Vienna Conference Proceedings 2007, P. Moser et al.

A control measures based approach to risk management

E. Diacolabrianos
Initiating Explosives Systems, Orica Mining Services, Australia

D.J. Twining
Aker Kvaerner, Australia

ABSTRACT:During the development and implementation of the Safety Case, to satisfy the requirements of the Major Hazard Facilities Victorian Regulations (Victoria is a State of the Commonwealth of Australia), a model of Risk Identification and Safety Assessment, (based on the regulations and current thinking in Risk Management), was successfully customized for Initiated Explosives Systems P/L in Deer Park.

The Model was interpreted and extended to incorporate the needs not only of designers (Technical and Engineering staff), but also of operators of plant both line management and workers.

The model is used to develop the Basis Of Safety (BOS) training and operational procedures for plant personnel, at every level. The model also has been extensively used in training of operators, as it is very clear way to show how Control Measures are linked to Hazards and hence a more conscious management of these hazards.

The authors argue that the model is applicable to all the Chemical Process Industries (CPI's) and adaptable for ANY hazardous process however simple or complicated.

1. INTRODUCTION

During the development and implementation of the Safety Case, to satisfy the requirements of the Major Hazard Facilities (MHF) Victorian regulations, a model of Risk Identification and Safety Assessment, was successfully customized for Initiated Explosives Systems P/L (IES) in Deer Park.

The model uses a Control Measures based approach to risk management.

The model was used to develop further an existing Basis Of Safety (BOS) training and operational procedures, for plant personnel, at every level. It has also been extensively used in training of operators, as it is very clear way to show how Control Measures are linked to Hazards and hence a more conscious management of these hazards.

The model incorporates a risk register, which is used as the knowledge depository/management tool to maintain the inherent/design safety and manage the residual risk of the plant design.

The model is applicable to all the Chemical Process Industries (CPI) and adaptable for any hazardous process no matter how simple or complicated.

2. RISK MANAGEMENT MODELS

2.1 Traditional risk management

Hazard and Operability (HAZOP) studies have been used extensively in the Chemical Process Industry together with Failure Mode Analysis (FMA's), Hazard Analysis (HAZAN's), Quantitative Risk Assessment (QRA's) and other tools. Risk and Process Engineers used these tools to design safety and operability into plants new and old, by identifying hazards and then applying the risk reduction strategies of the hierarchy of controls (Eliminate, substitute, minimize, manage, PPE etc).

These processes take place, usually, in a frame of what is technologically possible at the time and for the right price. This last point, "price", always means a compromise in the Control Measures that are adopted and therefore the final risk that would be inherent in the design.

In the last decade, focus by businesses on "core" activities and now Globalization added to and compounded the problems of Risk Management at the Plant level.

- There is a steady loss of process/risk engineering & technology experience from high risk plants and therefore knowledge, by downsizing & re-engineering
- The outsourcing of design, construction & commissioning of new plants / upgrades to different companies, (and a lot of times each function taking place at a different part of the world), the compromises on the control measures, (reliability, functionality, maintainability, survivability & availability), are now multiplied. Standards used might be different and the substitute of "equivalent" type control measures/components, without due regards to the original design assumptions

HAZOP studies in particular are carried out in the design phase of plant or modifications to plant. Generally the context in which a control measure

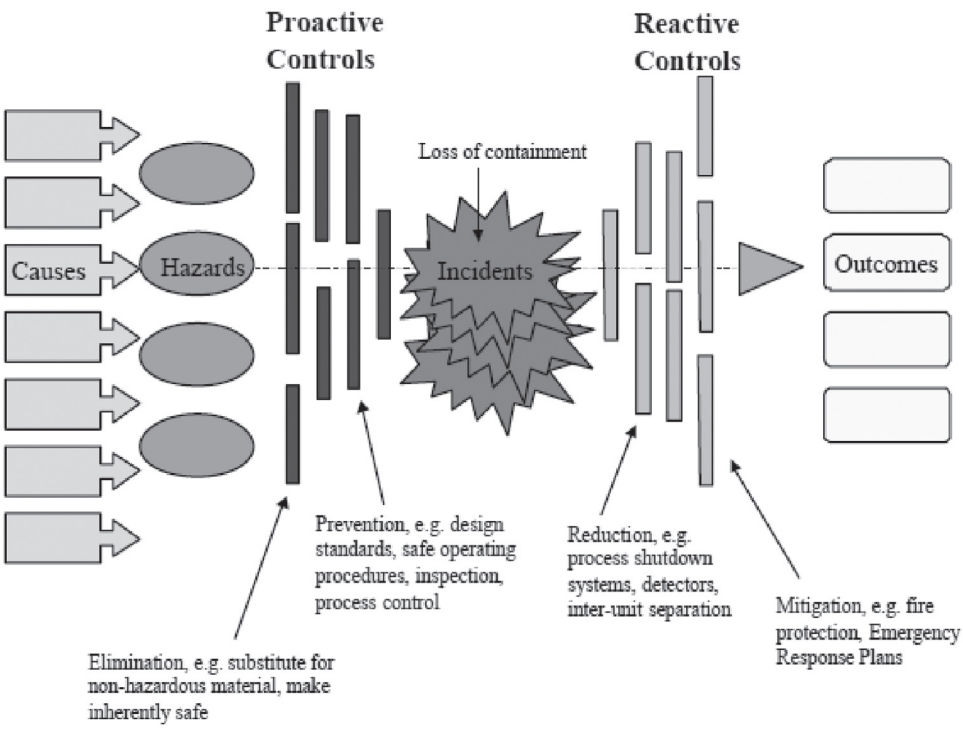

Figure 1. Bow-Tie diagram

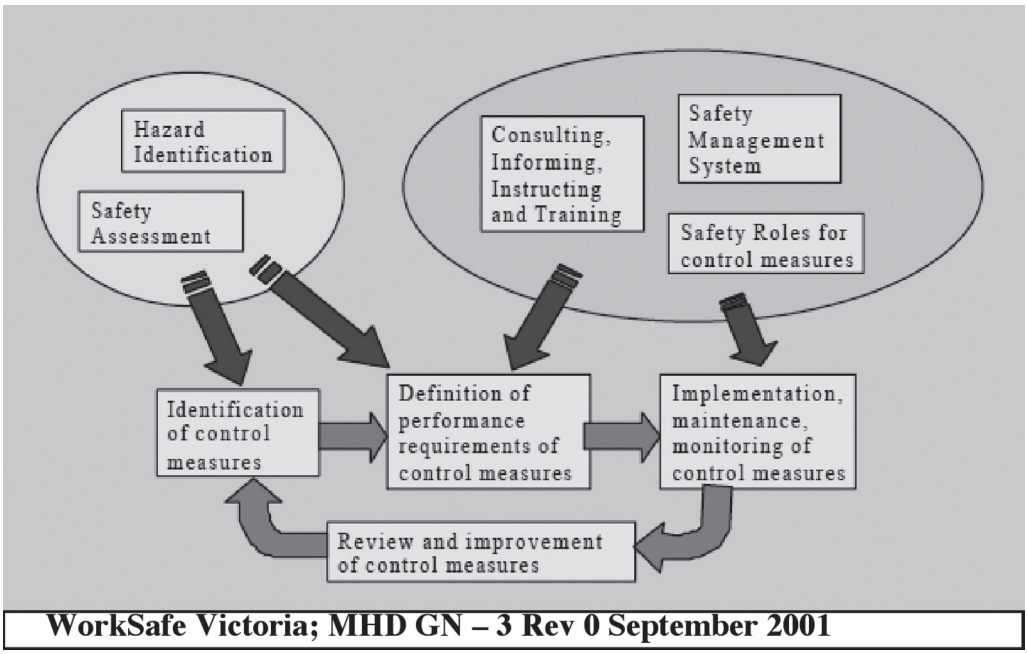

Figure 2. WorkSafe Victoria guidance note GN 3 rev 0, Sep 2001.

is chosen and possible alternative (but rejected) control measures is not well documented. The knowledge of a control measure's criticality and its limitations (applicable operation range) rarely gets passed on to plant operations (managers, operators and maintenance staff).

2.2 *Control measures based model of risk management*

The MHF Victorian regulations and its model of Risk Identification and Safety Assessment (customized at IES as a control measures based approach to risk management) bridges the gaps that traditional and current models of Risk Identification and Safety assessment such as HAZOPS / HAZAN /QRA have, when applied in practice.

"Understanding what parts of a facility are in fact control measures, and how they actually control or affect hazards and risks, is critical to safe operation, as only through this understanding will the Control Measures are maintained."

This concept is illustrated in Figure 1, also referred to as a Bow-Tie diagram.

Control measures are the barriers between the hazards and the consequences/outcomes. Once we view the safety of the plant as the integrity of the control measures that were designed into it, then it also follows that the role and place of systems, (Design, Risk Management, Safety Management, Knowledge Management), becomes clearer. They are there to support the identification of control measures, their definition, their implementation and maintenance and of course their improvement. The concept is depicted in Figure 2.

Here are some inferences/statements coming out of the model;

- If you did not design the Control Measure into the system, then it is not there to protect you
- If you took short cuts at the design stage, you better tell the operations people what they were
- If you, the operations engineer/operator/manager do not know what the Control Measures that protects you, ie, what were the assumptions of the design engineer, you bound to have an incident

Another strong message coming out of the model, when someone takes into account the complexity of modern CPI, is that the operator of plant needs a knowledge management system to help him maintain the control measures and

Table 1. Example of Hazid/SA process and showing the listing of the control measures.

Process/Process step	Detonating cord spinning/semifuse take up spooling
Hazard	Friction; (from a set of key words)
Scenario/cause	Traverse mechanism fails, accumulation of cord semifuse on one side of the spool, jumping off the flange and getting tangled in the rotating shaft.
Consequence(s)	Possible fire, leading to explosion.
Control measures	Plc monitored traverse stops process if mechanism fails, tension controlled emergency stop, slow speeds of take up spool, preventative maintenance on traverse mechanism, modification and clearance procedures.
Safety assessment	Residual risk; level IV (extremely unlikely, single death)

improve them. That system, must serve the needs of ALL the stakeholders i.e. designers/system managers /operations/ engineering maintenance and management at All levels.

2.3 IES customised model

The IES Plant is one of several manufacturing facilities on the Orica Deer Park Site, which produce a range of industrial chemicals and products. Like the site, it is an old plant with various generations of explosives technologies meshed together over its 100 plus years of operation. IES forms part of the Orica Mining Services Group and produces initiating explosives for use in commercial mining operations. Materials used in the production of initiating explosives and posing the greatest risk within the facility are Explosives at various stages of manufacture, Nitric Acid and Acetone.

As a result of the hazardous nature and quantities of these (MHF Schedule 1) materials, the plant is considered a major hazard facility (MHF) under the Major Hazard Facilities Victorian regulations.

To successfully meet the requirements of the MHF regulations, the Victorian WorkCover Authority model of Risk Identification and Safety Assessment, was customized at IES, and incorporated into an existing Explosives Basis Of Safety corporate model that was developed also as response to low frequency high consequence events.

The first stage of developing the model consisted of a comprehensive and consultative Hazard Identification (Hazid) and Safety Assessment (SA) review process. Like any other old CPI plant original design calculations/assumptions /hazard studies were not available and therefore much emphasis was placed on consultation with current and past operators and technical experts in the field from within the company but also from outside. Also personnel on site were trained in the Hazid/SA process and participated in it when his/hers section were analysed. The process was aimed to identify and assess all scenarios associated with the MHF Schedule 1 materials that could lead to major incident. A total of over 3000 causes were considered out of which 2700 were linked to major incident scenarios. An example of the development of an incident scenario in the detonating cord spinning room together with the safety assessment is given in Table 1.

Control measures in place to prevent or mitigate the escalation and/or consequences of each hazard scenario were listed and using traditional techniques (QRA, Probits, risk matrices etc.) a residual risk was determined. Alternative controls were considered and residual risk re-visited. Table 1 shows the listing of control measures for a particular scenario.

The scenarios and associated control measures (actual and alternative) and residual risks were then compiled into a Risk Register, configured to show the direct link between hazard scenario, control measure and residual risk.

That direct link was transposed into the Basis of Safety (BOS) checklists that are used to manage control measures on a day-to-day basis (see section 2.4).

2.3.1 Model used as the key to risk management

2.3.1.1 Control measures

For hazard scenarios involving explosives, a sequence of events takes place from a FISH (Friction, Impact, Static/Spark, or Heat) initiation

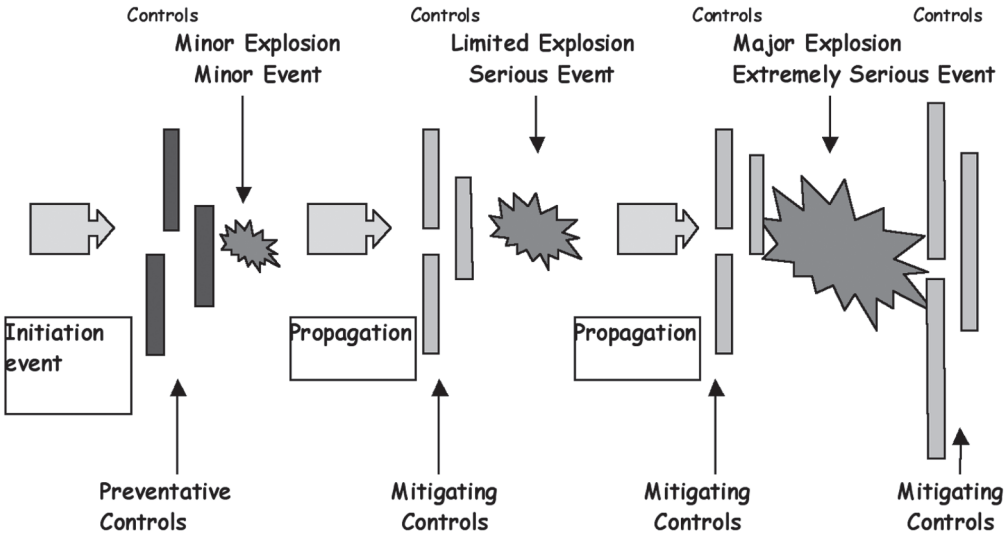

Figure 3.

event through to a full-scale detonation of bulk explosives. The event sequence starts when a FISH event occurs with sufficient stimulus in the presence of explosives to cause a "minor crack". Propagation to a limited quantity of explosives may lead to a "Limited Explosion", propagation to bulk explosives may lead to a "Major Explosion".

The different stages involved in this progression, suggest natural control points to prevent or limit the escalation and consequences of accidental initiation. This can be shown in the following diagram (Figure 3), which depicts the escalation of an initiation event through to a major explosion. At every stage, a range of control measures can be employed to break the chain of events and/or limit the consequences.

A similar progression and range of control measures can be applied to hazard scenarios involving non-explosives materials. For example, in a fire scenario a loss of containment, combined with an ignition source, can start a local fire that can escalate fire that can escalate to a limited fire or onto a major fire. Again a range control measures can be employed to break the chain of events and/or limit the consequences.

As a general rule more than a single layer of protection is implemented to break the chain of events and/or limit the consequences of a hazard scenario. Refer to Figure 1.

Control measures can be defined in three categories:

Preventative controls -

Separate explosives from F.I.S.H. sources;

- Physical separation from ignition sources, motors etc
- Housekeeping and cleaning of explosive dusts
- Engineering arrangements, (exclusion seals, vertical surfaces etc)
- Plant maintenance
- Safety Management System and procedures, (Operator training & awareness, clearance and modification systems etc.)
- Packaging and containment of explosives
- Electrical and engineering practices, (design standards, storage separation distances, pressure relief valves, temperature controllers etc)

Control measures to minimise process potential;

- Soft materials
- Low speed of movement
- Low heights / Low mass
- Earthing/conductive materials and equipment, humidity control
- Temperature controllers, high temperature cut-outs

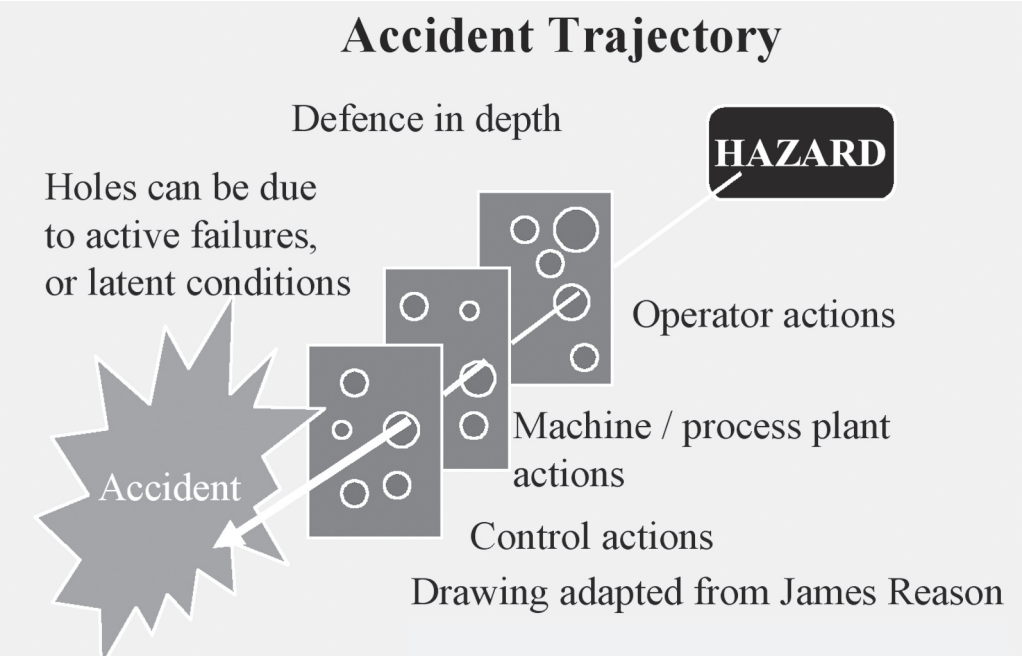

Figure 4.

