated temperature. Procedures for minimising spillages of explosives need to be developed and where possible spillages must be cleaned up immediately. The procedures
should also ensure that initiating systems do not come into contact with the spilt explosives as the possible decomposition of the explosive may cause the initiation system to degrade or detonate.

5.5 Risk Management through Physical Separation

Generally the use of physical separation to insulate explosives from elevated temperature ground is not recommended. If this approach is taken then the associated risk assessment must take into account all hazards and all likely failure modes to ensure that an appropriate level of safety is achieved and can be maintained. (Note:- Details in Section 6.5 should also be considered.)

5.6 Risk Management through Product Selection

Choice of bulk, packaged and initiating explosive product can be a particularly effective way of addressing the risks associated with elevated temperatures. All products must be used in applications stated as per their Technical Data Sheets which shall indicate whether or not products are suitable in elevated temperature applications.

Where a site is known to have elevated temperature ground conditions, the following products may be suitable for use:

- bulk products – these need to be formulated to withstand elevated temperatures;
  and
- initiating and packaged products – these need to be formulated and/or packaged to withstand elevated temperatures.
SECTION 6 Reactive Ground Blasting

6.1 Principles for Reactive Ground Management

Reactive ground may be a condition specific to individual sites. Case histories (see Section 3.1) indicate that in the past this type of condition has only been identified following an incident. The preferred approach to reactive ground management is to be as pro-active as possible, minimising the recognised risks rather than responding post incident. It is not possible to completely eliminate all risks as it is not possible to account for the characteristics of every section of rock. However, there are risk management approaches that can be and have been successfully adopted that provide acceptable safety margins thus preventing further incidents occurring. This Section of the Code covers a number of recommended risk management approaches.

6.2 Chemistry of Reactive Ground

The reaction of nitrates with sulphide containing minerals is an auto-catalysed process that can, after some induction time, lead to a runaway exothermic decomposition even if the starting temperature of the mixture is ambient. Typical nitrates used in the explosives industry include (but are not limited to) ammonium nitrate, calcium nitrate and sodium nitrate. The reaction scheme developed over the last 30 years of research by groups such as the US Bureau of Mines (USBM) and others is described in a simplified form below (reference - John Rumball's thesis, “The Interaction of Partially Weathered Sulphides in the Mt McRae Shale Formation with Ammonium Nitrate”).

Natural oxidative weathering of iron sulphides such as pyrites by atmospheric oxygen generates solutions of ferrous ions and acid. This process occurs whenever the sulphides are exposed to air along cracks, in drilled holes, in the muck pile after blasting, on pit walls and in old stopes. No nitrates are required for this to occur.

\[
\text{Iron Sulphides + Oxygen + Water} \rightarrow \text{Ferrous Ions + Sulphuric Acid}
\]

This reaction is exothermic and can lead to hot blast holes for particularly reactive ores. This temperature increase can be as little as 2°C or as much as several hundred degrees.

On contact with ammonium nitrate, the ferrous and acid species from weathering can begin to catalyse the breakdown of nitrate. The breakdown process is auto-catalytic in that it generates its own catalysts as it proceeds.

\[
\text{Nitrates + Iron Sulphides + Ferrous Ions + Sulphuric Acid} \rightarrow \text{Nitric Oxide + Ferric Ions + HEAT}
\]

The nitric oxide and ferric ions produced in this stage react with more pyrites, generating more ferrous ions and sulphuric acid.

\[
\text{Iron Sulphides + Nitric Oxide + Ferric Ions} \rightarrow \text{Ferrous Ions + Sulphuric Acid}
\]

Although these reactions are exothermic, their rate may be initially so slow that little or no temperature rise is detectable. This is due to the concentration of catalytic species building up to some critical level. The time taken for this to occur is often referred to as the induction period. When sufficient catalysing species have built up, the reaction rate increases sharply and the heat generated causes the temperature to become so high that a rapid, potentially violent decomposition of the remaining ammonium nitrate is inevitable.

\[
\text{Nitrates + Fuels (sulphides, diesel etc) + Heat} \rightarrow \text{EXPLOSION}
\]

Specific conditions are required for the reaction to progress to detonation of the explosive product. For this reason, mines have been known to operate for many years without incident using uninhibited explosives. Years of operation using uninhibited explosive products is therefore not a valid argument as a basis for safety for blasting in reactive ground.
6.3 Risks and Hazards – Blasting in Reactive Ground

The hazards associated with blasting reactive ground can be summarised as follows:

- sudden violent decomposition of nitrates;
- evolution of toxic NOx and SOx fumes;
- premature detonation of detonators due to the heat generated;
- mass detonations:
  - deflagration-to-detonation in single holes (heat generated causes the contents of the hole to catch fire and then to detonate);
  - communication to other holes via cord.

6.4 Risk Management through Operating Practices

Once a site has been identified as having reactive ground conditions, the operating procedures and on-bench practices need to be adjusted accordingly to minimise the risks outlined in Section 6.3. These should include the issues outlined hereunder.

6.4.1 Site Specific Operating Procedures

The customer is responsible for ensuring that site specific operating procedures are developed involving all key stakeholders. Appropriate document control procedures shall be put in place to ensure all key stakeholders are formally notified of any intention to change the procedures and agreement is reached on these changes. Areas to be included in site specific operating procedures include:

- training;
- sleep time;
- hole temperature monitoring;
- surface temperature measurement;
- shot design in reactive ground blasting;
- hole loading sequence;
- stemming material;
- product spillage;
- overfilling of holes;
- occupational health and safety considerations;
- ongoing review of risk assessment;
- delineation of zones;

6.4.2 Training

The customer is responsible for ensuring that training in these procedures occurs. Training is to extend to all personnel operating on the bench or involved in the management of these personnel. Training shall also include reassessment. (See also Section 13.)

6.4.3 Sleep Time

The sleep time of product in reactive ground shall be kept to a minimum to reduce the exposure time of nitrate based products in potentially reactive material.

More information on how sleep time is determined can be found in Section 8.3.

6.4.4 Hole Temperature Monitoring

In reactive ground, there is a risk that after drilling holes, the hole temperature may rise above ambient conditions due to oxidation with air. It is important to monitor hole temperature to confirm that the ground temperatures do not rise above a level in which the selected product is no longer appropriate for both elevated temperatures and reactivity conditions.

Temperature logging may be used as part of a process of mapping the temperature and reactivity
zones in an existing site. Where it can be shown, through a reasonable measurement campaign, that in hole temperatures in reactive ground do not exceed those considered ambient, it may not be necessary to monitor hole temperature on an ongoing basis. The requirement for monitoring of hole temperature (or not) must be specified in site specific procedures. These procedures may specify suitable methods for rapid detection of hot holes, such as IR guns and/or thermal imaging equipment. However the procedures shall ensure that thermocouple measurement is utilised for all identified hot holes to allow monitoring and recording of maximum temperatures.

6.4.5 Surface Temperature Measurement

Any elevated temperature or reactive ground risk assessment may consider the possibility of bench surfaces reaching higher temperatures than in the hole due to solar radiation. Based on the risk assessments consideration can be given to testing the bench materials in the isothermal test with the proposed explosives to be used at the temperatures reached by the surface rocks plus an appropriate buffer.

6.4.6 Shot Design in Reactive Ground Blasting

When blasting in reactive ground consideration must be given to designing shots to minimise the risk of hole dislocation during blasting, ie maximise the use of free face where possible and avoid Box Cut type designs. Hole dislocation can potentially lead to misfires or bulk product remaining in the ground for longer than the recommended sleep time.

If decked shots are required in reactive ground areas, an additional risk assessment should be completed with the assistance of specialists from the explosives supplier. When blasting decked shots in reactive ground consideration should be given to the use of electronic initiating systems to lower the risk of hole dislocation or misfires.

Prior to the shot, consideration should also be given to plans to dig out misfires within the recommended sleep time of the product should upset conditions occur

6.4.7 Hole Loading Sequence

When working in reactive ground areas, it is preferable that loading occur near the initiation point first (ie load in the sequence in which the blast will be fired). This is to allow the pattern to be quickly tied up and fired in the event of a change in conditions (eg weather, approaching maximum allowable sleep time, or signs of reaction).