- Safety Management Systems & procedures, Operator Training & awareness, Clearance and Modification systems etc
- Local emergency, abnormal operation work instructions
- Plant maintenance

Mitigating controls -

Engineering control or emergency response procedure that reduces the probability of propagation of a "minor event" into a "serious event" or "extremely serious event".

- Elimination of propagation paths
- Physical layout to provide separation from bulk material
- Housekeeping and Cleaning
- Detonation traps, remote operations, blast walls
- SMS procedures, Operator training and awareness, clearance and modification systems
- Bunding, safety showers, fire fighting equipment, emergency procedures, etc

Generic controls -

Any general control measure that may affect the event frequency, process potential, probability of explosives or fuel or other hazardous material present, probability of propagation, and injury consequences.

- Hazard study system, modification procedure, clearance procedure or permit to work, unusual incident reporting system, maintenance, operator awareness, training work instructions, etc

2.3.1.2 Critical control measures

For each hazard scenario identified one or more specific "critical" control measures are selected on the basis of their importance on reducing the risk level. Usually last line of defence measures such as blast walls and /or detonation traps would fall into this category, but also control measures that run across the preventative and mitigating divide such as housekeeping.

2.3.1.3 Hazard ID / risk register

By identifying the link between hazard, control measures in place and residual risk a more conscious management of these hazards through maintenance of control measures can be achieved. To enable that link to be maintained and managed throughout the

Cord potential Major Incident Scenarios

Explosion in AO1 Spinning Room at Spinning Hopper

- Cause : Friction contact of PETN Spinning Hopper with Spinning die caused by maladjustment or subsequent movement.

Controls

Control Type	Control Description
Preventative Controls (2) Process Control / Securities	Yarns would break if hopper rested on die. Thickness detector senses broken yarn and stops machine.
Preventative Controls (5) Housekeeping	Hopper check at the end of each reel when sock is removed.
Mitigating Controls (3) Blast Wall	Blast Wall Present.
Generic Controls (3) Operator Awareness, Training & Procedures	Set-up procedure & operator monitoring machine especially if yarn keeps breaking.

Your Role:

- **Spinning hopper must be aligned centrally with spinning die and have sufficient clearance from die so as not to touch the spinning yarns**
- **No modifications to process or equipment without an Alteration Authority**

Figure 5.

life of the plant a Risk Register was developed. The Risk Register takes the form of a relational database that links Hazards with the Control Measures that prevent or mitigate them, and Control Measures with their standards and KPI's, on a scenario based approach. It also safety assesses the scenario and assigns a risk level to it.

2.3.1.4 Basis of Safety (BOS) checklists

The explosives industry is one of the oldest, one of the most hazardous and based on very unforgiving products and processes. A mistake involving explosives can be costly, and it can be the last one someone can make.

The Explosives BOS concept was developed by ICI now Orica Explosives Group, in response to the number of causes of fatal accidents in the manufacture and handling of explosives. The concept assumes and accepts that there are a number of hazards / control measures / consequences (H/CM/C) that are unique to every industry because of the nature of their products and processes.

For explosives the H/CM/C are very well understood and known, and this is apparent from the

fact that all incident investigations into near misses and fatalities fail to bring to the surface any new hazards or causes. In fact all incidents irrespective of industry follow a classic James Reason "Swiss Cheese" model of accident causation as depicted in Figure 4.

The problem, as has been argued above, is that the holes in the control measures as well as the conditions/scenarios that will align them, must be in the mind/active memory of the person actually running the plant, the operator, and not only in the minds of engineers, technologists, or managers.

Monitoring implementation and performance of individual control measures poses a considerable challenge given the large number of control measure / scenario combinations. However this is achievable with little additional effort when incorporated into daily operator and maintenance activities.

Each plant area may be divided into process or other geographical or logical units for which a Basis of Safety (BOS) Checklist can be prepared. The checklists detail the critical maintenance and operational checks to be performed on a regular basis to ensure that control measures are in place and performing to required standards.

An example of such a critical operational check, associated with a Friction Hazard, in the detonating cord spinning room, is given in Table 2 below;

Table 2. Example of a critical operating check.

Control Description	Standard of control required	Frequency
Spinning hopper adjustment	Spinning hopper must be aligned centrally with spinning die and have sufficient clearance from die so as not to touch the spinning yarns	Each lot

The checklist then becomes a BOS performance standard for the process area and can be used for job cycle checks, audits, training etc.

Figure 5, is an example of bringing control measures and conditions that align them into the active memory of the operators during training and retraining.

The example is associated with the one given in Table 2. The Hazard/Scenario is outlined, then the control measures, (preventative, mitigating and generic), are given, and finally the role of the operator in maintaining the control measure(s) are also given.

For technical / design / management / operational / maintenance personnel (but also available for anyone who has a need to look at it), the hazard(s), the control measures, and the BOS checks, are linked in the Risk Register.

2.3.1.5 Risk assessment of plant modifications

Existing risk assessment methods of plant modifications can be upgraded to include a review of the Risk Register and control measures in place to ensure the existing control measures are not compromised or residual risk increased by the modification. Any additional controls used in the plant modification are reviewed and incorporated into the risk register. BOS safety checklist, training, etc.

2.3.1.6 Portability of the control measures model

The Control Measures Risk Management model applies to all the H/CM/C situations simple or complicated from Manual Handling, Working at Heights, Storage of Dangerous Goods or Hazardous Substances, entry into Confine Spaces, to driving or cooking.

All of the above processes assume that there are layers of Control Measures that make the operation safe and are specific to the hazards. The Controls Measures model can be used to explain why and to help reinforce in the minds of people who carry out these processes what keeps them safe. In the case of manual handling i.e. lifting of a heavy object, "bending your knees" might be the only Control Measure between a safe lift and a strained back.

3. CONCLUSIONS

A model using a control measures based approach to risk management was successfully customized and developed by Initiated Explosives Systems P/L in Deer Park.

It bridges the gaps that traditional and current models of risk identification and safety assessment such as HAZOPS / HAZAN /QRA have, when applied in practice.

The model shows the direct link between hazard, control measure and residual risk. Through training

this provides operators and line management with the knowledge of "What keeps them safe" and trough Basis of Safety (BOS) checks provides practical and ongoing monitoring of controls.

The authors argue that the model is applicable to all the Chemical process Industries and adaptable for any hazardous process however simple or complicated.

4. ACKNOWLEDGMENTS

The authors acknowledge:

The Initiating Explosives Basis Of Safety Model was the work of the authors, Nick Strolla, and Trevor Cowper in the course of the IES Safety Case development.

John McPherson for his contribution in grouping and defining the Control Measures.

Chris Blake, the IES Deer Park management team and ALL the operators who have contributed immensely in the model's implementation.

Nick Strolla for his brilliant Risk Register database.

Initiating Explosive Systems P/L Safety Case Steering Committee, for supporting financially and encouraging the work and its outcomes.

Orica Limited, as the owner of IES P/L, but also of a number of other MHF's in Victoria and who ultimately funded the Safety Cases.

WorkSafe Victoria MHU staff that oversaw the safety case process at each step.

REFERENCES

WorkSafe Victoria Online; Major Hazard Guidance Material, Guidance Notes: GN10-Control Measures and Performance Indicators under the Occupational Health and Safety (Major Hazard Facilities) Regulations, (last updated 6/03/2006). http://www.worksafe.vic.gov.au/wps/wcm/connect/WorkSafe/Home/Safety+and+Prevention/Your+Industry/Major+Hazards/Guidance+Notes?&a=Major%20Hazards&p=popularWorkSafe Victoria Online;

WorkSafe Victoria Online; Major Hazard Guidance Material, Guidance Notes: GN3-An Overview of the Safety Case Regime under the Occupational Health and Safety (Major Hazard Facilities) Regulations; (last updated 6/3/2006). http://www.worksafe.vic.gov.au/wps/wcm/connect/WorkSafe/Home/Forms and Publications/Guidance Notes/GN3 - Safety Case Regime Overview.

Vienna Conference Proceedings 2007, P. Moser et al.
 ISBN 978-0-9550290-1-1

Advancing public relations through simplifying communication

B.T. Lusk
University of Kentucky Mining Engineering Department, Lexington, Kentucky, USA

ABSTRACT: Commonly used units for reporting airblast measurements may be detrimental to quality public relations. Recent research has shown that the current practice of reporting airblast in decibels creates discomfort in residents living in proximity to blasting operations. The study briefly discussed in this paper utilized Likert Scaled Surveys to determine residents' comfort levels with many different airblast reporting units including decibels, millibars, and pounds per square inch (PSI). The surveys were distributed in close proximity to several quarry operations in the Midwest United States, and results were analyzed based on location and demographics. The results were also compared to other groups of survey participants that did not reside near blasting operations. Analysis of the collected data shows that using similar surveys as a potential tool for proactive public relations shows promise. Using surveys to establish baseline communication levels with neighbours could advance public relations efforts for mining operations by providing insight and direction for site specific public relations programs.

1. DETRIMENTAL USE OF CONFUSING UNITS FOR AIRBLAST REPORTING

In the past, extensive research has been undertaken on blast damage levels; however, this work has done little more than slow down the onslaught against the blasting industry. While it has been important work since it has provided the industry with certainty about what vibration and airblast levels are harmful to structures, a problem still remains. Although structurally safe levels have been met, complaints about blasting do not cease. At this point, the problem immediately transforms from a structural damage issue into one about abating complaints and fighting lawsuits. It should be obvious that the key or keys to this problem are somewhere else besides levels of vibration alone. Certainly the use of public relations in our industry is a relatively new idea and definitely making ourselves understandable to the public is a novel concept. Nearly twenty years ago, the blasting industry faced similar challenges as can be seen in a journal article by Petro and Anderson in 1986 (Petro 1986). The abstract begins "Blast vibration problems are often a matter of neighbour complaints rather than compliance with regulations." (Petro, 1986). At the 2005 International Society of Explosives Engineers (ISEE) Conference on Explosives and Blasting Technique, Spathis (Spathis, 2005) states, "It is also interesting to note that in certain circumstances a person can feel levels of ground vibration that are lower than human comfort limits and thus be disturbed even though there has not been an exceedance (of regulatory limits)".

In order to clarify the problem faced at quarries forced to interface with numerous

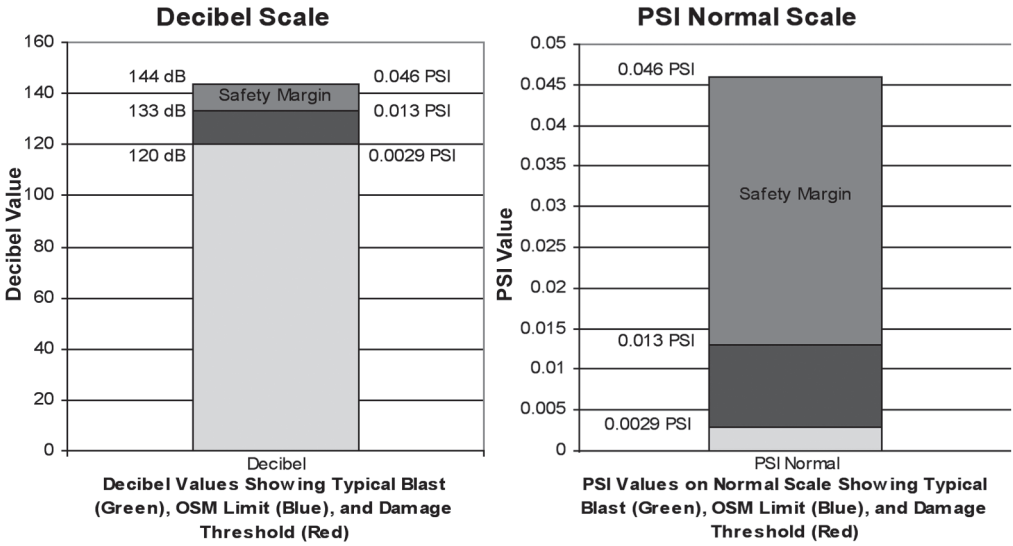

Figure 1. Comparison of logarithmic decibel scale and normal PSI scale. Corresponding values for kPA are 0.046 PSI = 0.317 kPa, 0.013 PSI = 0.090 kPa, and 0.0029 PSI = 0.020 kPa. (Lusk, 2006).

neighbours, background information is necessary. Disturbances like blasts from nearby quarries instil worry in people. In many cases, residents will start looking for damage following blasts. They may encounter damage or defects in their homes that occurred prior to any blasting activity nearby. Many times, lawsuits are initiated against the mining company or blasting contractor for damage not caused by blasting.

The use of confusing units may be the root of many problems associated with neighbours in close proximity to blasting. The simple fact that residents may not understand the units used to report ground vibration and airblast data has been overlooked to date when considering public relations for mining and blasting operations.

Warneke (Warneke 2004) introduces the use of indicators to help in the creation of mining-related public policy. Through discussing the many definitions and characteristics of indicators, Warneke identifies a common thread among effective indicators. He states "characteristics necessary for effective indicators:… Simple to interpret, accessible and publicly appealing" (Warneke 2004). In the same way, blast reporting units are indicators of the success of a blasting program; thus, the units should follow the same characteristics.

The use of the decibel scale for airblast reporting can be shown as possibly detrimental when the logarithmic nature of the scale is considered. Figure 1 is a bar graph providing a visual comparison of the decibel scale and a linear PSI scale. The figure shows how a resident might be uncomfortable with the decibel scale because the values of a typical blast, the Office of Surface Mining (OSM) limit, and the threshold for damage appear to be very close relative to the scale. In contrast, the PSI scale shows that the actual pressure values of these items are farther apart. The safety margin appears to be much larger when using the PSI scale.

2. COLLECTING SURVEY DATA FOR ADVANCED PUBLIC RELATIONS

Beginning in the summer of 2004, a large amount of survey data has been collected from many different constituents in order to analyze the overall perception of reporting units for blast vibration and airblast. The surveys were administered by mail to several groups of people. A critical step in the research process was to determine appropriate survey pools. Five distinct pools were identified. They are

as follows:

- Alpha Group – Public in proximity to blasting operations
- Beta Group – Control groups of the public who are not exposed to blasting
- Gamma Group – Civil Engineers
- Delta Group – Blasting Professionals
- Epsilon Group – Local and State regulators and administrators

These survey pools were selected in order to obtain a view from each perspective involved in the regulation process. The residents living in close proximity to blasting operations were surveyed in order to find possible reasons for low comfort levels with blasting. A control group of residents who are not exposed to blasting were surveyed as a control group that is not affected by blasting. This could provide insight as to how certain public relations policies are working. Civil engineers are included to provide a strong scientific basis for damage criteria as these are the people who design and build the structures. A group of blasting professionals was also subjected to a survey to identify differences in their responses to the other groups as these are the individuals who would likely be the most comfortable with all units for reporting blast vibrations. Local and State regulators and administrators are a separate group because they will have different perspectives on the issues. They are ultimately responsible for politically dealing with citizens that complain about blasting.

The example provided later in this paper describes analysis of data from the Alpha Group only. The Alpha survey questions are as follows, and future figures will refer to the question names listed below each question. Each survey pool was administered a similar survey; however, some groups were asked additional pertinent questions. Nevertheless, the core questions remained identical for each group.