6.4.8 Stemming Material

When blasting in reactive ground applications it is highly recommended that stemming is carried out with non-reactive materials. In particular stemming with drill cuttings is to be avoided. This is because the fine particle sizes associated with drill cuttings maximises the surface area available for contact with the explosives resulting in an increased likelihood of reaction.

It is a well established principle that increasing the surface area of contact between two potentially reactive materials significantly increases the probability and rate of reaction.

6.4.9 Product Spillage

At all times the spillage of explosives on the bench needs to be minimised and eliminated if possible. This is due to the possible interaction of the explosive and potential or proven reactive surface rock/drill cuttings.

6.4.10 Overfilling of Holes

At all times the overloading of holes in reactive ground should be avoided. To prevent overloaded holes, ensure loading takes place with enough manning to have someone dipping holes while loading. An overloaded hole must not be washed out.

6.4.11 Occupational Health and Safety Considerations

Areas of reactive ground may generate sulphur dioxide and sulphuric acid which may affect people operating in the area and process equipment. Site specific procedures need to include guidelines for:

- evacuation procedures when sulphur dioxide reaches a critical limit;
• personnel to wear appropriate gas monitoring equipment and breathing apparatus when necessary.

6.4.12 Ongoing Review of Risk Assessment

Risk assessments should be reviewed on a regular basis to check whether conditions have changed since the initial conditions. This will include:

• changes in geology – eg different levels of sulphides;
• changes to blasting practices – eg sleep time requirements;
• changes in explosive product;
• changes in explosives provider;
• change in the degree of oxidation/reaction.

No ongoing reactive ground testing is required if the following apply:

• none of the above changes have occurred. However, this is unlikely since the degree of oxidation is constantly changing;
• sulphides are absent from site geology. This is the only real valid reason for not undertaking on-going sampling and testing.

If any changes have occurred or the site is a known reactive ground area, ongoing reactive ground testing shall occur at both reactive and non-reactive areas to ensure the following:

• ground conditions at the site are monitored to understand ongoing conditions as production moves into different areas – this applies to both known reactive ground areas and also areas that have not been classified as such;
• for reactive ground sites, to assist product selection in response to the current level of reactivity in order to reduce the risk of a reaction;
• to increase understanding of the critical areas of reactivity on the site or to uncover reactivity in areas that have not previously been identified.

Refer to Section 8 for frequency of ongoing reactive ground testing based on the risk profile of the site.

6.4.13 Delineation of Zones

Delineation of a site into reactive and non-reactive ground shall only occur after significant research into the nature and extent of reactivity has been carried out. In some cases it may not be possible to delineate and the entire site should be classified as reactive.

Delineation requires close cooperation between those with geotechnical expertise and explosive providers based on reactive ground sampling and testing.

Delineation of a site should not occur if there are no clear indicators as to what ground is reactive and what is not. This particularly applies to so called ‘vertical delineation’ of mines, or sections of mines. In addition to risks identified with delineation, knowing when operations are entering or approaching the transition zone (oxidised to partially oxidised sulphides) as the mining progresses is very important. Another potential risk could be associated with the leaking of dissolved nitrates through the ground from the shot above into the reactive area below.

Delineation may be possible if there are:

• clear zones of geological type;
• clear zones based on sulphide levels;
• drill cuttings that are geologically logged for the presence of sulphides and a procedure is in place for utilising this information to determine what product is to be loaded into the reactive and non-reactive holes;
• temperature profiles across the site.

If delineation is established across a site appropriate buffer zones between reactive and non-reactive areas must be established and rigorously managed. Procedures for the loading of
explosives into the two areas needs to be developed, and must include a detailed emergency action plan should the wrong product be loaded into the wrong area.

6.5 Risk Management through Physical Separation

Barriers which prevent rock from contacting the explosive product have been used in the past for reactive ground applications. Blast hole liners are one option, however, there are limitations which impose a significant increase in risk, such as:

- liners may split exposing uninhibited product to reactive ground;
- overall strength and suitability of the liners may not be applicable for all conditions or to changes in conditions that may occur (e.g., variations in temperature with time) on the bench to which they are being subjected;
- liners do not prevent material that is spilt on the bench from reacting;
- bulk explosives may be spilt down the side of the liner potentially allowing uninhibited product to contact reactive ground;
- if a primer misfires damaging the liner but leaving bulk product unfired, uninhibited product would be left to potentially react;
- loading times may increase due to handling issues associated with liners on the bench.

The total cost of using liners and standard uninhibited explosive products, and assessing the associated increased risks at a particular site will be a commercial decision that the site operator will need to consider.

The use of packaged explosive products where the plastic outer casing acts as a physical barrier is also an option. Generally this is an option only for small shots as costs may become prohibitive. The loading of packaged product can involve the splitting of the casing (for the insertion of the initiators or damaged during charging) which will compromise the layer of protection. In some cases the packing material may not be acid and/or tear resistant leading to the packaging being breached and thus allowing uninhibited product to be exposed to reactive ground.

For reactive ground applications, the use of blast-hole liners (with uninhibited bulk explosives) and uninhibited packaged products should be discouraged. This is not industry ‘best practice’ and has lead to unacceptable incidents of uninhibited products being exposed to reactive ground at an extremely high risk.

6.6 Risk Management through Explosive Product Selection

Choice of bulk, packaged and initiating explosive product can be a particularly effective way of addressing the risks associated with reactive ground. All explosive products must be used in applications stated as per their Technical Data Sheets and through compatibility testing with the ground in question (see Section 8 for further details). Explosives providers shall indicate in Technical Data Sheets whether or not explosives products are suitable in reactive ground applications.

Where a site is known to have reactive ground conditions, the following products may be suitable for use:

- bulk products – inhibited products with recommended sleep times based on compatibility testing with reactive ground;
- initiating products – products suitable for reactive applications;
- packaged products – inhibited products with recommended sleep times based on compatibility testing with reactive ground.

Following explosive product selection, and during loading, the use of “start-up” product shall be carefully monitored. This start-up product should be loaded into non-reactive blastholes wherever possible. Alternately, the product should be manufactured into a bucket for later disposal as active stemming in non-reactive blast holes. In situations where this is not possible, then the start up product should be manufactured in an emulsion-rich state by the MPU operator.

Variation in explosive product selection should also be considered in the event of having to extend sleep time beyond current limits. For example, when machine breakdown occurs on bench or in an electrical storm. A higher emulsion content product will have more inhibitor (if the inhibitor is contained within the emulsion), and therefore a greater safety margin.
SECTION 7 Sampling for Reactivity Testing

7.1 Sample Selection

Reactivity sampling and testing is a crucial component of reactive ground management. It must be noted that it is rarely possible to statistically take enough rock samples to fully characterise the geology and hence the reactivity of a site. Testing, and in particular screening for reactivity, needs to be targeted to analyse the rocks containing sulphides in order to identify the “worst case” reactive rock samples and hence to minimise the risk of incidents. Other indicators listed in Section 4 may be used to identify the most likely locations from where rock samples should be taken.

The role of geotechnologists (e.g., site and consulting geologists) is essential for the identification of high potential samples. Where possible, the expertise of site geotechnologists shall be employed and geological knowledge (targeting sulphides) shall be used to implement safety margins and to allow for the limited numbers of representative samples. The sampling method requires selection of “worst-case” samples present on the site at that point in time.

Samples should be taken so that their exact location is known. Samples picked from a wall or drill core samples are the most useful for screening purposes. Samples picked up from the floor may have fallen from a much higher point or been moved from a different location and hence are less useful when it comes to identifying risk zones. Drill cuttings can result in “diluted” rock samples and allow for some oxidation to occur before testing – hence the best samples are whole rocks from known locations.

7.2 Handling of Samples

In order to obtain accurate results, testing shall occur just prior to explosive supply commencing using fresh samples (i.e., newly exposed rock rather than old core drill samples). This is to ensure that the effects of oxidation do not “hide” potentially reactive samples.

7.2.1 Sample Size

Sample size should be appropriate for the testing that is to be carried out. For standard laboratory scale screen testing or verification work, a minimum of 0.5kg with the maximum rock size approximately “fist-size” (i.e., 50mm diameter).

7.2.2 Sample Identification

To ensure the traceability of samples back to their location on the site, records are to be kept of sample identifications, collection points and date of collection.

7.2.3 Sample Packaging

The following considerations shall be made when packaging:

- packaging can easily be linked with a sample (e.g., indelible markings);
- packaging is to be robust enough to prevent rupture (and potential mixing) of samples;
- where it is not possible to collect whole rock samples (e.g., when only rock chips or drill cuttings are available), samples are to be taken immediately after drilling and stored in vacuum sealed plastic bags to minimise oxidation through exposure to oxygen.

7.2.4 Sample Timing

Allow a suitable time between the collection of samples and the time frame in which the area is to be blasted. A suitable time may vary depending upon the explosives provider and the length of sleep time test required. However, 2 months would generally be a reasonable time.

7.3 Sampling for Initial Screening

A “green field” site refers to the following scenarios:

- new site that has never been excavated;
- excavation commencing in a new development on an existing site;
- excavation commencing in an area of untested geology;
- where this Code has not been applied.
Before site development commences a risk assessment of the site should be carried out based on Section 4. If no indicators are present then it may be assumed that the site is non-reactive.

If the risk assessment indicates the likelihood of reactive ground, the ground is to be tested for reactivity as per the Isothermal Reactive Ground Test. The role of site geotechnologists is essential when identifying high potential samples that characterise the most potentially reactive ground. At this initial stage, sulphide analysis can be used to target areas (as a minimum) to eliminate the need to take samples from areas that contain no sulphides.

The minimum recommended number of samples selected and collected for testing is 12. The most suitable number is difficult to quantify but they should be a well-chosen set of samples (ie obtained with assistance from geotechnologists), following a documented risk assessment procedure conducted by the customer. Best practice is to take samples from each region of the site and from each strata within that region that contain sulphides. If the sulphide content is unknown, then samples must be taken.

Refer to Flowchart in Section 13 for further information.

7.4 Sampling for Ongoing Testing

Periodic testing at a known reactive ground site is an important part of the reactive ground risk management process for the following reasons:

- to clarify the extent of reactivity at a known reactive site;
- to confirm that the level of chemical inhibitor used at the site remains sufficient to continue to inhibit a reaction within the recommended site sleep times;
- to allow for extensions of sleep time to meet the needs of the customer;
- to assess whether changes in raw material sourcing effects the ongoing suitability of the explosive product for the established conditions.

7.4.1 Existing site – No previous reactivity

Even if sites have shown no previous signs of reactivity, ongoing testing shall continue on a regular basis according to the risk profile of the site (if there is no major excursion from the initial risk assessment, then retesting may not be required). The level of ongoing testing, based on the risk profile, may need to be agreed between the site operator and the explosive supplier.

Site geologists shall initiate retesting if entering a "green field" zone or an area that is yet to be blasted and contains geology that has not been tested for reactivity. Retesting, however, is not required if the indicators as detailed in Section 4 are absent from the geology of the specific zone/area.

The minimum recommended number of samples is 12. Samples are to be selected based on records of core sampling and mineral analysis or ore body mapping.

7.4.2 Existing site – Reactive ground site

For sites that have shown evidence of reactivity (through either incidents or positive reactive ground testing results), a suitable ongoing sampling program shall be set up and included in site operating procedures. At a minimum, retesting shall occur every 12 months. A qualified site geologist shall select at least 12 samples in order to try and obtain the most reactive samples.

The aim of this testing is to ensure that the recommended products are still sufficient to prevent a reaction and hence maintain the basis of safety.
Table 2 Frequency of Sampling Summary – Based on a Risk Profile of the Site

<table>
<thead>
<tr>
<th>Type of Site or Scenario</th>
<th>Frequency of Testing</th>
<th>No. of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screening at “Green Field” sites:</td>
<td>Before commencing development in the new area.</td>
<td>Recommended minimum of 12. (Number of samples to be determined between explosives provider and customer). Best practice is to take samples from each region of the site and from each strata within that region that contain sulphides</td>
</tr>
<tr>
<td>• New site that has never been excavated.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Excavation commencing in a new development on an existing site.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Blasting commencing in an area of untested geology (identified by on-site geology).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Where this Code has not been applied.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ongoing testing at:</td>
<td>Annual testing.</td>
<td>Minimum of 12.</td>
</tr>
<tr>
<td>• Non-Reactive sites (non-inhibited products in use).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Reactive ground sites (inhibited products in use, no change in geology).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ongoing testing at:</td>
<td>Testing required prior to blasting in area</td>
<td>Minimum of 12.</td>
</tr>
<tr>
<td>• Reactive ground sites (inhibited products in use, change in geology).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SECTION 8 Reactive Ground Testing and Product Selection

8.1 Introduction

In order to identify reactive ground and to determine the effectiveness of inhibited product in preventing reactions, laboratory scale test methods have been developed to simulate the conditions in the field. There are two separate steps that need to be considered when discussing testing procedures:

- Reactivity Screening – this test method is used to identify whether ground samples are reactive with ammonium nitrate;
- Product Selection Testing – this test method is used to confirm whether an inhibited product is suitable for a specific reactive application.

It may also be appropriate on some sites to carry out additional large scale testing for reactivity and to ensure the ongoing suitability of selected bulk explosive products for use in reactive ground. This form of testing should not be used as a replacement for the laboratory Isothermal Reactive Ground Test (section 8.2.1). However, it may give customers the opportunity to carry out their own evaluations of products under local site conditions.

8.2 Reactivity Screening

Two laboratory screening tests may be used in determining the reactivity of ground samples and in determining the suitability of explosive products to be used within the ground.

8.2.1 Isothermal Reactive Ground Test

The Isothermal Reactive Ground Test has been developed for use in screening reactive samples and for carrying out sleep time analysis. “Standard” test conditions cover blasting in normal temperature ground (i.e., <55°C). However, if the risk assessment indicates that a higher temperature may be experienced then this higher temperature should be adopted as the standard for that site.

A summary of the test steps is outlined below with the detailed test procedures given in Appendix 1.

- Rock samples are crushed to a fine powder.
- The rock powder is then mixed with chemically pure ammonium nitrate and a solution to simulate the by-products of sulphide rock weathering.
- The mixture is heated to and kept at 55°C, (for non-elevated temperature ground sites) the adopted standard temperature and monitored for exothermic reactions. For elevated temperature ground sites, the test is carried out at the maximum recorded in-hole temperature based on temperature logging and historical data, or at the maximum nominated temperature limit at the site.
- The screening test for each sample should run for a duration of 7 days unless any of the following is applicable:
  - if the sleep time used in the blasting application is less than 7 days, the test should run for the length of sleep time, but must be a minimum of 48 hours;
  - if the sample reacts, then the testing can be terminated within the 7 day period;
  - if a group of samples from a site are being screened in order to identify the most reactive, testing may cease for all samples from the group once the desired number of the most reactive samples have been identified.

If exceptionally long sleep times are required in specialised blasting applications, a detailed risk assessment should be conducted by the site operator and the explosives supplier. It may also be appropriate to use a Temperature Ramping Test (see Section 8.2.2).

- The mixture is monitored for any visual reactions (such as colour change or signs of chemical reactions such as gas liberation) and reactivity is identified by a change in temperature, detected using thermocouples with continuous temperature logging.
This test method is capable of picking up exotherms of 1°C and greater that are above the background temperature. Samples that exhibit an exotherm of 2°C or more are classified as reactive and require further investigation.

Samples that exhibit a greater rate of increase while ramping up to the test temperature need to be investigated further. This investigation should involve an analysis of the time temperature chart generated from the test. More details are in Appendix 1, section 4.