The Alpha Survey was designed for distribution to members of the public who reside within 1 mile of an ongoing blasting operation. In all cases for this research, the participants were selected who lived adjacent to surface aggregate quarries. The survey consisted of seventeen questions total. The initial five questions asked for general demographic data including home ownership, age, sex, working hours, and duration at the current residence. This information was used to partition the data into further groups. Not all of the information gathered here proved useful for this research; however, in future studies it may provide answers for questions not asked here. The remainder of the survey asked questions regarding blasting and reporting practices for ground vibration and airblast. Question #6 asked:

6. How comfortable do you feel having a blasting operation within 1 mile of your home?

1 Very Uncomfortable
2 Uncomfortable
3 Neutral
4 Comfortable
5 Very Comfortable

This question was designed to determine how comfortable respondents were with blasting close to their home in general. For reading simplicity through the analysis of the data each question will be assigned a short name for reference throughout the remainder of the dissertation. The above question #6 will be referred to as Alpha General Likert from this point forward. Question #7 asked:

7. Based on good scientific research, the Federal Safety limit for air blast overpressure is 133 decibels. How comfortable are you with a blast producing 120 decibels of air blast overpressure?

1 Very Uncomfortable
2 Uncomfortable
3 Neutral
4 Comfortable
5 Very Comfortable

This question (Alpha Decibel Likert) begins a series of questions regarding airblast reporting. The series contains two more questions which are identical to Alpha Decibel Likert but utilize direct conversion of units to millibar and pounds per square inch (PSI). The other three questions in the series ask what the respondent associates with each unit.

The questions followed by their abridged names are as follows:

8. What do you associate with decibels? (Alpha Decibel Association)

9. The translated Federal Safety limit for air blast overpressure is 0.89 millibars. How comfortable are you with a blast producing 0.2 millibars of air blast overpressure?

1 Very Uncomfortable
2 Uncomfortable
3 Neutral
4 Comfortable

5 Very Comfortable

(Alpha millibar Likert)

10. What do you associate with millibars?

(Alpha millibar Association)

11. The translated Federal Safety limit for air blast overpressure is 0.013 pounds per square inch (PSI). How comfortable are you with a blast producing 0.0029 PSI of air blast overpressure?

1 Very Uncomfortable
2 Uncomfortable
3 Neutral
4 Comfortable
5 Very Comfortable

(Alpha PSI Likert)

12. What do you associate with PSI?

(Alpha PSI Association)

The above series of questions was designed to determine whether residents would be more comfortable with a reporting unit other than decibels. The qualitative association questions were an attempt to begin explaining why.

Three questions followed which addressed ground vibration reporting units. The following series of questions were identical except for the direct unit conversions using sinusoidal wave equations.

13. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement also has a regulated safety limit for ground vibration of 1.8 inches/second at 35 Hz. How comfortable are you with ground vibrations at your home with velocity in the range of 0.5 inches/second at 35 Hz?

1 Very Uncomfortable
2 Uncomfortable
3 Neutral
4 Comfortable
5 Very Comfortable

(Alpha VF Likert)

14. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.00818 inches. How comfortable are you with ground vibrations of 0.00227 inches at your home?

1 Very Uncomfortable
2 Uncomfortable
3 Neutral
4 Comfortable
5 Very Comfortable

(Alpha Inches Likert)

15. Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement has a translated regulated safety limit for ground vibration of 0.21 millimeters. How comfortable are you with ground vibrations of 0.06 millimeters at your home?

1 Very Uncomfortable
2 Uncomfortable
3 Neutral
4 Comfortable
5 Very Comfortable

(Alpha mm Likert)

Again, these questions were used to assess the respondent's preference for reporting units, but these questions targeted ground vibrations. Questions eight through fifteen constituted the major scope of this research, and the majority of the data analysis is based on these questions. All five survey pools were asked these questions. Other group-specific questions were asked for the reason of looking forward to future research. The Alpha survey contained two more questions as follows:

16. Have you ever lodged a complaint against a blasting operation?

Yes No

(Alpha Complaint)

17. Federal safety limits are reasonable for public safety.

1 Very Uncomfortable
2 Uncomfortable
3 Neutral
4 Comfortable
5 Very Comfortable

(Alpha Federal Likert)

While analysis of the final two questions in the Alpha Survey is not necessary for reaching the goals of research, they do provide insight when planning for future studies. With these questions, evaluating relationships between comfort levels, complaints, and the potential use of federal blast vibration limits can be achieved.

Many conclusions were drawn from the analysis of the data. The following section provides one example of how the survey data could be used to target specific public relations efforts for individual operations. Future publications will present more results and other examples of how the data can be used. Extensive statistical validation was performed on the data; however, discussion of this process is beyond the scope of this paper.

3. EXAMPLE OF CONCLUSIONS DRAWN FROM SURVEY DATA

It is technically and scientifically proven that blast vibrations already have accepted limits that are safe and preclude damage from blasting. The problem of complaints about blast vibrations is now one of annoyance levels and public relations. Public relations overall offers the most fruitful path as zero annoyance will only occur when blast vibrations are almost eliminated. Mining operations should create proactive public relations policies especially concerning the use of explosives at their mines. Surveys could be a pivotal tool for determining what types of information neighbours might like to see regarding blast vibration and airblast data. Baseline surveys could determine a level of education that is currently found amongst the majority of its neighbours. This provides an excellent starting point for developing quality public relations. A short example of how survey data could be used to target issues follows.

A simple comparison of average comfort values at two separate quarry locations shows that the survey information could be used as an effective public relations tool. Table 1 shows average comfort values for a partitioned data set for an Ozark, Missouri, quarry that was specifically surveyed as compared to the partitioned data set for a Little Rock, Arkansas, quarry similarly surveyed. These two locations were chosen for the example analysis due to a visible difference in the aesthetics of the neighborhoods. In Ozark, the homes were newer construction and higher property-value homes than those around the Little Rock quarries. The averages summarized in Table 1 show that there is a difference in comfort levels for the two locations.

It can easily be seen that comfort levels are much lower from the Little Rock respondents. Trends found in the analysis of the entire Alpha Survey group showed PSI as the preferred unit for airblast and mm displacement the preferred unit for ground vibration, thus the partitioned data agrees. The values themselves do not provide any aid as to how to handle the distinctly lower comfort values; however, taking a closer look at both the demographic information and the answers to the qualitative questions in the survey provides some

Table 1. Summary table for comparison of Ozark quarry and Arkansas quarries.

Partitioned Location	General Likert	dB Likert	millibar Likert	PSI Likert
Ozark	2.00	2.00	2.44	2.50
Little Rock	1.67	1.83	2.00	2.50

Partitioned Location	VF Likert	inches Likert	mm Likert	Federal Likert
Ozark	2.24	2.34	2.28	2.90
Little Rock	2.09	2.00	2.18	2.64

Table 2. Summary table of association analysis of partitioned data for Ozark, Missouri quarry and Little Rock, Arkansas quarries.

Partitioned Location	dB Association	millibar Association	PSI Association
Ozark	72% Sound	32% Pressure	69% Pressure
	25% Don't Know or No Answer	44% Don't Know or No Answer	25% Don't Know or No Answer
Little Rock	83% Sound	83% No Answer or Don't Know	83% No Answer or Don't Know
	17% Don't Know or No Answer	8% Pressure	17% Pressure

direction. Table 2 shows the results of a simple analysis of the association questions asked in the survey about units for airblast measurement. The table values do not add up to 100% for each question due to the fact that some answers did not fall into the major categories summarized.

The summary table above provides insight for the lower comfort values from respondents in the Little Rock area. Specifically, 83% of respondents did not have an answer or replied 'Don't Know' for the questions regarding what they associate with both millibar and PSI. This is particularly higher than the percentages responding 'Don't Know' in the Ozark area. This suggests that education of the neighbours on something as simple as the units for pressure might help raise their comfort levels with reporting units for airblast.

Much could be learned about what residents find annoying about any specific operation with quality surveys. Findings could reveal that blasting is not the most annoying factor involved in the mining process. Crusher noise, dust, backup alarms, and truck traffic could all have adverse effects on the image of an operation. Expansion of the survey questions could address many of these issues.

Gathering demographic and qualitative data will enhance an operator's ability to communicate and, thus, circumvent complaints. The key to positive public relations is to give neighbours what they want without creating undue financial burden on the operation. For example, learning that the majority of neighbours do not understand anything about blast vibrations could prompt local meetings to discuss these issues. Likewise, surveys could show that neighbours are well educated in terms of blast vibrations and airblast, and thus another avenue must be chosen.

4. ADVANCES IN PROACTIVE PUBLIC RELATIONS

Many situations where quarries are surrounded by development can be found all over the United States today. Favorable public relations are an increasing problem for quarries and mines in areas of rapid growth. In the past, the explosives and blasting industry has taken a soft-spoken approach with the public. The idea of ignoring public relations in hopes that complaints will eventually go away is no longer effective.

Already, many people harbor ill feelings toward blasting operations. Positive public relations are necessary. However, the blasting and mining industries in general are way behind in creating a positive image in their communities. It is imperative that over the next several years, the aggregate industry follows the lead of industries, such as plastics, in educating the public about the good things that are created through the use of explosives and mining. Already, the mining industry is well versed in public relations regarding environmental concerns with mine closures and pollution. The expertise obtained through cleaning up the mining industry's environmental image could be directly applied to the issues with blasting complaints.

The first step in achieving positive public relations is educating the public on how blasting operations conduct business, and how these operations affect the public. People are naturally uncomfortable with events that they perceive as potentially dangerous to their homes. Current reporting practices leave much to be desired when considering that the public must understand what is actually happening when blasting takes place. In order for the blasting industry to sustain positive public relations, the information that is reported about each particular blast not only must be easily understood by the public, policy makers, and explosives users alike, but it is imperative that they also have a good comfort level with these numbers. Survey results similar to those described in this paper are a first attempt at locating a proper medium for transferring seismograph data to the public in an easily understandable format.

Recently the Mississippi Valley chapter of the ISEE entertained discussions about appointing or electing a public-relations representative. The idea has not been totally accepted by all members; however, the idea is intriguing. Many times media coverage will interview neighbours of blasting operations and make statements that are unchecked and for the most part wrong. A public-relations representative for the chapter would be responsible for quickly responding to such media. Once the media is informed that such a person exists, it is hoped that their opinion would be solicited when coverage of such events are imminent. The use of such a representative would allow the blasting industry an opportunity to protect

its image when slandered by angry residents during media coverage. While this public-relations effort is somewhat reactive, it does present an interesting idea of creating publicity for the positives produced from explosives and blasting.

5. CONCLUSIONS

Over the past several decades, extensive research has been undertaken involving airblast and ground vibrations due to blasting. While much quality work has been done, a key piece to the public-relations puzzle has been left out of the research. This key piece is "What does the public think about blasting?" This generalized question has been answered qualitatively thousands of times at the informal discussions of many conferences. However, the question has never been answered quantitatively, and further, it has never been correlated to reporting practices within the blasting industry until the research briefly described in this paper was performed. The research discussed here provides new concepts for the blasting industry.

With the data collected, the industry stands to seize an opportunity to take public relations to a new level. The data begins to tell a story about what people want to know about blasting. It also shows that quarry neighbours are not comfortable with blasting near their homes. By utilizing the most easily understandable units for reporting ground vibration and airblast data to the public, there is potential for improving comfort levels with blasting in general.

Creating industry standards for discussing ground vibrations and airblast with easy-to-understand terms and units would make public-relations efforts much easier. Consider the compound effect of communication. While discussing this research with industry members, one vibration consultant claimed to be very capable of explaining the technical aspects of blast vibrations to any quarry neighbour during seismograph setup and measurement. The question is: can the quarry neighbour then effectively explain the issue to other neighbours? The use of simple units would increase this neighbour's ability to do so.

In general, the blasting industry will have to be very creative and novel in order to deal with this emerging problem effectively. Major changes will need to take place in order for quarries and residential neighbours to continue living together without serious issue. The mining and blasting industry will be ultimately responsible for bridging the communication gap.

REFERENCES

Lusk, B.T. 2006. *An Analysis and Policy Implications of Comfort Levels of Diverse Constituents with Reported Units for Blast Vibrations and Limits:* Closing the Communication Gap. PhD dissertation, University of Missouri – Rolla, 2006.

Petro, A. J. & Anderson, D. A. 1986. Blast vibration problems: Where do we go from here? *Journ. of Mines, Metals & Fuels. v34 n11 November* 1986. 502-505.

Spathis, A.T. & Brodbeck, A. 2005. Future Directions in Ground Vibration and Airblast Control Within Australian Regulatory Context. *Proc. of the Thirty-First Ann. Conf. on Explosives and Blasting Technique, Int.Soc.of Explosives Engineers,* Cleveland, OH, 2005. 263-275.

Warneke, J. R. 2004. *The Development of a Coal Material Flow Analysis, Indicators, and Models to Facilitate the Creation of Public Policy.* PhD dissertation, University of Missouri – Rolla, 2004.

Vienna Conference Proceedings 2007, P. Moser et al.
 ISBN 978-0-9550290-1-1

Blasting operations: training strategies

G. Sen
Visiting Professor, The University of Wollongong, Australia

M. Hayward
Operations Manager, Moultrie Database and Modelling (formerly Principal Inspector of Explosives, Queensland Department of Mines and Energy, Australia)

ABSTRACT:The impact of increasing safety and environmental legislation, greater interaction with the community and increasing explosives security requirements demand that blasting operations should be managed by shotfirers and engineers who are competent in all facets of explosives usage.

Generally speaking, qualified shotfirers should have adequate knowledge, training and experience to handle and charge explosives and to supervise persons servicing the blast. However, a qualified shotfirer may not be proficient in addressing some allied and fringe aspects of blasting such as computer design options, ground vibration control, cost options, complying with statutory requirements, liaising with the community, environmental impact and improving overall outcomes. There is also another factor. It has been noticed that occasionally shotfirers become quite blasé after handling explosives for many years and take some risky shortcuts. A periodic reminder of safety aspects, citing accidents due to careless practice, may have positive outcomes.

Conversely, many mining engineers or blast engineers have university training but may lack sufficient practical training and experience to adequately interface with the shotfirer and his team. In the opinion of the authors, all engineers engaged in blasting operations (mainly in mining, civil and structural disciplines) should undergo competency based training of about five days duration, covering the essentials of blasting operations. An essential outcome of such a course would be the acquisition of knowledge and application of the legislative requirements relating to explosives usage. It is proposed that this type of course should be repeated at least every five years by all personnel involved in blasting operations so that up-to-date knowledge is disseminated. This practice, in time, should translate into fewer explosives related accidents.

It is proposed that such a course would be competency based and would include attendance at lectures, blast site visits, hands-on experience and reference to notes, legislation and standards. The level of knowledge acquired by each course participant would be assessed by oral and written tests and the completion of a blasting assignment.

The course attendees would benefit by the acquisition of additional skills and practical training to deal with complex blasting issues and management of blasting systems.

Historic data suggests that blast exclusion zone breaches, flyrock and misfires are the most common blasting related incidents. Detailed investigations into many such incidents have identified inadequate training as a contributing factor in many instances.

The legislative requirements for training and appointment of shotfirers in Australia are examined with particular respect to the state of Queensland, and some industry-wide training issues are explored with proposed solutions offered.

1. INTRODUCTION

The construction, quarry and mining industries combined account for 97.5% of high explosives usage in many countries including Australia and the USA[Verakalis & Lobb, 2007]. It is recorded [Wallace et al, 2006] that blasting related accidents have claimed the lives of more than a thousand people around the world since the turn of the Millennium. A large portion of these accidents has been caused not by failure of design, but by human failure. It has been established that much of the human failure can be due to the lack of competencies, skills and adequate training of the people involved. Explosives being an inherently high risk activity, it is no surprise that the spotlight is held on training for occupations in this industry, perhaps to a greater extent than some others.

Consistent with trends in other jurisdictions in Australia and other countries (eg USA[Verakalis & Lobb, 2007]), the major types of explosives related incidents are breaches of blast exclusion zones, flyrock and misfires. Investigations into many cases have identified inadequate training as a common contributing factor.

It is the authors' belief that this kind of mishap could be reduced, at least to some extent, if the quality and take-up of training, particularly with respect to the design and management of blasts was improved. The effectiveness of communication between blast engineers, shotfirers and drillers was another area highlighted for potential improvement.

2. SCOPE

This article examines some of the commonly recurring explosives related incidents and the input that quality of training has to play in both their cause and subsequent strategies to improve blasting practices. Specific examples and trends are provided from Queensland, Australia, and although relating exclusively to open cut mining operations and quarries, many of the outcomes could be extrapolated to underground mining and civil construction arenas as well.

3. SOME POTENTIAL BLASTING MISHAPS

3.1 Flyrock

Detailed investigations into high potential flyrock incidents in Queensland, Australia commonly highlight poor communication between the technical services crew (bore tracking, face profiling etc), drillers, shot crew supervisor, shotfiring crew, contract explosives companies and site senior executives/mine managers as a contributing factor.

It could be argued that occurrences of the three main incident types (flyrock, exclusion zone breaches and misfires) could be reduced by a combination of better blast design, including product selection and hook-up plan, more rigorous geotechnical studies, comprehensive risk assessments and joint sign off by blasting contractor and mine manager prior to firing.