The experimental conditions have been selected based on the following reasoning:

- temperature at 55°C – the location specific standard temperature; by definition, this is the maximum temperature anticipated under non-elevated temperature operational conditions;
- finely ground particles – this allows for the presence of very fine particles generated during the drilling process;
- ammonium nitrate – chemically pure ammonium nitrate is used as the additives in other grades of ammonium nitrate, particular those in porous prilled ammonium nitrate, may have an effect on the test method;
- weathering by-product – research has shown that the chemical by-products of weathering contribute to the reactivity of the ground;
- sleep time – testing for the duration of the sleep time is imperative to determining whether the ground is reactive with AN within the maximum timeframe exposed to the explosive product. For significantly long sleep times this may be adjusted based on a detailed risk assessment of actual site conditions and practices.

In carrying out the “Isothermal Reactive Ground Test” there are a number of precautions that must be taken:

- samples must not be oven dried at temperatures >50°C prior to testing as drying presents an opportunity for premature air oxidation;
- a maximum milling time shall be adopted to ensure that samples are not oxidised before testing;
- once samples have been milled, they shall be immediately stored in vacuum sealed bags or containers;
- milled samples that are not used immediately shall be stored in vacuum-sealed bags or under nitrogen, for storage periods greater than 48 hours the bags shall be stored in a freezer. Where possible, unused samples shall be kept in rock (uncrushed/milled) form;
- retests (if required) shall be completed within 60 days of milling provided the sample has been stored in a freezer and vacuum sealed throughout the storage. After this time, the milled samples should be discarded, and unused rock samples should be milled and retested.

A reactive response is identified by an increase in temperature from the base line test temperature. As outlined in the definitions (Section 1.2), the “reactivity” of a sample or the ease at which a sulphide/nitrate reaction occurs is related to the induction time. For example, a series of samples can be ranked as “most reactive” to “least reactive” under the same test conditions according to the time taken to react with the “most reactive” sample reacting first. The “intensity” of a reaction is related to the size of the exotherm and does not relate to the induction time. The intensity may be a reflection of the overall sulphide content but the size of the exotherm cannot be relied upon to classify a sample as more or less reactive.

Movement of the thermocouple and/or frothing of the sample can result in the hottest section of the reacting mixture not being measured.

8.2.2 Temperature Ramping Test

The Temperature Ramping Test may be a useful test for efficiently identifying samples which could be reactive from a large number of samples.
Sample preparation is as for the “Isothermal Reactive Ground Test”. Testing is carried out by subjecting the prepared sample to a linear temperature increase over time until a reaction occurs. Samples which exhibit exothermic reactions at temperatures below the normal decomposition temperature of ammonium nitrate would be considered reactive. While this test does not give a direct measure of induction time, samples can at least be ranked according to the onset temperature of the exothermic reaction (the most reactive samples having the lowest onset temperature). The most reactive samples can then be checked for induction time in the isothermal test.

A detailed test method for the Temperature Ramping Test is not provided in this Code as the Test is not widely used. The details of any proposed Ramping Test Method and the intended interpretation of results would need to be agreed before it can be adopted into the Code.

8.3 Product Selection Test

Once reactivity screening tests indicate any sign of reactivity, rock samples, including the most reactive samples identified, are retested against the intended explosive to be used in the ground. This must be done to determine the most appropriate formulation that is required to prevent an exotherm and its suitability for the blasting application. (Note: Chemical inhibition and physical separation are the only options for loading explosives in reactive ground. Chemically inhibited explosives products offer the lowest risk, are industry best practice and hence the preferred option.)

The “Isothermal Reactive Ground Test” is repeated replacing the ammonium nitrate with the inhibited bulk explosive. A range of bulk products may need to be assessed to determine which one is suitable for use in the reactive ground so that adequate sleep time is achieved. Each explosive provider will use their own methods (formulation, ingredient selection and inhibitor levels) of ensuring that their products are suitable for the reactivity conditions under investigation.

8.3.1 Sleep Time Testing

Product selection is closely linked to sleep time and products selected for use in reactive ground must also have an appropriate sleep time. Sleep time testing involves testing reactive ground with inhibited product using the “Isothermal Reactive Ground Test” for a period equivalent to four times the required product sleep time, up to a maximum test period of one month.

For existing reactive ground sites, the maximum recommended sleep time in reactive ground is one week (ie laboratory test for one month). Beyond this period, a risk assessment involving the explosives provider and the customer should be carried out and documented, and consequently extended laboratory sleep time testing may be appropriate. There may be a requirement to advise the outcome of the risk assessment to the appropriate regulator.

8.3.2 Additional Product Testing

As well as using the “Isothermal Reactive Ground Test” for product selection with an appropriate sleep time, additional product testing must be carried out should any of the following changes occur:

- use of a new or different bulk explosive product especially from a new supplier;
- raw material sourcing or significant formulation changes of the existing bulk explosive product;
- increases in the required product sleep times;
- changes to site geology;
- changes in ground temperatures.

8.4 Large Scale Testing

For some sites and as part of ongoing reactive ground management, testing in the form of the on bench Bucket Tests may be appropriate. In the Bucket Test several kilograms of crushed ground are combined with the inhibited product and left on bench for an extended period.

The Bucket Test is in effect a large scale version of the Isothermal Reactive Ground Test but without any temperature control. It can be used to confirm the results of laboratory scale testing. However, these large
scale methods are not as sensitive as the isothermal test and should not be used as a substitute for the
isothermal test when suitable laboratories are available.

The method involves using several kilograms of sample rock which is stored with the explosive product
in a bucket on the bench, where it is exposed to ambient temperatures (ie day and night temperatures)
over an extended period. Details of the Test are given in Appendix 2. In carrying out the test appropriate
measures must be taken to ensure the security of the bucket and its contents as per the relevant explosives
legislation.

The Bucket Test offers a number of advantages:

- enables the on-site testing with fresh ground samples from known locations and with site
  manufactured explosive products;
- is visible to the site operator;
- larger sample size gives the ground more opportunity to react;
- the last evaluation step prior to introduction of a bulk product to a site.

The Bucket Test, using ANFO and if carried out regularly, may be used as a method of monitoring the
ongoing “reactivity” across a site.

The Bucket Test only detects when the reaction progresses to the final stage of the auto-catalytic reaction.
It does not detect reactions that (for whatever reason) do not progress to the final stage of reaction, but
could still potentially result in a premature detonation in-situ.

The Bucket test should not be used to replace the Isothermal test. It should be used to compliment the
Isothermal test.

8.5 Recommended Testing Agencies

The test methods outlined above for screening potentially reactive samples and selecting suitable inhibited
products should be carried out by the following groups:

- explosives providers with the appropriate laboratories and trained personnel;
- site and independent laboratories with the appropriate equipment and trained personnel.

These laboratories should only carry out the initial screening test using ammonium nitrate as the
use of fully formulated explosives within their laboratories may introduce hazards with which they
are not familiar or are in breach of relevant explosive regulations.

The performance of laboratories must be assessed at least annually to ensure compliance with this Code.

Assessment of compliance for laboratories conducting the Product Selection testing should be through self
assessment by the explosives provider using appropriately-trained and experienced personnel. Explosives
providers shall also conduct assessments of any site or independent laboratory that is conducting reactivity
testing for customers utilizing that explosive provider’s products. Records of the assessments shall be
retained indefinitely by both the assessors and the laboratories.

A recommended guideline for the assessment of laboratories for operation in accordance with this Code
is contained in Appendix 3.

Within the laboratory, appropriate precautions must be in place to ensure the safety and security
of ammonium nitrate and explosives at all times. In some jurisdictions the laboratory may need to be
approved and licensed to handle ammonium nitrate and explosives by the relevant statutory authority.
SECTION 9 Elevated Temperature and Reactive Ground Blasting

Where a site is known to have both elevated temperature and reactive ground conditions, explosives products that are suitable for withstanding the elevated temperature conditions in addition to the level of reactivity shall be used. All the precautions as detailed in Sections 5, 6, 7 and 8 of the Code must be applied. Greater vigilance in determining the “reactivity” of the ground is required due to the high ground temperatures promoting the nitrate/sulphide reaction.

9.1 Implementation of Elevated Temperature and Reactive Ground Products

Typically when the performance requirements for reactive ground products are being defined, the focus is on sleep time limitations. Consequently, other aspects of the full life cycle of the product may not be fully considered, right from the ground being dug through to loading the holes and including the consideration of misfires. Therefore, current blasting practices at site need to be risk assessed across the full reactive ground life cycle. Moreover, during product implementation, risk assessments should place greater emphasis on potential controls if delays, such as misfires, impose extended sleep times beyond established limits. The risk assessments should include multidisciplinary input from both the site and the explosives supplier, including: shotfiring, technical service, geology, engineering, and explosive product specialists.

Training programs covering the signs of a reactive ground event for personnel involved with managing any misfires should also be developed and conducted on a regular basis (reviewed yearly).

9.2 Shot Design in Elevated Temperature and Reactive Ground Blasting

When blasting in reactive ground consideration must be given to designing shots to minimise the risk of hole dislocation during blasting, ie maximise the use of free face where possible and avoid Box Cut type designs. Hole dislocation can potentially lead to misfires or bulk product remaining in the ground for longer than the recommended sleep time.

If decked shots are required in reactive ground areas, an additional risk assessment should be completed with the assistance of specialists from the explosives supplier. When blasting decked shots in reactive ground, consideration should be given to the use of electronic initiating systems to lower the risk of hole dislocation or misfires.

Prior to the shot, consideration should also be given to plans to dig out misfires within the recommended sleep time of the product should upset conditions occur.
SECTION 10  Selection of Accessories

Initiating explosives used in elevated temperature and/or reactive ground conditions must be compatible with the high explosives they are to be used with and the environment in which they are to be used. Relevant technical data sheets should be consulted and the suitability or otherwise of the initiating explosives discussed with the supplier.

As a guide most commonly used initiating systems like detonators and Pentolite boosters may be used at temperatures up to 70°C. For initiating systems above these temperatures consult your explosives supplier.

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Melting Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMX</td>
<td>275°C</td>
</tr>
<tr>
<td>HNS</td>
<td>318°C</td>
</tr>
<tr>
<td>Pentolite</td>
<td>70°C</td>
</tr>
<tr>
<td>PETN</td>
<td>141.3°C</td>
</tr>
<tr>
<td>RDX</td>
<td>204°C</td>
</tr>
<tr>
<td>TACOT</td>
<td>378°C</td>
</tr>
<tr>
<td>TATB</td>
<td>350°C</td>
</tr>
</tbody>
</table>

Some initiating explosives, particularly boosters, may contain nitrates and therefore appropriate precautions as detailed in this Code must also be taken when used in reactive ground. Booster formulations must be enclosed in a suitable packaging capable of withstanding the chemical environment and temperatures encountered in the application of use. This can range from plastic coating, treated cardboard, tin cans and other metal containers or high temperature plastics.
SECTION 11 Treatment of Misfires and Processes for Extending Sleep Time in Reactive and/or Elevated Temperature Ground

Misfire procedures need to take into account the increased risk of blasting reactive and/or elevated temperature ground and in particular, the increased exposure time of products to elevated temperature and/or reactive ground in the event of a misfire.

A risk management process is required in both the event of a misfire and the instance that sleep times are extended beyond the recommended values. In the event of a misfire, the explosives provider shall be involved in the misfire investigation. The customer shall contact the explosives provider to inform them of the situation. Details of the product used in the area will be provided and a reassessment of the recommended product range may be required.

In the first instance it is critical that for any misfire:

- personnel on bench be minimised to only those directly involved with the management of the misfire;
- an exclusion zone be put in place around the misfire area for activities not directly associated with the recovery of the misfire;
- an Emergency Evacuation Plan be developed, and communicated to all personnel involved in managing the misfire, covering what should be done should a reaction be observed during the recovery of the misfire;
- the charging of associated patterns, which are hot/reactive and whose firing could negatively impact on misfire recovery proceedings, immediately cease.

11.1 Misfires in Elevated Temperature Ground

Standard misfire procedures are applicable unless explosive exposure time is likely to go beyond the recommended sleep times. In addition to standard misfire procedures, water may be used to wash out elevated temperature holes, though it must be noted that water temperature may become hot with exposure to hot ground conditions.

11.2 Misfires in Reactive Ground

Due to the importance of sleep time minimisation, timely action and prioritisation of misfire activities is essential, including, but not limited to:

- focusing all efforts on dealing with the misfire to minimise the time the product is in the ground beyond the authorised sleep time;
- minimising people in the affected area and setting up an exclusion zone;
- identifying and documenting the exact location of misfired hole(s) for digging out;
- implementing ongoing visual inspections of the area to observe any signs indicating an impending reactive ground event or an event in progress;
- consideration of the use of a thermal imaging camera to assist with identifying any heat released from the misfire area which may indicate a reactive ground event;
- refiring of the misfired holes immediately if possible;
- excavation within the rated product sleep time.

Timely action is particularly critical if physical separation (ie liners) is used as there is a higher risk of uninhibited product coming into contact with potentially reactive surfaces. Limitations on sleep time for initiating systems must also be considered.
Standard misfire procedures are applicable unless explosive exposure time is likely to go beyond the recommended sleep times. Additions to standard misfire procedures would include:

- where refiring is not possible, the product should be removed from the holes with a vacuum truck. The recovered product can be diluted with water; dumped from the vacuum truck in a known non-reactive area where possible; or decanted into appropriate vented storage for disposal;

- if use of a vacuum truck is not possible, then washing out could be considered, but not with water. Water must not be used to wash out holes in reactive ground due to the potential of accelerating reactivity and to spread nitrates to other areas while diluting any inhibitor if present. If washing out is required, an inhibited solution (ie 20% urea or Soda Ash solution) should be used.

11.3 Extending Sleep Time in Hot and/or Reactive Ground

During blasting operations, events may require the extending of sleep time beyond existing defined limits. Examples of this could include, misfires, on-bench floods, machine breakdown on bench or electrical storm activity.

In the case of the misfire not being able to be removed within the authorised sleep time of the product the appropriate risk assessment procedures shall be followed. This shall include technical advice from the explosive supplier and shall consider the type of bulk product loaded (a higher emulsion content product will have more inhibitor and may offer a greater safety margin), and the type of zone risk (high versus medium). Prior to re-entry to extended sleep time zones, the management principles detailed in Section 12 of this Code should also be reviewed.

At all times the importance of minimising the time that the misfired product is in the ground must be emphasised and the number of people allowed to re-enter the blast area minimised.

Any authorisations to extend sleep time due to a misfire shall follow a risk assessment that takes the following information into consideration:

- length of sleep time tests performed – any reactions recorded?
- the sleep time characteristics of the product, specifically taking into account any aspects relating to the emulsion/inhibitor level in the loaded product;
- the status of the ground temperature measured before loading, and how that compares with the standard test temperature of 55°C:
  - note that if temperature checks over several days are available (e.g. 3 readings over 3 days) and are increasing, then the initial temperature at the time of firing can be estimated by extrapolation;
  - if only one temperature check is available, and that is higher than either ambient temperature or the rest of shot, then measurement over time shall be continued to determine if the misfire area is rising above product limits before the time of firing;
- information on previous history of non-inhibited product performance in the reactive zone prior to discovery of reactive ground.
SECTION 12 Premature Reaction/Detonation Events in Reactive and/or Elevated Temperature Ground

Whilst the measures described in the Code are designed to minimize and mitigate the risks associated with blasting in reactive and/or elevated temperature ground, the possibility still exists that a premature reaction/detonation event may occur. This Section of the Code provides some guidelines to assist with the management of such an event.

In the first instance, it is critical that all personnel evacuate the area and the incident is reported immediately to senior site officials, the explosives provider and the relevant statutory authorities.