Resultant cases of flyrock are commonly accompanied by excessive ground vibrations and air blast overpressures. Whilst flyrock is the most significant incident type from a safety perspective, fortunately projected material is generally contained within the lease boundaries so of little consequence to neighbouring properties. However, particularly in relation to quarries operating near built up areas, the ground vibration and air blast effects often trigger complaints and level criticism against the industry.

A spate of recent construction-related explosives incidents in Brisbane and in Canberra [Sen & Abrahams, 2005] have highlighted deficiencies in individual training, the safety management system of blasting contractors and contravention of standard operating procedures. It is likely that these recent flyrock incidents could have been prevented by the proper use of blast mats and/or safety screen. Construction blasting in Townsville in Queensland conducted by a competent licensed shotfirer involved over 100 blasts. Through careful planning of each shot, conducting detailed risk assessments and common use of false burden, no incidents were recorded, even when blasting within 3m of nearby residences.

A recent paper [Bajpayee, et al, 2005] advocates the widespread use of blasting shelters, citing a number of fatalities and injuries that have been sustained by shotfirers who have remained inside or near the limit of the blast exclusion zone.

3.2 Blast exclusion zone breaches

The same paper [Bajpayee, et al, 2005] proposes that one of a shotfirer's greatest challenges is to accurately determine the blast exclusion zone. They list the following factors which need to be considered when determining any given blast exclusion zone:

– Geology or material to be blasted

- Blast pattern
- Burden, depth, diameter and angle of holes
- Blasting experience of the mine
- Delay systems, powder factor and amount of explosives per delay
- Type and amount of explosive material
- Type and amount of stemming material

When using explosives in the demolition of a structure UK Health & Safety Executive recommends (Anon, 1995) that an exclusion zone is built up (from) OF four areas: a) Plan area, b) Designed drop area, c) Predicted debris area and d) Buffer area. The size of the exclusion zone is not only related to the height of the structure. The projection of any debris from explosive charges is a function of the energy of the explosion and the effectiveness of any blast protection.

It is apparent that a particular shotfirer may not be competent to adequately assess ground conditions and predicted blast outcomes, particularly if he has no access to historic records of blasting at any site. Similarly, shotfirers may simply be required to tie in and fire a shot which was designed, drilled, and loaded by contract crews. The responsibilities are blurred in such cases, but such examples highlight the need for clear and complete communication between all parties from drill and blast engineer, mine geologist, surveyors, drillers, explosives manufacturing contractors, right through to the shot crew and ultimately the shotfirer.

Commonly, modern explosives legislation requires a shotfirer to be proficient in design, calculating powder factors etc, yet in many cases it is not the direct responsibility of the shotfirer to do so. Interacting parties have a joint responsibility to ensure that all the information they need is exchanged. This is an area on which the authors believe more attention should be focussed during initial training, refresher training and during actual operations.

The authors (Bajpayee, et al, 2005) highlight the fact that while blast exclusion zones should vary from shot to shot, many operations work to a constant pre-defined exclusion zone without adequately re-assessing the risk for each individual blast.

A significant number of incidents have been reported from mines in Queensland, Australia in recent years arising from unauthorised entry (or in some cases inadequate clearance of) blast exclusion zones. Despite the presence of administrative controls and often physical controls such as bunds, flagging or even gates, deliberate violation or inadequate enforcement of site rules is often the cause of such incidents. Clearly this is a cultural issue that needs to be addressed. Another paper (Brulia, 1993) reports that approximately 80-90% of all accidents are caused by human factors. The five major elements contributing to such accidents include negligence, hasty decisions, inadequate instruction, overconfidence and lack of planning.

The authors strongly concur with the proposal (Bajpayee, et al, 2005) which states that while a multi-faceted approach to safety (including training, standard operating Procedures, and engineering controls) is commonly adopted by many operations, a commitment to safety by all personnel involved is the most necessary ingredient.

4. ADDRESSING THE PROBLEM

4.1 Legislative requirements

Queensland's explosives and mining legislation requires that any person working with explosives must be trained and competent for the activities they undertake. It is anticipated that these requirements would be similar in most other jurisdictions worldwide.

Perhaps because a 'shotfirer' holds a statutory licence or occupies a statutorily appointed position on a mine or quarry, his/her qualifications are more closely scrutinised in this respect than those of others involved in blasting operations.

Since the late 1990s the Queensland Explosives Inspectorate within the Department of Mines and Energy has placed a greater reliance on the national vocational education framework, with training now provided by nationally accredited Registered Training Organisations (RTO's). By involving itself in both initial registration and ongoing monitoring audits as a technical advisor to the state training authority, the Explosives Inspectorate has been able to retain good control over the quality of providers and their training materials.

Counterparts in other jurisdictions may accredit RTO's in other states or territories, but under the national training regime, the candidate's qualifications must be acknowledged in all Australian states. It is widely recognised that differences in rigour of audits conducted by other state or territory training authorities and explosives competent authorities may provide for some differences in training quality between different

jurisdictions. These differences need to be ironed out to an acceptable common denominator. This is one area being addressed by the recently formed Australian Forum of Explosives Regulators – a body seeking to harmonise explosives regulation throughout Australia.

Similar progression in training regimes from the United Kingdom is also cited in a published paper [Turner, 2006]. Interestingly, she refers to identified shortcomings in the examination-only method of assessing competence and highlights the need for candidates to demonstrate, in their own workplaces, the competency requirements defined in the relevant National Occupational Standard (NOS). Under this system, a candidate's competency will be re-assessed every five years. A similar system operates in Queensland, Australia with licensed shotfirers required to undergo a 'recognition of competency' process by a Registered Training Organisation prior to renewal of a maximum 5-year term licence. If successful in the recognition process, the candidate is issued updated statements of attainment for those competency units, which are the submitted in support of their application to renew their shotfirer licence.

4.2 Training modules

The essential modules of a blasting course should consist of the following:

a) Familiarisation of common types of explosives and accessories
b) Types and modes of initiation
c) Blast design and calculation
d) Precautions to be taken before and after firing
e) Consideration of environmental factors
f) Dealing with misfires

Although a misfire does not occur very often, when it does, it is a potential hazard if it is not treated properly.

A substantial section of this course should be conducted at a site. This practical component should comprise a small group for an effective impact on the participants. In the authors' experience this group should not be more than ten participants.

4.3 Training at mine sites

Whilst the responsibility for training lies with any given organisation, commonly such organisations do not possess sufficient expertise to facilitate in-house training in all aspects of blasting operations.

External training organisations are commonly used to directly deliver training and conduct assessment or to validate and sign off on in house training and assessment. The dramatic upturn in the mining sector in Australia has created an imbalance between the supply and demand for quality explosives trainers and assessors.

4.4 Training competencies available for use by industry

Currently blasting competencies are embedded within a number of nationally accredited training packages. These include military, transport, coal mining, quarrying, metalliferous mining, civil construction and agricultural training packages.

With reference to courses available for blasting, the three nationally accredited mining training packages each contain units which outline competency requirements for topics from magazine keeping to blast design. Currently the Resource and Infrastructure Industries Skills Council (RIISC) is managing a consolidation project aimed at rationalising duplication of similar competency units within several closely allied training packages. It is anticipated that the resultant common units will be released in late 2008, for use in metallferous and coal mining, quarrying and construction industries.

All Australian Explosives Competent Authorities have undertaken to transition towards using these nationally accredited competency units as a basis for their respective shotfirer licensing regimes.

It is important to recognise that there is currently a 'delivery gap' between competency based courses designed for practitioners (magazine keeper, shotfirer's assistant, shotfirer), and university-delivered explosives training courses normally included as a component of mining and occasionally in other engineering degrees. This gap covers critical topics such as establishing blasting systems and managing blasting activities.

In Australia, nationally accredited units of competency have been developed to cover these areas. The units MNMG 406A (Manage Blasting Activities), MNMMSM626A (Establish a Blasting System) and MNMG 414A (Monitor and Control the Effects of Blasting on the Environment) are available from the Metalliferous Mining Training Package MNM 05 (refer to the National Training Information Service (NTIS) website at www.ntis.gov.au. Other similar units are available from the national Quarry Training Package (MNQ 03), also

available from NTIS.

Although these units of competency have been available for Registered Training Organisations to deliver for some years, it is the authors' opinion that access to training courses for these units is very limited. This may be due to lack of demand from clients, a lack of suitably qualified practitioners who want to enter the training industry or a combination of factors.

Very few courses are currently offered in the subject areas of blast design and development of blast safety management systems, despite the availability of some national competencies for these topics. If this 'delivery gap' is addressed, and shotfirers and blast engineers receive competency based training at the upper level currently not serviced, there would likely be an improvement in the safety record.

5. SOME OF THE MAJOR CHALLENGES

5.1 Strategies employed to address incidents

Mine sites are required to investigate high potential incidents (HPI's) and on the basis of the findings, modify standard operating procedures (SOP's) and training materials accordingly. Possibly due to production pressures, it is likely that most sites either do not adequately investigate HPI's, do not implement the recommendations arising from such investigations, or both.

Statutory authorities issue numerous safety alerts and incident reports to industry stakeholders. The roll-out of such advice at mine sites is commonly via notice board or tool-box talks. It is not well understood to what degree the content of such safety notices is actually incorporated into reviewed versions of SOP's and training programs.

5.2 Mining boom, skills shortage and aging workforce

Australia is currently experiencing unprecedented growth and activity in the mining sector. Several new mines are coming on line each year, each with a demand for many hundreds or even thousands of skilled workers. This demand, combined with historic and current insufficient training outputs is one factor leading to the now widely accepted 'skills shortage' within the industry. Queensland's unemployment rate is at a record low level. Increasing average mine employee wages are also at record levels and staff turnover is reportedly as high as 50% in some jobs. Strategies such as interstate 'poaching' of employees is not a viable option given the widespread nature of the boom within Australia, with some major explosives companies stating the same issues in USA and Canada. Many training organisations are also at full capacity, with demand for the provision of quality training continuing to outstrip supply capabilities.

5.3 Conflict between safe work practices and production pressures

This is an area of increasing concern within the industry, where it appears that there are incidences where safety is often compromised in favour of continued or increased production. Production managers and shotfirers have approved equipment being left within blast exclusion zones and this has resulted in damage to the equipment from flyrock, albeit that the mine has accepted the risk prior to blasting.

5.4 Communication and coordination

In Australia, mining utilises a considerable percentage of contract labour and services (up to 70% on some sites). Accordingly, there is a great need for mine operators to ensure that contractors are compliant with site procedure and legislation. This can be time consuming and costly for both parties to achieve. There is often a requirement for contractors to operate in accordance with the safety management system (SMS) of the principal. Not only can this necessitate training or sign-off of contract staff against standard operating procedures (SOP's), but can cause conflict between two or more parties, who each believe their SMS to be of the highest quality.

5.5 Security

A recently published paper[(Hayward, et al, 2006)] highlights increased explosives security requirements implemented in Queensland, Australia, following a case there where a person purchased explosives after falsifying documents and then used the product to manufacture improvised devices. It is widely recognised that due to recent terrorist acts across the world (9-11, Bali bombing, London backpack bombings etc) there is a heightened need for greater security of explosives throughout its lifecycle from manufacture, transport, storage to use. Most current training competency units focus on safety, but fail

to adequately address explosives' security.

5.6 *Ongoing review*

It is recommended that shotfirers and blast engineers regularly conduct and review risk assessments to determine appropriate blast exclusion areas. It should be noted that if flyrock extends beyond the exclusion zone, then clearly the risk assessment and/or risk control measures in place are likely to have been inadequate.

6. CONCLUSIONS

Training and continuing professional development are very important mechanisms for increasing the underpinning knowledge and experience of those involved in blasting.

These activities form part of a truly competency based training regime, over and above lectures and examinations. Developing a safety culture and professional attitude is also essential if the number of explosives related incidents is to be reduced.

7. ACKNOWLEDGEMENT

The authors wish to thank Bob Sheridan, Chief Inspector of Explosives, Queensland for providing a useful critique of early drafts of this paper.

REFERENCES

Anon. 1995. Establishing exclusion zones when using explosives in demolition. HSE (UK) Information Sheet, 8/95.

Bajpayee, T.S., Verakis, H.C., & Lobb, T.E. 2005. Securing the blast site to prevent blasting-related injuries. Blasting safety-revisiting site security. *The Journal of Explosives Engineering*, USA. July/August.

Brulia, J. C. 1993. Quality: a new approach to improve blasting safety. *Proceedings of the 19th Annual Conference on Explosives and Blasting Technique*. January 31 - February 4. Cleveland, OH. International Society of Explosives Engineers, USA. pp. 55-64.

Hayward, M.A., Downs, G.R., & Sheridan, R.A. 2006. Regulatory overhaul of the fireworks industry in Queensland, Australia: implementation of recommendations from investigations into the Bray Park and other fireworks accidents. *The Journal of Explosives Engineering*, USA. September.

Richards, A. and Moore, A. 2006. Effective strategies for controlling flyrock. *Quarry*, Australia. November. pp 26-27.

Sen, G., and Abrahams, D. 2005. An analysis of some explosive related accidents. *Proc. of EFEE 3rd World Conf. on Explosives & Blasting*. September. Brighton, England. pp 45 – 54.

Turner, H. 2006. Continuing competence for blasting operations. *Quarry Management*, UK. October. pp 39-43.

Verakis, H. and Lobb, T. 2007. Flyrock revisited. *The Journal of Explosives Engineering,* USA. March/April. pp 6-12.

Wallace, I., Akhavan, J., Parry, R., Clarke, D. and Capel, N. 2006. Developing and maintaining in the UK and European Explosives Sector. Explosives Engineering. The Journal of the Institute of *Explosives Engineering*, UK. March. pp 4 – 8.

Vienna Conference Proceedings 2007, P. Moser et al.
 ISBN 978-0-9550290-1-1

Decontamination of military ranges and battle fields. Development of technologies and toolbox

E. K. Lauritzen

I. G. Sanches
NIRAS DEMEX, NIRAS A/S, Alleroed, Copenhagen

G. Bunte
Fraunhofer ICT

ABSTRACT: The hand-over of military areas for urban development or opening of the military areas for the public use requires clearance of contamination of the area from military activities, especially clearance of unexploded ammunition and other explosive items.

Obsolete ammunition is a major problem in many countries and especially in war torn countries like Afghanistan, Iraq, Sudan and Lebanon. In order to restore peace it is imperative to dispose of the ammunition, as this will reduce the capabilities to continue the warfare.

This article presents status for technologies, methods and standards for the clearance of explosives remnants of military training and wars. Munition-polluted sites and the environmental problems are described. Guidelines and technologies for the disposal of ammunition in an economical and environmental feasible way are presented together with practicable examples of ongoing demilitarisation projects in Afghanistan and Denmark.

The contents of the article are based on the experiences gathered under the umbrella of the Research & Development (R&D) programmes WEAG EUCLID[1] and EU LIFE , together with the study carried out for NATO Maintenance and Supply Agency (NAMSA), followed by field studies on ammunition stock pile destruction in mine action programmes. ([1]Western European Armament Group - European Cooperation for the Long-Term in Defence)

1. GENERAL NEED FOR THE CLEARANCE OF LAND CONTAMINATED BY MUNITIONS-RELATED ACTIVITY

In all countries and regions where there have been munitions-related activities, whether manufacturing, storage, maintenance, training or conflicts there is considerable potential for historical contamination. The nature of the contaminants associated with these activities range from munitions and ordnance, to concentrations of residues originating from munitions and related equipment, such as may be associated with the various manufacturing, storage, usage or disposal activities. These various forms of contamination pose a risk both to the health and safety of people and to the environment.

The impact to the environment caused by chemical contamination from munitions-related activities has a number of parallels in other industries which utilise these or similar chemicals. The pollution arising from exploded or unexploded munitions is in many cases, however, much more difficult to assess and eliminate. The effect that explosions and the resulting build up of contaminants over time (e.g. particles of heavy metals) have on biotypes has not been examined in any detail. In particular, the long-term effects of such pollution on the ecological balance have not been fully examined.

The ever increasing demand of the development of 'brown field sites' to 'green field sites' and the pressure against the use of 'green field sites' for future developments means that land formerly used for munitions-related activities is becoming increasingly attractive, both financially and environmentally. This land does in the main, however, need to be rigorously assessed and where necessary cleared and reclaimed before it can be deemed suitable for use for housing, industrial development, agriculture, public use or other non-military use.

The aforementioned risks to people and the environment, and the value of former military sites are strong driving forces for the clearance of land contaminated by munitions-related activity. An even stronger need for clearance exists, however, in those nations which still have legacies associated with mined areas dating back to the Second World War and other conflicts. The Ottawa Agreement, signed by all WEAO countries, has established a precedent by setting a target for the clearance of those areas polluted with land mines within 10 years of the ratification of the agreement.