Subsequent management of the event should take into consideration the following:

- setting up and maintaining an appropriate exclusion zone;
- identifying from a safe distance the detonated/fuming/reacting blast hole/s;
- constantly monitoring the complete loaded pattern and recording any unusual events and times these occur;
- prohibiting re-entry until any signs of chemical activity have completely ceased;
- establishing an agreed plan for tie-in and firing of the loaded portion of the blast pattern taking into consideration:
  - the need to minimise the number of personnel and their duration on the pattern;
  - an Emergency Plan (including evacuation) which all parties clearly understand;
  - ensuring all personnel have means of rapid egress from the blast pattern (and immediate area) at all times;
  - utilising a simple design to minimise the time to tie-in and to minimise opportunity for on-bench confusion.
- taking steps to tie-in and fire the pattern as soon as practicably and as safely as possible;
- ensuring that, whilst ever there are personnel on the blast pattern, they are in radio contact with at least one observer located at a safe distance from the pattern. The observer must immediately advise by radio of any unusual observations and the pattern immediately evacuated;
- it is highly recommended that detonating cord NOT be used for surface tie-in;
- the tie-in sequence must take into consideration the location of the detonated/reacted hole/s. Initially it is recommended that a buffer be set up around these hole/s whilst the remainder of the pattern is tied-in. The buffer area should be tied in at the latest possible time before firing. Depending on reactivity level of the ground, affected holes may not be able to, or need to, be tied in. In case they are not tied in, refer to the Misfire section of the Code;
- where signal tube based surface connectors are used, their tie-in should be sequenced in a manner that ensures the shot-firer is walking away from tied-in holes and thus can distance him/herself from possible multiple-hole initiation;
- video record the blast from a safe vantage point that allows a reasonable post-blast analysis for misfires;
- conduct a thorough post blast inspection of the muck-pile for potential misfired blast holes.
SECTION 13. Activity Sequence – Management Flowcharts

The following flowcharts are designed to show the logic in assessing a site which may have potentially elevated temperature and/or reactive Ground conditions.

13.1 Identification and Analysis of the Risk of Reactivity at Green Field Sites

- Operation planned for new site - no previous blasting operations
- Conduct initial Risk Assessment of indicators for the presence of reactive ground (as per Section 4)
- Indicators present?
  - NO
  - YES
  - Initial Reactive Ground Sampling (using "worst case" sampling technique) and Screen Testing
- Reactivity detected?
  - NO
  - YES
  - Recommend suitable product range to users
  - Recommend suitable product for reactive ground situations
  - Product verification and sleep time testing
  - Development or update of operating procedures. Establishment of temperature measurement protocols. Establishment of sleep time limits
- Basis of Re-Assessment
  - Annual re-assessment
  - OR
  - Operations entering new geology
  - OR
  - Reactive ground incident occurs
13.2 Identification and Analysis for the Risk of Reactivity at Existing Sites

Existing Site - previous blasting operations have occurred

Operations entering new geology OR Annual re-assessment due

Yes

Known reactive site

Conduct initial Risk Assessment of indicators for the presence of reactive ground (as per Section 4)

Indicators present

No

Yes

Initial Reactive Ground Sampling and Screen Testing

Reactivity detected?

No

Yes

Recommend suitable product range to users

Continue to recommend and use suitable products

Basis of Re-Assessment

Annual re-assessment OR Operations entering new geology OR Reactive ground incident occurs

Reactivity Incident occurs

Immediately cease supply of uninhibited product

Supply highly inhibited product and recommend 8 hours sleep time.

Extensive sampling and testing program to locate extent and level of reactivity

Further testing of products and determination of suitable sleep time

Product verification and sleep time testing

Development or update of operating procedures. Establishment of temperature measurement protocols Establishment of sleep time limits

Recommend suitable product for reactive ground situations

Recommend suitable product for reactive ground situations
SECTION 14 Training

Based on this Code and other relevant documentation a comprehensive training package shall be developed for all involved in the handling and charging of explosives in elevated temperature and/or reactive ground conditions by the customer at each affected site. The training will ensure that each employee and contractor has a full and comprehensive understanding of:

- standard operating procedures developed for the handling and charging of explosives in elevated temperature and/or reactive ground conditions;
- site specific procedures;
- job responsibilities;
- hazards associated with the handling and charging of explosives in elevated temperature and/or reactive ground conditions;
- the use and ongoing maintenance of personal protective equipment (PPE). In some application specialised PPE may be specified for the employee to use;
- emergency procedures especially where explosives exhibit any violent reaction during charging.

All training will be documented and a process of verification and validation of competencies established. Revalidation of competency is to be carried out on a regular basis the frequency of which must be established on a site by site basis taking into consideration the site complexities of dealing with reactive and elevated temperature ground.
APPENDIX 1 Isothermal Reactive Ground Test.

This test is used to assess rock samples for exothermic reactivity with ammonium nitrate. The general aim of the test is to measure the induction time of the reaction at a constant temperature. The test conditions are intentionally designed to mimic a ‘worst likely case’ of rock particle size, temperature, exposure time and the presence of by-products from oxidative weathering of the rock. This is partly to counter the fact that it is never known whether the most reactive ground on the site has been sampled and tested.

The test mixture consists of finely powdered rock, ammonium nitrate and a solution of ferrous and ferric sulphates.

The term ‘isothermal’ is used to indicate that rock is being tested in an environment with a constant and pre-determined background temperature. Exothermic events are signified by an experimentally significant increase in the temperature of the sample mixture beyond that of the background.

For normal temperature blasting applications at sites with either known or unknown reactivity, the background temperature to be used is 55°C and the test is run for 7 days. The occurrence of an exothermic reaction at any time before that period terminates the test. The test duration can be reduced down to the sleep time used in the blasting application if it is less than 7 days, but the test duration must be a minimum of 48 hours. Also, the test can be terminated before 7 days if the test is being conducted in order to identify the most reactive samples from a site or section of a site.

Where elevated ground temperature is evident, the same test is run but the test temperature is at least equal to the highest in-hole temperature, or at the maximum nominated temperature limit at the site. If the site changes its nominated maximum temperature then the isothermal testing must be repeated at this new temperature.

1. Equipment Required.
   - Aluminium blocks – these are metal blocks with holes drilled to accommodate the glass tubes and distribute heat to the tubes evenly. In the example shown at the end of this section, the holes are 75mm deep with a 15mm radius rounded bottom, 30mm diameter. If there is more than 1 hole per block, the holes must be separated by a minimum of 10mm between the walls of the holes. The blocks may also feature a shallow depression on the top to capture any overflow from vigorous reactions. Some variations in dimensions may occur, however in all cases the tubes shall be sized to ensure that samples sit below the top level of the heater block.
   - Ammonium nitrate – technical grade pure.
   - Data logger – any data logger able to log temperatures at a rate of at least one data point per 30 seconds. It should be accompanied by a computer system to process the data.
   - Dry block heater – an electrically heated tray able to heat the aluminium blocks uniformly at a heating rate of 0.6°C min-1 or slower, and keep them at a pre-set temperature in the range 10 - 200°C and to maintain that temperature to ±1°C.
   - Ferric sulphate – Fe2(SO4)3.9H2O technical grade or better.
   - Ferrous sulphate – FeSO4.7H2O technical grade or better.
   - Jaw crusher – Any crusher allowing fist-sized rocks to be broken into pieces of suitable size for the pulverising mill.
   - Pan balance – any electronic pan balance may be used provided it can weigh at least 300g to an accuracy of 0.2g or better.
   - Protective clothing and equipment – safety glasses, rubber gloves, ear muffs or plugs, disposable dust mask and face visor.
   - Pulverising mill – A mill with a capacity of 600 – 1000cc and capable of milling samples from the jaw crusher down to a sieve size of ~250 micron within 60 seconds. A commercially available mill that meets these requirements is the Labtechnics LM1-P.
- Reaction vessels – glass centrifuge tubes of approximately 50ml capacity, 26mm ID neck and wall thickness of 2mm.
- Rubber stoppers - the stoppers fit into the glass tube have two 2mm diameter holes, one for a thermocouple probe, the other for pressure release.
- Sample bags – thermally sealable plastic vacuum bags able to hold at least 200g of powdered rock.
- Sieve – a stainless steel sieve with aperture size of 250 micron. The sieve should be inspected prior to use to ensure the mesh is not damaged.
- Vacuum bag sealer – commercially available household vacuum bag sealers are suitable for this test.