Since the end of the Cold War, military activity in the western world has been drastically reduced. In many countries, the armed forces have closed former training areas, depots, airfields and other sites, and have started to release the land for civil development. Much of this land is attractive to developers and has potentially a considerable value because of its close proximity to urban areas.

It is widely recognised that survey, search and clearance activities in areas contaminated with munition items or land mines are very time consuming and costly. The identification of a site's previous military or munitions-related activities is often difficult and costly due to either poor records of the inaccessible nature of the records. Detecting potential multi-contaminants (e.g. explosives, stabilisers, destruction products) is still cost-intensive. There are a wide variety of analytical tests to get complete information about the contamination. Especially quick and cost-saving detection techniques should be identified and evaluated.

Significant costs can be incurred in remediation of a site with an unsuspected munitions-related past due to programme delays and changes in remediation strategies. Additionally the costs of the actual remediation may be over estimated due to a lack of knowledge of the materials present, thus making redevelopment or re-use of the site uneconomical.

Recent clearance and remediation operations in Denmark, the UK and the Netherlands have proved to be difficult to plan and control, with concomitant consumption of time and money. In some European countries a number of recent development projects have been delayed due to either the presence of previously unidentified munition items or the suspected presence of munitions. In Germany there are experiences on the survey and remediation of former explosive production sites.

Also recent wars since 1990 in Kuwait, Bosnia, Kosovo, Afghanistan and Iraq have clearly demonstrated the urgent need for consideration of environmental protection issues during military operations, as well as the post-war management of clearance of mines, unexploded ordnance (UXO) and the huge stocks of abandoned ordnance.

2. TECHNOLOGIES, METHODS AND STANDARDS

Military Explosive Ordnance Disposal (EOD) methods and technologies have been developed over the years and are well established. Recently significant effort, sponsored by the European Union (EU), has been put into the development of multi-sensor detectors for use in humanitarian mine clearance operations.

There are a number of techniques and protocols available for the detection and clearance of buried ordnance. A need exists, however, for industry and governments to be aware of the best currently available techniques and to have a protocol for the appraisal of future technologies. Regarding the survey / detection of diffuse munitions-related contaminations new quick sensor techniques should be evaluated in respect to soil matrix effects and cross sensitivities.

There are no commonly available management tools for the investigation, clearance and reclamation of munitions-polluted land. Current work on the clearance of mines and UXO is based on military Standard Operating Procedures (SOPs) which are not generally considered satisfactory as management tools. In particular methods for decision making, prioritisation of work, environmental and health and safety management and quality control need to be developed. No officially accepted standards or specifications for the survey, search, clearance and documentation of UXO has

been completed, and criteria for the successful and adequate reclamation of munitions-polluted land are also non-existent. However, extensive work in the ISO / TC 190 (Soil Quality) has been carried out in relation to standardization in relation to UXO and energetic components. Furthermore, discussion on standardization in the field of munition-polluted soil has been started in the CEN/TC 345 (Characterization of Soils). Whilst the United Nations (UN) has developed international mine action standards (IMAS) for humanitarian de-mining operations, primarily in third world countries, these standards may not be acceptable for the clearance of mines and UXO in industrialised nations.

The presence of buried munitions is often also associated with chemical pollution. Although most countries have developed procedures and guidance for the management of conventional pollution, most do not have well-developed safety and general management procedures designed to deal with mixed munition contamination and chemical pollution.

The risks to the public on areas of former military activity can be classified into the following categories:

- Acute risks arising from possible detonation or deflagration of unexploded ordnance
- Chronic risks arising from the toxic effects of the chemical compounds associated with explosive manufacture, processing, use and destruction

Before reclamation of the soil within a given area can take place, safe disposal of any unexploded ordnance is essential, including those that may be buried in the ground. The risk to, and safety of, personnel engaged in the detection and clearance of UXO has yet to be fully assessed. Therefore, the working methods can potentially be improved.

The impact to the environment caused by chemical contamination from munitions-related activities has a number of parallels in other industries, which utilise these or similar chemicals. The pollution arising from exploded or unexploded munitions is in many cases, however, much more difficult to assess and eliminate. The effect that explosions and the resulting build up of contaminants over time (e.g. particles of heavy metals) have on biotopes has not been examined in any detail. In particular, the long-term effects of such pollution on the ecological balance have not been fully examined.

3. MUNITION-POLLUTED SITES

The reclamation of sites, which have been contaminated by munition-related activities, usually relates to the interest of the converting them into civil uses. These activities of demilitarisation/decontamination can be of different nature, resulting in different types of contamination:

- Production at industrial sites
- Transport, handling, maintenance and storage
- Demilitarisation of mines, UXO or discarded munitions
- Testing munitions and training operations
- Battle fields

The primary ordnance-related activity will assist in determining the potential ordnance and explosive (OE) hazards at the site; for example, an impact area at a firing range will have predominantly unexploded ordnance (fuzed and armed), whereas munitions manufacturing plants should have only ordnance items (fuzed or unfuzed but unarmed). At all of these sites, a variety of munition types could have been used, potentially resulting in a wide array of OE items at the site. The types and quantities of munitions employed may have changed over time as a result of changes in the military mission and advances in munition technologies, thus increasing the variety of OE items that may be present at any individual site. Changes in training needs also contribute to the presence of different OE types found at former military facilities. The type of military activity previously performed in the site determines therefore both the potential chemical hazards and the potential explosive hazards that may be encountered at the site.

3.1 Industrial production sites

Industrial production of explosives throughout history has generated explosive residues, i.e. substances containing explosive compounds that were released to the environment. In older times ammunition factories were often located close to military training and testing fields, and therefore old firing ranges might contain a certain amount of explosive waste from industrial production. More recently, production facilities are usually commercial sites that are not often co-located with military areas. Many of these facilities have contaminated soils and groundwater. Processing waters used during manufacture processes were in the past disposed of in unlined lagoons, leaving explosive

residues behind after evaporation. Red water, the effluent from TNT manufacturing was a major source of explosive waste in soils and groundwater at army ammunition plants. It is generally assessed that the pollution level is concentrated on localised hot spots, e.g. related to dump sites and sewage systems. Today military-related industry must follow rules on solid waste management and restrictions with the purpose of limiting the risk of polluting soil, air and water, and minimising waste to an acceptable level, according to national, regional and / or municipal regulation.

3.2 Handling, maintenance and storage facilities

Facilities for handling, maintaining and storing munition might be polluted depending on the specific activities. Inspection of explosives might cause spill of explosive material, and re-packing of munitions and explosives might cause explosive-polluted packaging waste.

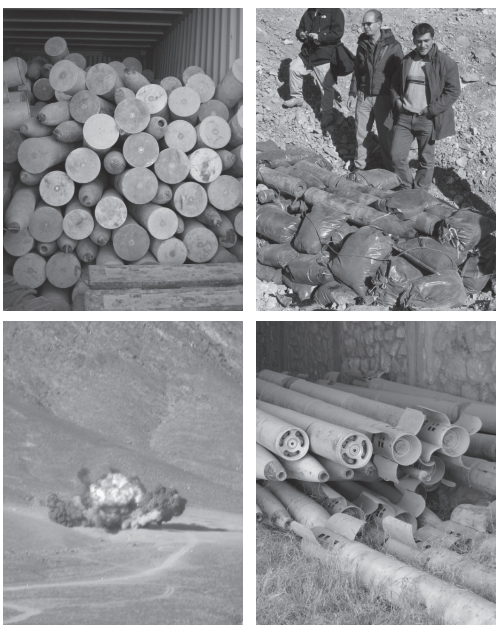

Figure 1. Demilitarisation process by OB/OD of tank ammunition and rockets in Afghanistan.

3.3 Demilitarisation sites

Demilitarisation is the processing of munitions so they are no longer suitable for military use. Munitions are generally demilitarised because they are obsolete or their components are deteriorated.

Demilitarisation of munitions involves several techniques, including both destructive and non-destructive methods. Destructive methods have been the most commonly used until recent strict environmental legislation. These methods include open burning (OB), open detonation (OD), shown in figure 1, and incineration. Non-destructive methods include the physical removal of explosive components from munition. Each of the demilitarisation techniques generates specific environmental problems derived form the processes carried out. For example in the demilitarisation operations conducted in the 1970s, explosives were removed from munitions with jets of hot water or steam. The effluent, called pink water, flowed into settling basins, and the remaining water was disposed of in unlined lagoons or pits, often leaving highly concentrated explosive residues behind. In more advanced demilitarisation operations developed in the 1980s, once the solid explosive particles settled out of the effluent, filters such as diatomaceous earth filters and activated carbon filters were employed to further reduce the explosive compounds, and waters were evaporated from lagoons or discharged into water systems.

3.4 Testing and training fields

A training range is used for conducting military exercises in a simulated conflict area or war zone. Training aids and military munition simulators such as training ammunition, artillery simulators, smoke grenades, pyrotechnics, mine simulators and riot control agents are used on the training range. While these training aids are safer than live munitions, they may still present explosive hazards.

The sites for testing the specific munitions and explosives contain all kinds of explosive-related pollution. Even though testing sites might be a part of training and firing ranges, the munition used in the former is real, on the contrary to the simulation items used during training.

Firing and training fields are typical polluted by

- explosion products from firing / launch of munitions
- impact of detonating grenades, shells and warheads
- impact of projectiles
- reaction products from smoke and pyrotechnic
- detonation of demolition charges

The typical set-up of a live fire area military range consists of a central 'impact area', where fired munitions are supposed to land. Surrounding the impact area is a buffer zone that separates the impact area from the firing / release zone (area from where the military munitions are fired, dropped or placed). Within the live fire area, the impact area usually contains the greatest concentration of UXO. Buried munitions may be found in other areas, including the firing area itself.

3.5 Battle areas

Former battle areas might contain many types of pollution like firing and training fields. The level of pollution depends of the activities and the intensity of the combat. Defence positions and strategic points might be exposed for impact of artillery and mortars causing pollution of detonation products and unexploded shells. It is assessed during the war in Kuwait in 1991, and in Kosovo in 1999, that up to 10% of all tube-launched and airdropped munitions did not function. The use of mines might result in a number of left mines, in some cases complete minefields. Depending on the speed of operations, considerable amounts of munitions might be left by the defeated part of the combatants.

Abandoned ammunition in Iraq and Afghanistan (see figure 1) together with many other countries creates major problems, which need specific solutions.

4. MANAGEMENT GUIDELINES

The Western European Armaments Organisation (WEAO) has developed the European Co-operation for the Long Term in Defence (EUCLID) programme, involving industry and research institutes, in order to strengthen the European position in Defence Research and Technology.

From July 2002 to December 2006 the project Reclamation of Land Contaminated by Munitions-related Activity has been conducted under Contract no.02/EF 14.12/001, within the framework of the EUCLID Programme.

The primary objective of the project was the development of guidelines, management tools and analytical measuring techniques for the investigation, clearance and reclamation of land that has been contaminated by munitions-related

Introduction

Part 1 IMSMA UXO Database

Part 2 Risk Assessment
- 2.1 Ecological Risk Assessment
- 2.2 Health & Safety Risk Assessment
- 2.3 Clearance Criteria

Part 3 Survey Techniques
- 3.1 Techniques for Survey of Unexploded Ordnance (UXO)
- 3.2 Effectiveness Assessment of UXO Survey Techniques
- 3.3 Selection of UXO Survey Techniques
- 3.4 Techniques for the Survey of Diffusely Contaminated Land
- 3.5 Selection of Techniques for the Survey of Diffusely Contaminated Land

Part 4 Clearance Techniques
- 4.1 Techniques for the Clearance of UXO
- 4.2 Techniques for the Remediation of Diffuse Contaminant Sources
- 4.3 Techniques for the Monitoring of Contaminant Sources

Part 5 Integrated Management Systems
- 5.1 Quality Management
- 5.2 Environmental management
- 5.3 Health & Safety Management
- 5.4 Guidelines for the Integrated Management Systems

Software
- IMSMA UXO tool
- EOD IMS tool
- CD ROM - Handbook on Reclamation of Munition-contaminated Land

Figure 2. Contents of the electronic Handbook on Reclamation of Land Contaminated by Munitions-related Activity.

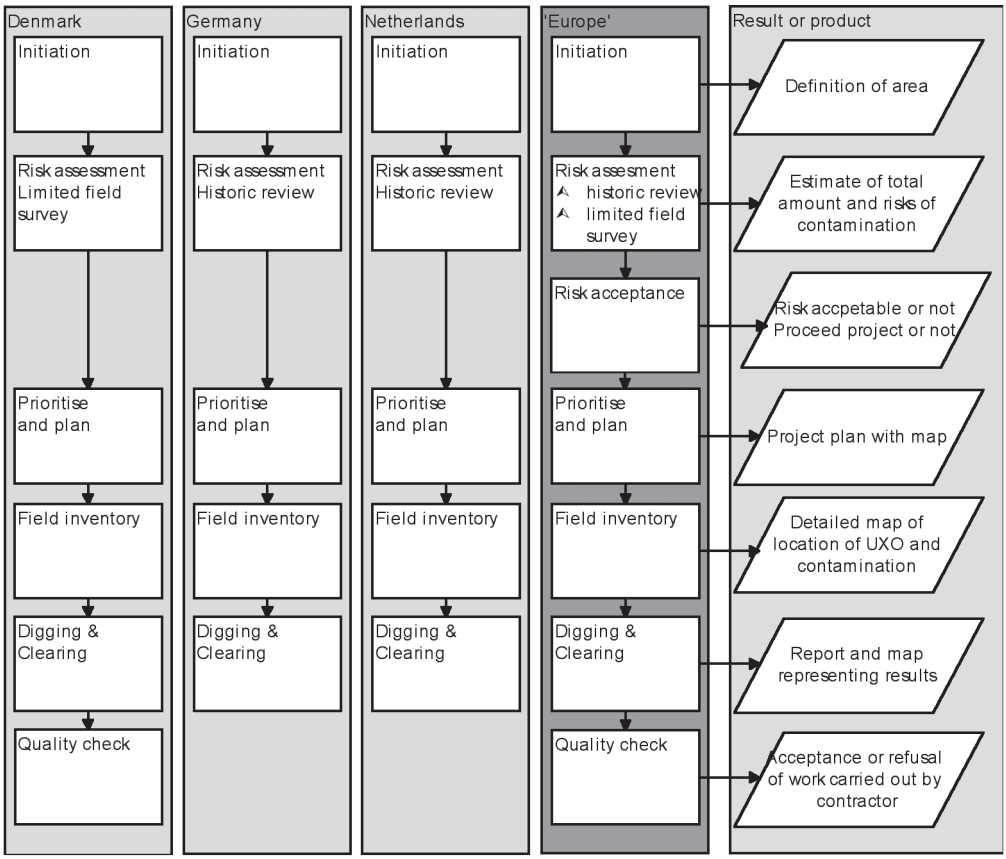

Figure 3. Generic 'European Model' of work processes in reclamation projects, presented in the Handbook Reclamation of Land Contaminated by Munitions-related Activity.

activities in Western European countries. These tools and techniques will de designed to render the land suitable for public open space, residential, industrial or agricultural use. The industrial consortium who is in charge of the execution of the project, was composed of NIRAS DEMEX (Denmark), Fraunhofer Institute for Chemical Technology (Germany), SARICON (The Netherlands) and the Netherlands Organisation for Applied Scientific Research TNO (The Netherlands).

The project addressed the practical and cost effective solutions for the clearance, and subsequent remediation and reclamation, of land contaminated by munitions-related activity. Particular emphasis is placed upon the development of an adaptable database methodology for the identification and quantification of polluted sites. Additionally quick and cost-saving detection methods for munitions-related contamination are analysed. Techniques for the assessment of the risk and impact associated with pollution by munitions, and for clearance activities are reviewed and developed. Procedures and methods potentially suitable for the survey detection of contamination and its subsequent removal are identified and their applicability established. Finally, the concept of an integrated management system for the planning, implementation and quality assurance of clearance and reclamation activities will be developed and suitable tools described.

The main outcome of the project is an electronic handbook in five general parts as listed in figure 2. The handbook is available as a part of the software programme EOD IMS, including guidelines, text

of the handbook, links to databases, templates for reports, standard operation procedures etc.

The Handbook describes a generic 'European Model' of the total work process cycle of a reclamation project, as shown in figure 3. The model and work flow has formed the basis of the Integrated Management System. It must be noted that the workflow and decisions may vary form project to project. It must also be noted that the work process used for the generic Integrated Management System has a different appearance. However, the principles of processes and decisions are the same.

Based on the experiences gathered in Denmark, Germany and The Netherlands, a database and software tool was developed for the application of the UN Information Management System for Mine Action (IMSMA) to the clearance of UXO. Furthermore, software tool EOD Integrated management System (EOD IMS) was developed by Bruhn NewTech on basis of the existing software program EOD Frontline.

5. CONCLUSIONS

Today the pollution of the explosive s ubstances in the soil and the impact of military demilitarisation processes must follow the general rules and legislation of environmental protection. OD and OB disposal of munitions should be replaced with industrial demilitarisation processes in order to minimize the load on the environment.

The WEAG EUCLID project on *Reclamation of Land Contaminated by Munitions-related Activity* contributes to the improvement of the management of the demilitarisation processes. The state-of-the-art and guidelines for demilitarisation are presented in a comprehensive handbook, which is organised in a simple software programme.

The results of the research and development project including the developed UXO integrated management system and the electronic handbook will be tested in Denmark and other countries. It is the hope of the Danish, German and Dutch project partners that the outcome of the project will contribute to the reclamation of land contaminated by munitions-related activity focusing on quality, environmental protection and highest possible safety to the people involved in the processes.

REFERENCES

Antipersonnel Mine & Stockpile Ammunition Destruction Programme in Afghanistan. Prepared by the Islamic Republic of Afghanistan, the United Nations Assistance Mission to Afghanistan and United Nations Development Programme, June 2005.

Egebart, C.L., Lauritzen, E.K., Larsen, S.G., 2001. The Challenge of Demilitarisation of Ammunition - Life Cycle Assessment in Relation to Munitions. In: *paper presented at the Global DEMIL Seminar*. Reno, NV: 2001.

EOD Integrated Management System (IMS) Bruhn NewTech, Denmark

EUCLID Contract 98/EF 14.6/004, 1998-2000. A Study into the Demilitarisation of Advanced Conventional Munitions. In: *project by DEMEX Consulting Engineers and BAE Systems Ro Defence*, 1998-2000.

International Mine Action Standard (IMAS) 11.10 *Guide for Stockpile Destruction* and IMAS 11.20 Open *Burning and Open Detonation*.

LIFE 96ENV/DK/18, 1997-2000. Research and Development of Technologies for Safe and Environmentally Optimal Recovery and Disposal of Explosive Waste. In: *project by DEMEX Consulting Engineers, RISØ National Laboratory, TNO Prins Maurits Laboratory, Kommunekemi and the Danish Army Ammunition Arsenal*, 1997-2000.

Lauritzen, E.K., Scott, R.J., Wenbo, M., February 2006. EU Support to Mine Action and Ammunition Stockpile Destruction, Assessment Mission and Preparation of Formulation proposal and Financing Proposal, Afghanistan. In: Report, February 2006.

NATO Maintenance and Supply Agency, 1994-1995. Study into the Effect of Environmental Protection Legislation on Ammunition Disposal, In: *project by DEMEX Consulting Engineers*, 1994-1995.

Ordnance Board Proceeding P115(2),2000. Design of munitions for disposal pillar proceeding.

Report on Reclamation of Land Contaminated by *Munitions-related Activity*, Contract no.02/EF 14.12/001, within the framework of the EUCLID Programme by NIRAS DEMEX (Denmark), Fraunhofer Institute for Chemical Technology (Germany), SARICON (The Netherlands) and the Netherlands Organisation for Applied Scientific Research TNO (The Netherlands).

STANAG 4187, Fuzing Systems - Safety design requirements.

STANAG 4518 (Edition 1), Safe disposal of munitions - Design principles and requirements, and safety assessment.

Wood, D.J., 1996. Design for demilitarisation. In: *paper presented at the 4th Global DEMIL Symposium*, Reno NV: 1996.

Vienna Conference Proceedings 2007, P. Moser et al.
 ISBN 978-0-9550290-1-1

Economical aspects on contamination levels in blasted material with SSE in tunnel operations

M. Ganster
Austin Powder G.m.b.H, Austin Powder International, St. Lambrecht, Austria

ABSTRACT: The increase in the use of 'site sensitized emulsion' in the Austrian tunnelling and power plant construction segment of the industry has focussed attention on possible contamination levels in blasted material. Both International and National refuse economy plans (Federal Refuse Economy Plan 2001) are required by the European Union. The Federal Refuse Economy Plan evaluation method is based on the OENORM S 2121 or OEN 2123-1 (sampling at the blasted material site). The current investigations are based at a power station pumping chamber construction site, located within the Tauern Window formation in the protected region of the Austrian Alps. The power station excavation was opened in a granite rock mass with relatively little presence of ground water inflow. Rock reinforcement is limited to the placement of Swellex bolts. The absence of shotcrete use at the site means that explosive use and machinery exhaust / residue are the only sources of environmental contaminants. For all investigations described in this paper the examination of eluate was conducted according to regulations, as soon as safely possible, following the firing of each blast.

1. INTRODUCTION

The Nassfeld pump storage scheme was created in one of Austria's most popular leisure centres. A large skiing area as well as a famous health spa are positioned in the catchment area of the construction site.The total volume of blasted material of 160,000 m^3 had to be handled within 4 months, this implied 5000 kg of explosives would need to be loaded every day. This means that only the use of bulk emulsion would deliver the required productivity.

The very short construction time had to be kept and the environmental protection was paramount and included the preservation of the quality of drinking water. There was no rock reinforcement such as shotcrete, so that the results of the investigations that were carried out were not complicated by external sources. The measured contamination of the blasted material could only be produced by the machines working in the tunnel and the explosives used.

The federal refuse economy plan 2001 was used as basis for the classification of the blasted material. Whereas water samples were taken from a water cleaning station, rock samples were taken directly from the blasted material.

2. GEOLOGY

The tunnel face was opened in the penninic

basement unit of the Tauern window. These units are situated within an epidote-amphibolite metamorphic series within the Habach complex and a migmatite/amphibolite grade series in the Storz and Stubach complexes (Grundmann 1989, Vavra & Hansen 1991). Both formations have varying degrees of intrusion by the Variscan granites and have been transformed into the Central Gneiss by Cenozoic tectonothermal events. The local granite-gneiss complex may be rated as very tough and abrasive and are very difficult to blast. The groundwater inflow was nearly zero, which means that the measured contamination was not influenced by percolation water.

In all there were perfect conditions to evaluate the influence of site sensitized emulsion explosives on the environment.

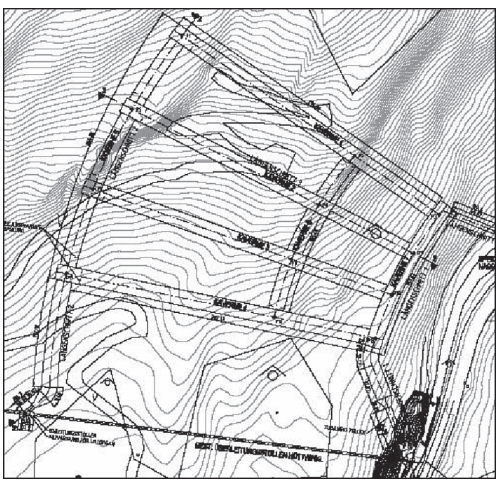

Figure 1. Layout plan of the Nassfeld pump storage scheme.

3. BLASTING OPERATIONS

3.1 Drilling pattern

The pattern was drilled with a programmable drilling machine from Atlas Copco. The location of the drill holes was very accurate.

- Cross Section: ~90 m^2
- Average number of holes: 178
- Drilling diameter: 51 mm
- Pattern: 1,10 m x 1,10 m
- Parallel Cut with 4 empty holes
- Length: 3,50 m
- Explosives per round: ~750 kg
- Booster: APG Booster 20 gram
- Detonator: Indetshock, MS and TS
- Volume blasted: ~315 m^3

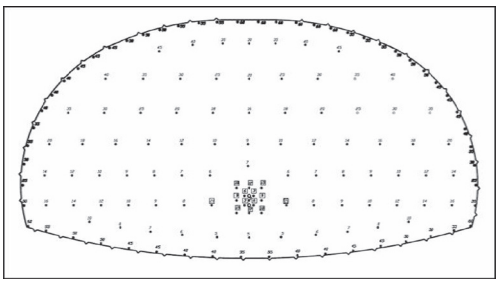

Figure 2. Full face firing pattern at Nassfeld.

3.2 Explosive characteristics

The site sensitized emulsion was pumped with two M.O.R.S.E. units. The final product was a gassed emulsion produced from a matrix supplied from Austin Powder G.m.b.H with following characteristics:

- Average product density: 1,10 g/cm^3
- Energy: 3 MJ / kg
- VOD: 4800 – 5000 m/s (diameter 51 mm)
- Loading density: 2,20 kg/m

Table 1. Chemistry of the bulk emulsion – Lambrex WP-G.

Parameter	Nitrates	Oil	Emulsifier
Content	~ 78-83 %	~ 5-8 %	~ 1- 4 %

4. SAMPLING

Immediately after the blast, during the excavation of the rock, sampling was conducted. In each sampling cycle 10 samples were taken out of 8 truck loads and each sample was placed in a separate bucket. Rock fragments with a size of more than 12 cm were excluded. In order to make a homogenous sample the 10 excavator buckets were mixed and then divided into two samples. One part was given to the analysis laboratory, the other part became a retention sample and was kept by the local construction supervision. The excavated

material had a high proportion of blocks and stones so that the sampled part with a fragment size of < 12 cm was only an estimated 20 % of the volume of the blasted material.

4.1 Results, aqueous eluate

Measured values for the ammonium ion were found to be up to 4 times higher than the limit value. This implies that the explosives could not be discounted as a source of the ion. The practice of restricting the sample fragment size to the sub-12 cm fraction creates a distortion (upwards) of the measured ammonium ion concentration. The measured values are not representative of the total volume of blasted rock. The remaining nitrogen ions (nitrite and nitrate) limit values were not exceeded (refer to Table 2).

4.2 Results, solid analysis

For all samples which were analysed, also detailed solid analysis were done. The results for the hydrocarbon – sum are shown in Table 3. With one exception the values that were determined lie below the permitted limit values of the Austrian Federal Refuse Economy plan. By calculating back the hydrocarbon – sum value, found in Gast1 we came to the conclusion, if the whole amount of the hydrocarbon comes out of the explosives, 99.2 % of the explosives mustn't detonate. Because of the excessive Hydrocarbon-Sum-value, found in the sample Gast1, further investigations had to be started to clarify the reason of the high hydrocarbon value.

The Austin Powder Company, producer of the used explosives, often involved in engaged to this topic, decided to assign a research project

Table 2. Overview of aqueous eluate results.

Parameter	Ammonium - ion [mg/kg DS]	Nitrate - ion [mg/kg DS]	Nitrite - ion [mg/kg DS]	Total Organic Carbon [mg/kg DS]
Limit Value according to ZI. 21601-954/74-2004	8	100	2	200
Gast 1 (chamber 4, station 57)	35.3	79.6	0.32	<27.1
Gast 2 (chamber 2, station 25)	20.4	49	0.27	<27.1
Gast 3 (chamber 2, station 106)	25.9	32	0.2	<26.3
Gast 4 (chamber 4, station 254)	20.5	26.4	0.26	<25.5
Gast 5 (chamber 4, station 307)	14.6	29.1	0.4	<27.3
Gast 6 (chamber 5, station 275)	12.6	23.5	0.35	<27.1
Gast 7 (chamber 2, station 267)	22.6	38.9	0.49	<27.2
Gast 8 (chamber 1, station 255)	19.1	31.8	0.26	<27.3
Gast 9 (chamber 2, station 306)	7.3	16.3	0.42	<27.1

to the Mining University of Leoben, Department of Applied Geosciences and Geophysics, Chair Prospecting and Applied Sedimentology.

Table 3. Overview results, solid analysis.

Parameter	Hydrocarbon - Sum [mg/kg DS]
Limit Value according to ZI. 21601-954/74-2004	20
Gast 1 (chamber 4, station 57)	49.8
Gast 2 (chamber 2, station 25)	14
Gast 3 (chamber 2, station 106)	4.8
Gast 4 (chamber 4, station 254)	7
Gast 5 (chamber 4, station 307)	6.2
Gast 6 (chamber 5, station 275)	4
Gast 7 (chamber 2, station 267)	4
Gast 8 (chamber 1, station 255)	7
Gast 9 (chamber 2, station 306)	6

5. GC / MS ANALYTICS

The present study illustrates the results of an approach to clarify the point of origin of these hydrocarbons by chemical fingerprints.

The results show that the sample Gast1 exceeds the limit value. This fact leads to a discussion concerning the possible sources of these hydrocarbons. One possibility is the presence of undetonated explosives and the second is fuel, hydraulic oil or lubricant associated with the construction site equipment.

5.1 Samples and methods

Sample preparation was done on air dried samples by sizing them into plus and minus 8 mm. This was achieved by sieving (see Table 4). The minus 8 mm fraction was used for organic chemistry determination. Hydrocarbons recovered from the rock samples were analyzed to determine the presence of the process oil and the emulsifier, contained in the explosives.

To enable presence of the process oil and emulsifier to be confirmed, samples of the specific explosive raw materials were also analyzed to determine their signature.

To determine the organic compounds, the minus 8 mm sample fraction was washed with dichloromethane. The samples were filtered and evaporated to a 1 ml sample size in a Zymark TurboVap 500 closed cell concentrator. The samples were analyzed in a gas chromatograph equipped with a 30-m DB-5MS fused silica capillary column (i.d. 0.25 mm; 0.25-μm film thickness) coupled to a Finnigan MAT GCQ ion trap mass spectrometer.

The oven temperature was programmed to increase from 70° C to 300° C at a rate of 4° C per minute followed by an isothermal period of 15 min. Helium was used as carrier gas. The sample was injected with the injector temperature of 275° C. The mass spectrometer was operated in the EI (electron impact) mode over a scan range from m/z 50 to m/z 650 (0.7 s total scan time). Data was processed with the Finnigan data system. Identification of individual compounds was accomplished based on retention time in the total ion current (TIC) chromatogram and comparison of the mass spectra with published data.

Table 4. Size fraction of the samples.

Sample	Total [kg]	< 8mm [%]	Sample	Total [kg]	< 8mm [%]
Gast1	5.78	10.39	Gast6	4.88	16.24
Gast2	6.63	6.32	Gast7	5.89	4.05
Gast3	5.46	8.09	Gast8	5.41	7.01
Gast4	5.14	4.74	Gast9	4.90	1.93

5.2 *Results of GC / MS Analytics*

The results are represented as the total ion current (TIC) chromatograms shown in the Figures below. In addition to the TIC chromatograms, the selected (m/z 85) chromatogram, representing the n-alkane distribution is also plotted. The specific n-alkanes and the diagnostic isoprenoids pristane (Pr) and phytane (Ph) are identified by their carbon number. In comparison note the different relative intensities especially in the TIC chromatograms. The following selected chromatograms are discussed in detail.

5.2.1 *Oil Phase (process oil), Lambrex WP-G*

The chromatograms of the oil phase represent a normal n-alkane distribution up to the range of 24 carbon atoms. The pristane/phytane ratio is approximately at 1.1. In the TIC chromatogram at retention time of 38:17 min there is a still unidentified compound. This compound, marked by an arrow, has also been detected in the samples Gast6 to Gast9 in a remarkably high concentration. The peak at retention time 38:04 is caused by a compound of high molecular weight.

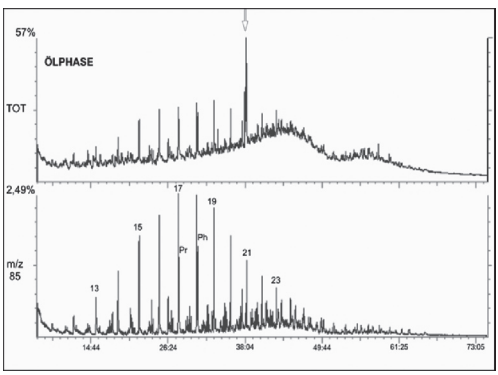

Figure 3. TIC chromatogram of the oil phase (process oil), Lambrex WP-G.

5.2.2 *Emulsifier, Lambrex WP-G*

The TIC chromatogram of this sample shows two groups of related carbon compounds. The first group shows two distinct compounds. These peaks are most possibly identified as $C_{15}H_{28}$-compounds. The second group is also marked by some distinct peaks, their compound classification has yet not been possible. The pristane / phytane ratio is in the same order as in the process oil.

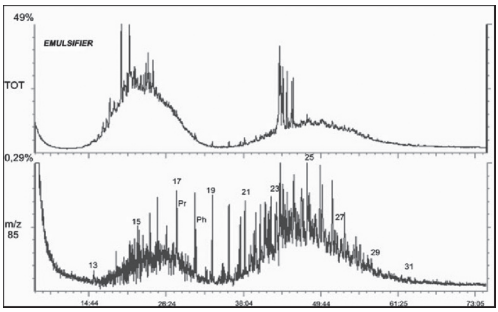

Figure 4. TIC chromatogram of the emulsifier, Lambrex WP-G.