2 Test method

<table>
<thead>
<tr>
<th>STEP</th>
<th>KEY POINTS</th>
<th>SAFETY/QUALITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock crushing</td>
<td>Check that the rock sample can fit into the jaw crusher. If required, use a hammer to break the whole rock into smaller pieces first.</td>
<td>Wear safety glasses, hearing protection and full face visor.</td>
</tr>
<tr>
<td></td>
<td>Ensure the collection tray for the crushed rock is clean, dry and in place.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Feed rock into the crusher. Activate the crusher and allow enough time for all sample to be consumed. Collect a minimum of 200g of crushed rock.</td>
<td>The sample should be milled and bagged within 15 minutes of crushing to guard against premature aerial oxidation of sulphides.</td>
</tr>
<tr>
<td>Rock milling</td>
<td>Ensure the internal surfaces of the mill are clean and dry.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Load the mill with 200g of freshly crushed rock and mill for not more than 1 minute.</td>
<td>The short milling time will help to minimise aerial oxidation of sulphides.</td>
</tr>
<tr>
<td></td>
<td>Mill for a minimum time to achieve 250um. This is usually 30s or less.</td>
<td></td>
</tr>
<tr>
<td>STEP</td>
<td>KEY POINTS</td>
<td>SAFETY/QUALITY</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Sieving</td>
<td>Remove the powdered rock from the mill. Sieve it using a 250-micron sieve and collect the material that passes through in a heat-sealable plastic vacuum bag.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sieving need only be performed once for a set of samples to ensure that the sample has been milled to 250um. This sieved sample must be discarded as it will have been exposed to oxidation.</td>
<td></td>
</tr>
<tr>
<td>Milled sample storage</td>
<td>Immediately vacuum seal the bags for storage. The bagged samples should also be frozen for further protection against aerial oxidation.</td>
<td>The integrity of the vacuum and seal should be verified by visual inspection of the bags.</td>
</tr>
<tr>
<td></td>
<td>Immediately vacuum seal the sample after milling.</td>
<td></td>
</tr>
<tr>
<td>Retesting</td>
<td>Samples may be required to be tested to confirm a result or for sleep time testing. The sample should be stored frozen and vacuum sealed. Samples should be retested within 60 days of milling if stored correctly. If tested after this time for sleep time, the test must include a reactivity test with AN to confirm that the sample is still active.</td>
<td>If sample is inert, then a fresh sample must be milled.</td>
</tr>
<tr>
<td>Weathering by-products</td>
<td>If milling occurs on site the weathering by-product solutions should be prepared and weighed prior to milling the samples. This will reduce the time from milling to the start of testing.</td>
<td></td>
</tr>
<tr>
<td>preparation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dissolve 3g of FeSO₄·7H₂O in 22g distilled water.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dissolve 5g of Fe₂(SO₄)₃·9H₂O in 13g distilled water.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Combine 2g of the FeSO₄ solution with 2g of the Fe₂(SO₄)₃ solution in a small glass vial.</td>
<td>The resulting 4g of ‘weathering by-products’ solution from this step is sufficient for 1 test.</td>
</tr>
<tr>
<td>Preparation of reactivity</td>
<td>In a 100ml glass beaker, combine 18g of milled rock sample, 18g of ammonium nitrate and the pre-weighed 4g of weathering by-products solution.</td>
<td>Re-vacuum seal the bag immediately after taking the sample.</td>
</tr>
<tr>
<td>test mixture</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mix the contents with a spatula and immediately transfer the mixture to the glass reaction vessel. Mixing can occur in the vessel if it is large enough.</td>
<td>The test steps following this must be done without delay since reaction may start at any time.</td>
</tr>
<tr>
<td></td>
<td>Insert a 2-holed rubber stopper into the glass vessel.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mixtures should be prepared in series rather than in parallel eg completed weighing and mixing one sample before starting the next sample.</td>
<td>This will reduced the rock exposure to aerial oxidation</td>
</tr>
</tbody>
</table>
**TABLE 3.1 Calibration of Equipment**

<table>
<thead>
<tr>
<th>STEP</th>
<th>KEY POINTS</th>
<th>SAFETY/QUALITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature probe set-up</td>
<td>Place the reaction vessel containing the test mixture into an aluminium block on the Dry Block Heater. The aluminium block shall be at ambient temperature at this stage of the test.</td>
<td>The Dry Block Heater is to be set up in a well ventilated fume hood.</td>
</tr>
<tr>
<td></td>
<td>Insert a thermocouple through the rubber stopper such that the tip of the thermocouple sits in the test mixture approximately 1 cm from the bottom of the tube.</td>
<td></td>
</tr>
<tr>
<td>Data logger set up</td>
<td>If milling occurs on site the datalogger should be set up prior to milling.</td>
<td>Refer to the operating instructions of the data logger.</td>
</tr>
<tr>
<td></td>
<td>Configure the data logger to log one data point every 30 seconds.</td>
<td></td>
</tr>
<tr>
<td>Testing the rock sample</td>
<td>Set the temperature of the Dry Block Heater to the appropriate background temperature.</td>
<td>For regular blasting applications, use 55°C. For testing related to ground at elevated temperatures, the test should be run at a temperature equal to or greater than the highest temperature actually measured at the site concerned</td>
</tr>
<tr>
<td></td>
<td>Allow the sample to reach the pre-set background temperature and continue the test by monitoring the sample temperature for a run time of 7 days or for a duration of 4 times the expected sleep time when testing known reactive samples.</td>
<td>The minimum run time for the isothermal test must be 48 hours, even if the ‘sleep time’ in the field is less than this. The test duration can be reduced to the sleep time used in the blasting application if less than 7 days. Also, the test can be terminated before 7 days if the test is being conducted in order to identify the most reactive samples from a mine</td>
</tr>
<tr>
<td></td>
<td>The test is terminated if an exothermic reaction occurs or the run time is reached without reactions occurring.</td>
<td></td>
</tr>
</tbody>
</table>

3. **Calibration of Equipment**

Heater blocks can give an overrun when reaching the set test temperature. This can be mistakenly interpreted as a reaction or a marginal sample. Reducing the heating rate of the dry-block heater to 0.6°C/minute or less usually eliminates heater overrun. However, all blocks must be calibrated to establish if overrun does occur for each position in the heater block. The calibration trace can then be used as a guide to interpret the result of the samples.

To calibrate, substitute sand for the rock sample and mix with the ammonium nitrate and weathering by-products and run the test. The resulting time-temperature trace will be the calibration curve for that position in the heater block.

Calibration curves must be stored indefinitely. Calibration curves are valid for 2 years, unless the testing facility has been instructed to complete calibrations more frequently as a result of either an internal or external audit of the test equipment.
4. Interpretation of Results

An exotherm that qualifies a sample as ‘reactive’ in this test has the following characteristics:

- it is 2°C or above the background temperature in the temperature/time trace of that particular sample;
- it shows both a rise from, and a return to the background temperature when the reaction is completed;
  
  \textbf{(Note):} the background temperature is best measured just before and after the exotherm to exclude fluctuations caused by experimental artefacts such as physical movement of the thermocouple, changes caused by air conditioning, etc.)
- reactions may be accompanied by visible signs, such as bubbling, and/or the generation of brown nitrogen oxides.

If a reaction occurs during the period that the sample is still being brought up to the isothermal set point, an exotherm is harder to distinguish. Nevertheless, a reaction would be indicated by physical signs such as bubbling and/or brown NOx fumes, and/or a temperature rise that was faster than in other (non-reacting) samples being done at the same time. Measurement of the exotherm is discussed below.

Mixtures that show visible signs of reaction but indefinite (<2°C) thermal responses are classed as marginal. Depending on the cause it may be advisable to prepare fresh samples and re-test, or to perform sulphide analyses to check the amount present. Marginal results may be due to very low levels of sulphide, premature aerial oxidation of the sample or reactions other than sulphide oxidation (e.g. carbonates reacting with acid) etc. It may be due to a reaction where the thermocouple has been dislodged due to the sample frothing and rising in the tube. In these cases the maximum temperature is often not measured by the thermocouple and a reaction is not detected.