5.2.3 *Samples Gast1 – Gast9*

The TIC chromatogram of all samples is more or less described by the group of high molecular weight compounds. Except in Gast6 and Gast7 all samples are contaminated by phthalate, (a plasticizer used in plastics) attributed to the buckets used for the samples. The samples Gast1, 6, 7 and 9 shows before the phthalate peak a compound that could neither be detected in the oil phase (process oil) or in the emulsifier. This compound is marked by a circle and cannot be attributed to the oil phase (process oil) or emulsifier.

Following the phthalate peak a series of peaks labeled by the letters a - h has been detected. These peaks represent still yet unidentified compounds and cannot be part of the oil phase (process oil) or emulsifier.

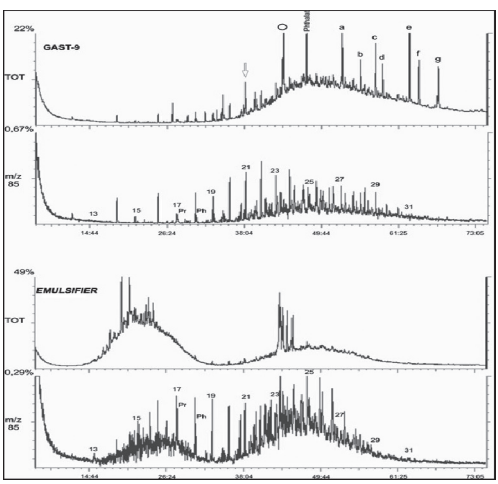

Figure 5. Comparison emulsifier – Gast9.

In the Gast samples, the n-alkane chromatograms show a distribution ranging from n-C_{13} up to n-C_{31} and are characterized by a pristane/phytane ratio about 0.6 – 0.7 different to the n-alkane distribution and the pristane/phytane ratio of the oil phase. The ratios described are different from those observed for oil phase (process oil) and emulsifier and thus represent a different source of the hydrocarbons.

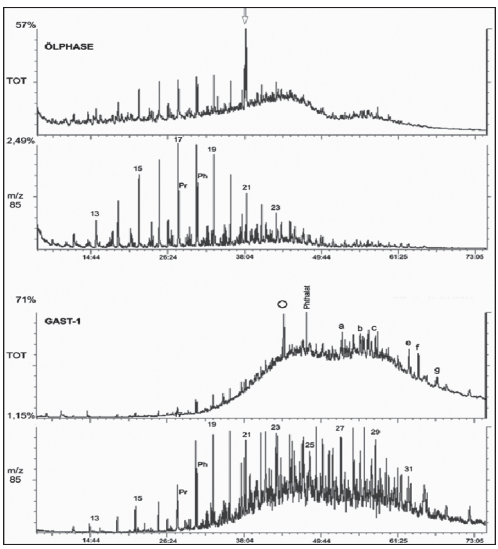

Figure 6. Comparison oil phase – Gast1.

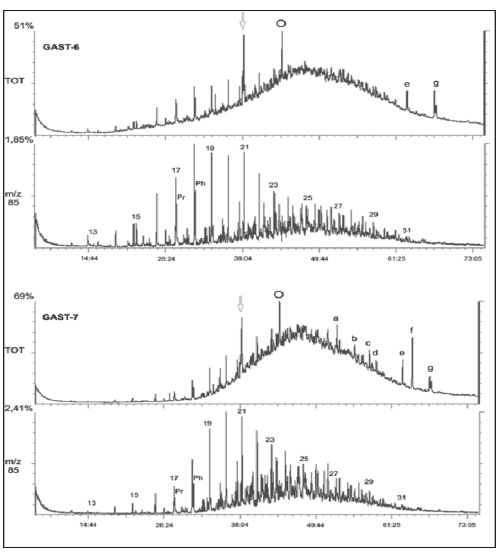

Figure 7. TIC chromatogram Gast6 & Gast7 shows the unidentified peak in front of the phthalate anomaly.

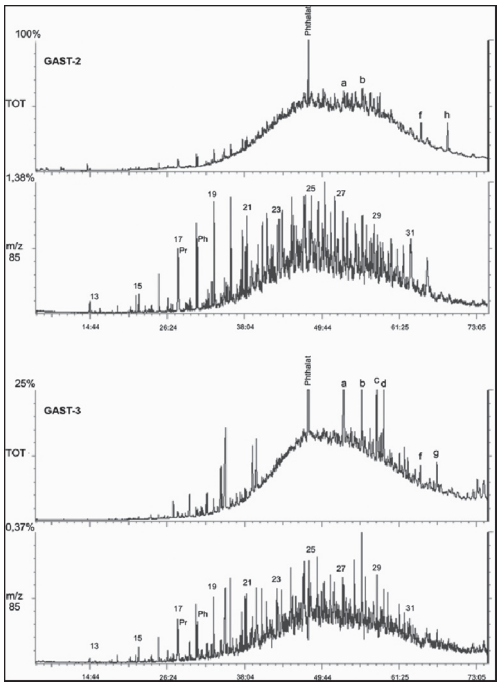

Figure 8. TIC chromatogram Gast2 & Gast3.

The TIC chromatograms of Gast4, Gast5, Gast7 and Gast8 are similar to Gast2 & Gast3. As has been demonstrated by the report above it is possible to detect very low hydro¬carbon content in different material, but the diagnostics of a specific compound is often complicated and time consuming. One option to solve this problem is to sample the different hydrocarbon sources like hydraulic oils and determine their individual signatures. In this way it is simple to compare the different hydrocarbon fingerprints and to identify the source.

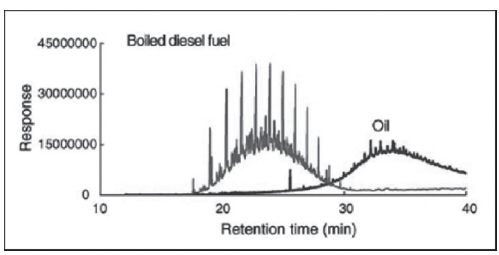

Figure 9. TIC Chromatogram of boiled diesel fuel (diesel fuel removed of low boiling point hydrocarbons) and lubricant oil (Akiyama 2006).

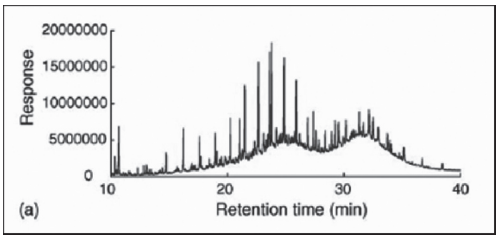

Figure 10: Typical TIC example of diesel exhaust particle extract (Akiyama 2006).

6. SUMMARY & CONCLUSIONS

In all samples which were analyzed the Ammonium ion content was high. This Ammonium ion content is probably associated with the explosive. As Table 2 shows, the ammonium ion content was variable. This variation depends on two important factors, the loading process, which include the amount of explosive that is spilt in the heading and the drilling pattern or the distances from hole to hole that may be responsible for a possible cut off of loaded holes. The lowest Ammonium ion values shown in Table 2 could not be correlated with the Nitrite or Nitrate values.

Hydrocarbon analysis indicated, the oil phase (process oil) has a distinct pristane/phytane ratio and does not show the unidentified compounds identified as having high molecular weights. Furthermore the pristane/phytane ratio ~ 1.1 in the oil phase cannot be changed to values of the order of 0.6-0.7 by the process of detonation.

Therefore another source of these hydrocarbons must be assumed.

The signatures of the oil phase (process oil) and emulsifier are unique and distinctive, furthermore both are different from the signatures of the unidentified hydrocarbon compounds detected in the samples. This implies that the hydrocarbon content in the Gast samples must be related to other sources such as lubricants and hydraulic fluids used in construction machines.

The Austrian Regulations in this matter refer to sampling procedures that exclude all fragments in access of 12 cm in size. This standard does not take into account the effect of particle size and therefore total surface area. The effect of this is to distort the values reported by the analyses. The distortion is probably to elevate the values reported by a significant amount. At present it is not possible to quantify the effect of the sampling procedure and additional investigation is required.

Rock and operation drainage water contaminated in excess of national regulations will require segregation or treatment to meet standards. Remediation is known to have high cost and would severely impact the ability of explosive companies to provide products that will meet the standards. Inability to meet these standards will imply that contractors will increasingly adopt mechanical mining methods.

The development of explosives solutions that allow the adequate fragmentation and removal of rock, while maintaining levels of associated contaminants within limits specified by National and Community standards, will provide a major contribution to the economic viability of both mining and civil projects.

REFERENCES

Akiyama, K. 2006. Gas chromatographic analysis and aerosol mass spectrometer measurements of diesel exhaust particles composition: China – Japan – Korea Environmental Analytical Chemistry Symposium 2006, 178 – 181.

Grundmann, G. 1989. Metamorphic evolution of the Habach formation: A review. Mitt. Österr. Geol. Ges., 81 (1988), 133 – 149.

Vavra, G. & Hansen, B.T. 1991. Cathodoluminescence studies and U/Pb dating of zircons in pre-Mesozoic gneisses of the tauern window: Implications for the penninic basement evolution. Geol. Rundschau, 80, 703 – 715.

Wetzig, V. 2003. Influence of different types of explosives on economical and working hygienic aspects in tunnels: Explosives and Blasting Technique, Holmberg 2003, 127 – 131.

Vienna Conference Proceedings 2007, P. Moser et al.
 ISBN 978-0-9550290-1-1

European explosives qualifications – the EUExcert Project

J.Akhavan & I.G.Wallace
Cranfield University, Shrivenham Campus, Swindon, SN6 8LA, UK

E Nilsson & H Wallin
KCEM AB, Gammelbackavagen 6, SE- 691 51 Karlskoga, Sweden

ABSTRACT: Over the past three years the UK together with Sweden, Norway, Finland and Italy have been taking part in a EU funded Leonardo Da Vinci programme. More recently EFEE have participated in the project known as the EU Excert project which is aimed at addressing the perceived loss of explosives expertise in several EU nations. This could have implications for explosives safety and industrial competitiveness. The paper outlines the work that has so far been done in phase 1 and describes the work planned for the second phase of the project. The paper will describe work in the UK to develop competencies for all explosives workers in both the civil and defence sectors. These competencies in the form of National Occupational Standards have now been approved in the UK and are accompanied by a range of 24 new National Vocational Qualifications launched in May 2006. The paper will show how the standards define knowledge and skills and how these form the basis for vocational qualifications as well as higher education awards and professional qualifications. This UK initiative is now being considered in other EU countries and the project has now been extended to also include Germany, France, Spain, Poland, Czech Republic and Estonia. To support the occupational standards and qualifications work is also being carried out to improve learning provision in the explosives area. In addition to formal educational and conventional training courses a series of workplace learning initiatives are being pursued as well as internet learning packages. Examples of these initiatives will be given.

1. INTRODUCTION

Since the turn of the Millennium there have been a number of well publicised explosives accidents around the world. One of the characteristics of these accidents is that they frequently have catastrophic consequences. In Lagos, Nigeria an ammunition dump exploded, the explosion created mass panic which subsequently led to the death of nearly 1000 people, most of whom were children. Another explosives accident aboard the Russian submarine led to the loss of 118 sailors, a loss of significant defence capability and serious political destabilisation of the Putin Government. In Holland an explosion involving fireworks destroyed 200 houses and killed 22 people, whilst in France an explosion involving ammonium nitrate destroyed a major industrial facility, killed 30 people and injured around 2000. The consequence of explosives accidents is frequently serious in human, economic and political terms.

Examining the cause of explosives accidents

invariably reveals that human error or failure is a major contributory factor. The Enschede incident in Holland was initiated by a deliberate act by a malcontent. However the catastrophic consequences were also a result of management failure, breaches of the explosives regulations and a failure to understand that storing fireworks inside steel iso-containers generates sufficient confinement to maximise the violence of the event.

One of the torpedos loaded on the Kursk is known to have been dropped prior to embarkation and this may be linked to the torpedo explosion which, the official report suggests, led to the loss of the submarine and its crew. In both cases it was the actions of individuals or the failure to act in an appropriate way which contributed to the accident. Effective explosives safety depends on people making the right decisions at the right time. It depends upon people having the necessary competence to carry out their jobs properly. The concept of competence is well recognised in UK safety management. Much of UK safety legislation calls for "competent people" in roles that affect safety. In the case of explosives, this will be in all stages of life, from the formulation of new explosives in the laboratory, through manufacture, storage, transportation, use and disposal.

Whilst the stove-piping of organisations in the European and UK explosives business has had an impact on the breadth of experience, the general contraction of the explosives business in Europe and the UK has had a major impact on the numbers of skilled specialists. Added to this many of the specialists were recruited in during a growth period in defence science and technology in the 1970s and are approaching retirement. A lack of recruitment in the late 1970s and 1980s has left a demographic trough, wherein there are insufficient skilled explosives specialists to replace those who will be leaving government service in the next few years. Figure 1 illustrates the typical problems faced by the European countries with respect to the loss of expertise, if you assume that the 'experts' are those who are of the age 50+

2. EUEXCERT

Four years ago Cranfield University together with KCEM, a Scandinavian explosives competence organisation, joined with other EU partners in a project funded by the European Union Leonardo da Vinci programme. This programme of work (called EUExcert) was aimed at replenishing explosives expertise, through vocational training and education across the EU with a view to setting up a European qualifications framework in order to award a European certificate for workers in the explosives sector. The purpose was not only to ensure the supply of specialists in key explosives safety functions, but also to maintain European competitiveness in the ordnance and explosives industrial sector. At the last EFEE conference which was held in the UK in 2005, the following objectives were identified as the keys aims of EUExcert (Wallace et al 2005):

- Identify the competencies required to sustain a safe and competitive explosives industry in the EU
- Establish the current and future needs for these competencies in the EU
- Develop training and educational programmes designed to develop this range of competencies
- Develop a range of novel education and training packages that form part of the programme
- Develop explosives qualifications which will be recognised and accepted across Europe
- Reverse the decline in expertise, knowledge and skill in European explosives business

In October 2006 the first phase of EUExcert was completed with the submission of a final report to the Leonardo da Vinci programme office. All the objectives above were achieved except for (6) which will take some time to achieve. Below are highlights of some of these achievements.

2.1 Competencies

A functional map and competency framework was developed in the UK for workers in the explosives sector. 13 key roles were identified and 440 National Occupational Standards (NOS) were written and validated in the UK (5 key roles were validated by the European partners). From these 440 NOS; 24 National Vocational Qualifications (NVQs) were developed. Table 1 gives details of the 13 key roles.

Details of the 440 competencies can be found on the following web link http://www.qca.org.uk/610.html under explosives substances and articles (ESA).

Table 1. Thirteen key roles for workers in the explosives sector.

Key Role
1. Research design and develop explosive substances and articles
2. Develop and manage explosives safety
3. Test and evaluate explosive substances and articles in field trials
4. Manufacture explosive substances and articles
5. Maintain and repair explosive substances and articles
6. Procure explosive substances and articles
7. Store and move explosive substances and articles
8. Transport explosive substances and articles
9. Manage explosives facilities
10. Prepare and use explosive substances and articles for engineering and entertainment purposes
11. Dispose of explosive substances and articles
12. Enable the public and armed services to continue their regular activities in peace and war by controlling and removing munition threats
13. Support the explosive substances and articles function

Table 2. Details of existing education programmes in explosives within EUExcert partner countries.

Country	Training Provider
UK	http://www.cranfield.ac.uk/prospectus/shrivenham/index.cfm
	http://www.issee.co.uk/explosives.php
	http://www.ribbands.co.uk/svcpages/training.htm
	http://www.isee.org/education/default.htm
	http://www.uec.ac.uk/csm/short-courses/quarry/shotfiring-explosives-supervisor.shtml
	http://www.chss.info/ourcourses.html#sho
	http://www.don.ac.uk/Default.aspx?page=652
	http://www.epicltd.com/page_view.asp?InfoID=209
Sweden	http://www.masugnen.se/utbildning/kurser/ky.htm
	http://www.fex.se/default.asp
	http://www.srv.se/templates/SRV_Page____672.aspx
Italy	http://www.nitrex.it/corsi/index.asp

2.2 Current and future needs

Details of existing education programmes in explosives which are provided by training organisations in the EUExcert partners were identified. There was found to be no external training courses for workers in explosives in Finland and Norway, it is possible that their training is either carried out in-house or supplied by the other Scandinavian countries. A catalogue of existing training and education provision material for the UK, Sweden and Italy is given in table 2.

2.3 Qualification framework

A qualification framework has been developed in

Table 3. Details of the qualification framework.