Samples are run in sets of 4 or more in the same dry-block heater. When a sample reacts when it is at the set test temperature, a line joining the start and end of the reaction can be drawn as the baseline of the reaction. The temperature of the exotherm can be measure from the baseline to the maximum temperature of the exotherm. If the temperature from baseline to maximum temperature is 2°C or greater, then the sample must be classified as reactive. If the temperature is >1 and <2°C, then the sample should be classified and reported as being marginal. Marginal samples should be considered if no reactive samples have been classified in a pit. Further testing must then be conducted to reclassify the marginal samples as being either not reactive or reactive. Further testing can include:

- quantitative Sulphide analysis. If there are no sulphides present, then the sample cannot be reactive;
- retesting existing samples (if unmilled samples are available);
- re-sampling the area of the mine.

If the sample reacts during heating to the test temperature the size of the exotherms are more difficult to interpret. The calibration curve can be used to provide a baseline of the heat-up curve. The heating rate of none reactive sample in the same heater can also be used to establish a baseline. The size of the exotherm is then taken from the extrapolated baseline to the sample trace at any point in time. The maximum difference in temperature should then be used to classify the reactivity of the sample.
Exotherm measured at 15°C
APPENDIX 2 Bucket Test for Reactive Ground

The Bucket Test is designed as a large scale test to determine whether or not selected ground samples are reactive to ammonium nitrate based explosives. The Test is carried out by mixing equal weights of explosive and crushed ground in a 20 litre plastic bucket and examining the contents on a regular basis to detect whether or not a reaction has occurred.

The test may be affected by the prevailing ambient conditions at the time the test is carried out and this may be needed to be taken into consideration when interpreting the outcomes of the test.

The bucket and its contents must be placed in a remote location and access to the site restricted to within 100m as, for safety reason, it must be assumed that a violent reaction and detonation may occur during the test. Where multiple tests are being carried out buckets must be separated by at least 5m.

1. Test Method

The test method is outlined below.

1. The selected ground sample is crushed to 5mm particle size in a jaw crusher, then to sub-2mm particle size in a roll crusher. 2kg of crushed ground is required.
2. 1kg of ground is placed in a 20 litre plastic bucket. 54 millilitres of water is added and thoroughly mixed into the ground with a flat stake. The amount of water added at this stage is half the total amount required for the test. The total amount of water used is 5.4% w/w based on the ground mass (ie 108ml of water).
3. 2kg of the explosive to be tested is added evenly on top of the ground.
4. The remaining 1kg of ground and 54ml of water is added and thoroughly mixed in with a flat stake until a homogenous mixture is achieved.
5. Breather holes are placed through the side of the bucket and the lid placed on the bucket to protect the contents from the weather.
6. The bucket is inspected on a regular basis to determine whether any reaction between the explosive and the ground has occurred. Inspection should be carried out at six regular intervals in the first 24 hrs; then three times per day for the remainder of the first week; and thereafter twice daily until the test is concluded.

2. Precautions

The buckets and their contents must be placed in a remote location with access restricted to within 100m. If there are any signs of reaction, as indicated by the evolution of gases/fumes, the site must not be entered, but must be immediately evacuated until at least two hours after all signs of reaction have ceased.

The generation of orange coloured fumes indicates that a violent reaction is underway and evacuation from the site must be immediate.

When inspecting buckets it is recommended that this be carried out by two people – one carrying out the inspection of the buckets and the other as an observer watching for the start of any reaction. Unless adequate lighting is available at the site all inspections should be carried out in day-light hours.

3. Interpretation of Results

A reaction between the explosive and the ground is deemed to have taken place if:

- there are obvious signs that an explosion has occurred;
- the bucket has melted or caught fire;
• evidence of charring and discoloration within the contents of the bucket;
• any signs of the generation of fumes and/or steam from the bucket.

It is recommended that the test be carried out in triplicate for each ground sample. Generally, the test is carried out with ANFO over seven days as a first indication as to whether or not the ground is reactive. Should a reaction occur in any of the triplicate samples the ground is deemed to be “reactive” and appropriate precautions as detailed in this Code must be adopted in charging blast holes on the site.

If a decision is made to use an inhibited explosive then the test should be repeated on the selected inhibited explosive with those ground samples, which reacted with ANFO, over a period of at least 21 days.
APPENDIX 3 Sample Audit Guidelines for the Inspection of Laboratories Conducting Reactive Ground Testing according to this Code

Example audit guide for the inspection of laboratories conducting reactive ground testing according to this code.

Audits are to be conducted with reference to the complete Code of Practice. This guide is provided as an indication of some specific items to be checked for laboratory compliance, it is not intended to be a comprehensive checklist of requirements.

In addition, any other aspects of laboratory operation that relate to the integrity of testing of reactive ground may be considered in order for the explosives supplier to be satisfied that the results provide a reliable indication of the potential for reactive ground.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Compliant or Non Compliant</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating blocks are aluminium with drilled holes that are of sufficient depth to ensure that the correct mass of sample is held below the top level of the heater block.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Holes are separated by at least 10mm (if there is more than 1 hole per block)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reagents are technical grade pure, or better. Ammonium nitrate, ferric sulphate, ferrous sulphate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data logger collects at least one data point per 30 seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pan balance calibration checks show balance is able to weigh at least 300g to ± 0.2g or better. E.g. 300g check masses give results within 299.8g and 300.2g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protective clothing is available and appropriate Safety glasses, rubber gloves, ear muffs or plugs, disposable dust mask and face visor.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laboratory personnel are using the appropriate protective clothing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vacuum sealing equipment is available and working</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sieve is stainless steel with aperture size 250 micron and is undamaged</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Samples are milled and bagged within 15 minutes of crushing</td>
<td></td>
<td>Sample treatment (note; milling may not occur at the same facility the testing is completed)</td>
</tr>
<tr>
<td>Samples are milled for less than 60 seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Samples are vacuum sealed immediately after milling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Samples are tested within 2 hours of milling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vacuum seals are in good condition</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Samples are clearly identified

Sample identification is traceable to customer reference

<table>
<thead>
<tr>
<th>Storage</th>
<th>Milled samples that are stored for possible retesting are vacuum sealed and stored in a freezer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Where testing of a milled sample for sleep time occurs more than 60 days after milling, a reactivity test with Ammonium Nitrate is performed first</td>
</tr>
<tr>
<td></td>
<td>Where the reactivity test shows a previously reactive sample is inert then a new sample is milled from retained rock sample for sleep time testing and confirmatory Ammonium Nitrate reactivity testing.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Testing</th>
<th>Tests are performed in a fume hood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tests are performed at 55°C for ambient temperature sites</td>
</tr>
<tr>
<td></td>
<td>Tests are performed at the adopted standard temperature where advised of potential for elevated temperatures</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Records</th>
<th>Laboratory report clearly shows the temperature used for the test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calibration curves less than 2 years old are available for each block position</td>
</tr>
<tr>
<td></td>
<td>Calibration curves are stored indefinitely and are retrievable</td>
</tr>
<tr>
<td></td>
<td>Records of calibration tests are kept and clearly identify the calibration curves to which they apply e.g. log book entries</td>
</tr>
<tr>
<td></td>
<td>Evidence is available to show that the heating blocks are able to maintain required temperatures to ± 1°C</td>
</tr>
<tr>
<td></td>
<td>Records are maintained and available of:</td>
</tr>
<tr>
<td></td>
<td>• date of sample receipt;</td>
</tr>
<tr>
<td></td>
<td>• date and time of milling;</td>
</tr>
<tr>
<td></td>
<td>• date of reactivity test;</td>
</tr>
<tr>
<td></td>
<td>• date of retest or sleep time testing;</td>
</tr>
<tr>
<td></td>
<td>• name of person performing the test;</td>
</tr>
<tr>
<td></td>
<td>• original observations.</td>
</tr>
</tbody>
</table>
About the AEISG

The Australian Explosives Industry and Safety Group (AEISG) is an incorporated association of Australian explosives manufacturers and suppliers originally formed in 1994. Since then, the AEISG membership has grown and currently 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

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

One of the strategies adopted by AEISG in this regard is to identify areas where improved standards of operation need to be consistently applied and then develop and issue appropriate codes of practice which capture industry best practice in these areas.

AEISG Codes of Practice are adopted by members for the benefit of their employees, their customers and the general community. They are also made available free of charge on the AEISG website, www.aeisg.org.au, for use by any interested parties.

Contact Details: info@aeisg.org.au