Key Role	Description	NVQ level
Research, Design and Development	Research into Explosive Substances and/or Articles	Level 4
	Design and/or Development of Explosive Substances and/or Articles	Level 4
	Research, Design and Development of Explosive Substances and/or Articles	Level 3
Safety Management	Explosives Safety Management and/or Advice and/or Regulation	Level 4
Test & Evaluation	Test and Evaluation Management of Explosive Substances and/or Articles	Level 4
	Test and Evaluation Supervision of Explosive Substances and/or Articles	Level 3
	Test and Evaluation Operations of Explosive Substances and/or Articles	Level 2
Manufacture	Explosive Substances and Articles Manufacturing Management	Level 4
	Explosive Substances and Articles Manufacturing Supervision	Level 3
	Explosive Substances and Articles Manufacturing Operations	Level 2
Maintenance	Explosives Maintenance Management	Level 4
	Explosives Maintenance Supervision	Level 3
	Explosives Maintenance Operations	Level 2
Procurement	Explosive Substances and/or Articles Procurement Management	Level 4
	Explosive Substances and Articles Procurement	Level 3
Storage	Explosives Storage Management	Level 4
	Explosives Storage Supervision	Level 3
	Explosives Storage Operations	Level 2
Transport	Explosives Transport Supervision	Level 3
	Explosives Road Transport Operations	Level 2
Disposal	Explosive Substances and/or Articles Disposal Management	Level 4
	Explosive Substances and/or Articles Disposal Supervision/Operations	Level 3
	Explosive Substances and/or Articles Disposal Operations	Level 2
Hybrids	General Explosives Operations	Level 2

the UK incorporating the 24 NVQs and 440 competencies. These qualifications are divided into 3 levels. Level 2 is the operator level, level 3 is the supervisor level and level 4 is the manager level. Details of this framework are presented in table 3.

2.4 Education and training

The 24 NVQ qualifications have been underpinned by a flexible educational and training programme, with vocational training as the main part of the learning objectives together with workplace training and e-learning based on CD-Rom and the internet. Online e-learning lessons have been developed in 'Introduction to Explosives', 'Burning and Detonation', 'Initiation' and 'Management and Legislation'.

3. EUEXCERT AND THE FUTURE

The Leonardo da Vinci programme office recently awarded EUExcert with a further two years funding in order to continue this programme of work. The objectives of this new programme of work is to improve the skills and competencies of workers in the explosives industries by building on the work completed in the previous EUExcert project on competencies and qualifications, and transferring this to a European competency and qualification framework for the explosive sector. It is intended to set-up a Foundation which will be able to regulate

Table 4. Timetable for objectives.

Objective	Completion date
Validate competencies	May 2007
Qualifications framework	November 2007
Educational material	May 2008
Establish foundation	November 2007
Network	July 2007
Exchange of students	January 2006 (Mobility programme)
Glossary	November 2008
EUExcert first Certificates	January 2008

this new European competency and qualification framework and also provide a degree of transparency for an EU wide EUExcert certificate. In order to deliver this qualification, the educational material needs to be developed. The education will be through vocational training using flexible learning and the promotion of social dialogue. In the longer term this programme of work will increase the opportunities for career development; improve the knowledge, skills, employability and mobility of the beneficiaries and target groups. The timetable for these objectives is given in table 4. Details of the objectives are given below:

3.1 Competencies and qualifications

The competency framework in conjunction with the qualification framework is an excellent tool for measuring competencies and can be used for career progression of employees. Table 3 summarizes the competencies together with the qualification framework developed in the UK during the first EUExcert project. The results from this project will be transferred to this new programme of work and developed into a European vocational qualification. More competencies may be developed for the European market. It is intended to award 7 certificates at the Introductory level (operator), 8 certificates at the Intermediate level (supervisor) and 9 certificates at the Advanced level (manager) although this number may increase. In order to be awarded these certificates the students must have completed a study of training at their place of work and assessed by an Internal assessor.

3.2 European partners

At the present time the number of participating countries in EUExcert has risen from 5 to 11, these are UK, Sweden, Norway, Finland, Italy, Spain, Portugal, France, Germany, Estonia, and the Czech Republic. Poland and Lithuania have recently expressed an interest in joining EUExcert and will become associated partners. It also important to note that EFEE is a member of EUExcert which represents 19 countries. In order to increase this number of participating countries, it is intended to widely disseminate the work undertaken in the programme by spreading knowledge about the competence framework to the explosive sector in Europe and the rest of the world by presenting papers and posters on the outcomes of the EUExcert project at national and international conferences, seminars etc.

3.3 Regulatory organisation

At the present time there is no European regulating board to either access or impose competencies in the explosive sector. Therefore there is a strong driving force by workers in the European explosive sector to continually improve the safety of handling explosives by ensuring that all workers are competent. This project will be one way of improving this situation by delivering a European Explosive certificate regulated by a Foundation, which will be created through this project for organisations in the explosives sector. The certificate is aimed at workers in the explosives sector who are required to be competent. The impact of this certification will be of great benefit

to the employers and employees. It will lead to an increase in mobility and employability of workers across Europe and it will also lead to an increase in the awareness of the hazardous nature of the explosive materials which, in the long term, will lead to fewer accidents.

In order to transfer and advance the qualification framework in forming a European vocational qualification a regulatory organisation needs to be established. This organisation will be responsible for the validation and accreditation of the qualification and the issuing of EUExcert certificates. Discussions have been undertaken with the Foundation for the ECDL (European Computer Driving License) qualification with the view to setting up a similar Foundation for the EUExcert qualification. This vocational qualification will be trans-national between partner countries and in the longer term be recognised throughout Europe.

It is intended for the Foundation to be self-funding after the project has ended. Members of the Foundation steering group will be represented by one partner from each European country who is a member of the EUExcert partnership. The Foundation will be similar to the Foundation which is responsible for the European Computer Driving Licence (which also started as a Leonardo da Vinci project). The Foundation will issue European certificates to competent workers in the explosive sectors. These certificates will have a cost associated with them. The Foundation will also contain a European membership in order to self finance their work – where the members pay a fee. In the future the membership may expand to incorporate most European countries at first and then to expand to other countries outside the EU.

3.4 Educational materials

Workplace learning will be explored for this type of vocational training system due to the hazardous nature of the industry. Methods of delivery will be via video conferencing, e-based learning, modern technology, and flexible learning. The target groups will be adult workers in the explosive industries and will want to undertake their training at their place of work. It is intended to use partner groups to deliver some of the training via video conferencing. This type of activity has already taken place between the UK and Sweden where the lesson was given in the UK to a group of students in Sweden via video conferencing. This joint venture between Sweden and the UK will be transferred to this new proposal and expanded to incorporate other partner countries.

The language for the development of the curriculum and study material will be in English; however the educational and assessment material will be prepared for translation to other languages. The educational material will be adapted for flexible learning and to work based training. For example learning centres will be set-up in companies where the students will have access to computers, video conferencing, study facilities and training aids. An example of this type of learning centre is the Learning Centre at Masugnen in Sweden. Other methods of delivering training will also be explored particularly for countries where learning centres may be difficult to set-up. Here the training may be a combination of work-base and web-based training, where the student may be required to attend educational establishments for a short period of time.

3.5 Network of industries and institutions in the explosives sector

In order to improve the network capability and capacity of our partners, collaboration with other European institutions and agencies will be paramount for the program to succeed. This new network will consist of a database of organisations and institutions who are interested in this programme of work. The members of the network will receive regular newsletters and updates of EUExcert activities. Their views and comments will be sought when setting up the Foundation, validating the competencies and qualifications, and writing the glossary for explosive terminology. This will be a living network. The network will also provide a platform for the harmonisation of legislation and practice in the explosives sector. Currently there are 183 people registered with an interest in explosives from which 10 are outside the European community. Registration can be carried out by logging on to the EUExcert web-site at www.euexcert.org.

3.6 Glossary

During the 4 years of working within the EUExcert project it was evident that there were serious problems associated with incorrect translations of terminology within the explosives sector. A basic glossary of terms for the European explosive sector

Table 5. Reference details of the basis for the glossary of terminology.

Web-addresses for reference material for glossary
http://www.fas.org/man/dod-101/sys/land/glossary.htm
http://www.glossary.oilfield.slb.com/Display.cfm?Term=high%20explosive
http://fermat.nap.edu/openbook.php?record_id=10998&page=126
http://www.mi5.gov.uk/output/Page137.html#b
http://www.americanpyro.com/Safety%20Info/glossary.html
http://www.globalsecurity.org/military/systems/munitions/glossary.htm
http://www.army.mil.nz/footer-links/default.htm
http://lanl.gov/history/hbombon/glossary.shtml
http://www.eod-solutions.com/glossary.htm
http://www.newsweekeducation.com/extras/landmines5.php
http://www.flbgr.org/project/glossary.html
http://www.middlepowers.org/dpe/glossary.html
http://www.explosives.com/glossary/a-e.htm
http://www.psemc.com/references.asp
http://www.dep.state.pa.us/dep/deputate/minres/Districts/Blasting/glossary.htm
http://www.missilethreat.com/overview/glossary.html

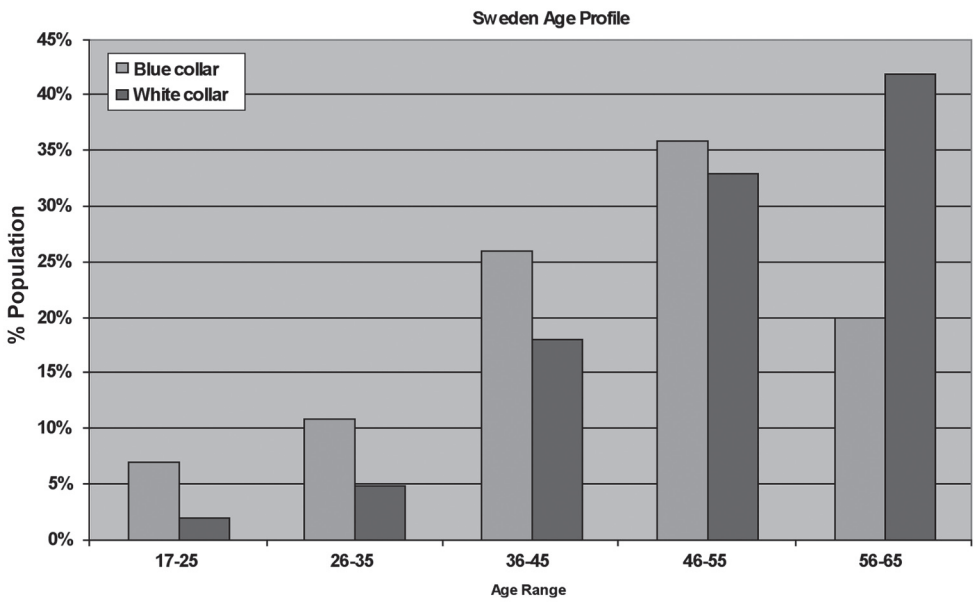

Figure 1. Age profile of White and Blue Collar workers in the explosives industry in Sweden.

is being compiled using the information supplied by the web addresses given in table 5.

3.7 Student exchange programme

Exchange of students or distance education between partner countries will be set-up via a separate programme i.e. the Mobility programme. Students who will be registered for the EUExcert will be able to study in one of the partner countries. For example Cranfield University will be responsible for the students who want to study in the UK. Cranfield University will seek placements for the students. These placements will be in companies who are affiliated to the Foundation and have the infrastructure to assess and award NVQs. The Foundation will then award the equivalent EUExcert certificates which will be recognised in all the European countries.

4. CONCLUSIONS

EUExcert has been so successful that recently it was nominated as one of the Leonardo da Vinci projects for best practice. On assessing phase 1 of the project the Leonardo da Vinci Swedish programme office states that 'the pilot project has fulfilled its commitments and the project has reached even further than that. It is characterized by its innovative work'.

The next phase of EUExcert will build upon the goals delivered in the 1st phase. This is just the beginning and hopefully by 2009 there will be a European recognised certification for workers in the explosives sector.

REFERENCES

Wallace, I.G., Akhavan, J., Wallin, H., and Nilsson E., 2005. Developing and Maintaining Skills in the Explosive Sector, *EFEE Conf. proc., Brighton,UK Sept 2005*.

Vienna Conference Proceedings 2007, P. Moser et al.
 ISBN 978-0-9550290-1-1

Northern Link – tunnel blasting in environmentally sensitive surroundings

S.E. Johansson
Nitro Consult AB (Orica Mining Services), Stockholm, Sweden

H. Lundquist
National Swedish Road Administration (Vägverket), Stockholm Region, Sweden

D. Jonson
Nitro Consult AB (Orica Mining Services), Stockholm, Sweden

ABSTRACT: Preparatory work on the so-called Northern Link project in Stockholm, Sweden, began in the autumn of 2006 with the awarding of contracts for five works access tunnels. They are to be located in Norrtull, Teknikhöjden, Albano, Värtan and Bellevue.

Much of the blasting work for the works access tunnels and main contracts will be carried out in surroundings very sensitive to vibrations, close to buildings, the Stockholm Metro, utility tunnels, research institutes etc. The AlbaNova University Centre houses equipment that is extremely sensitive to vibration. The limit value for one of the apparatus is just 1µm/s (0.001 mm/s). The most sensitive equipment has been insulated from vibration with the aid of an air damper. Blasting times are fixed so that the research activities can be scheduled around them.

During the autumn, blasting was carried out in Teknikhöjden to slash out an existing tunnel that crosses directly over the Metro. The Metro is subject to a limit value of 60 mm/s. Using cartridge explosives and hole-depths of at least 2 m, it has been possible to comply with the limit. In the Albano and Värtan access tunnels, the preliminary grouting and reinforcement work is complete and excavation of the full tunnel cross-section has started. Work on the Bellevue access tunnel has started with the first grout shield. The slashing of an existing entrance tunnel to the Ormen surge chamber has just began. Blasting of the access tunnel in Norrtull has also just began this spring of 2007.

1. INTRODUCTION

The Northern Link is a new expressway that will connect the E4 at Norrtull with Roslagsvägen in Frescati and Lidingövägen in Värtan, where there is a large ferry terminal. It will be located underground in separate tunnels for each direction of travel. The total length of the Northern Link will be approximately 5 km. About 1 km of it, between Karlberg and Norrtull, is already built and open to traffic.

Most of the expressway will be in tunnels. The total length of all tunnels is approx. 11 km, about 9 km of which will be rock tunnels, the rest concrete tunnels. The estimated cost of the project is SEK 7 billion (≈ €766 million). The Swedish government

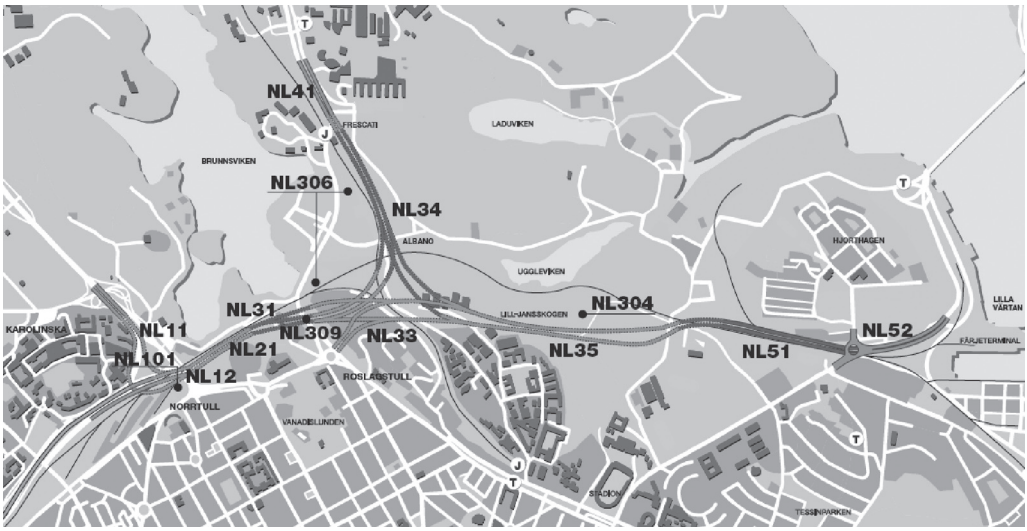

Figure 1. The Northern-Link route from Norrtull to Värtan, connecting with the E18 in Frescati. The notations in the plan indicate the various contract numbers.

will finance 75 % of the cost via the National Road Administration (Vägverket). The remaining 25 % will be paid by the City of Stockholm. Construction time will be 9 years.

Since intervention in national-city parkland or the natural environment is prohibited by law, the tunnel north of the Wenner-Gren Center (WGC) will be constructed from underneath.

Provided the Supreme Administrative Court rejects legal challenges to the scheme, the main contracts will commence in the autumn of 2007. Before they can begin, preparatory work must be carried out in the five works access tunnels located in Norrtull, Bellevueberget, Albano, Teknikhöjden and Fiskartorpsvägen, Värtan.

2. CONTRACTS

The preparatory works for four of the access tunnels started in the autumn of 2006 and is estimated to be complete during 2007, so that the main contracts can begin at the turn of the year 2007/2008. Figure 1 (above) shows the locations of the different contracts. The works access tunnels will be constructed in four contracts:

- NCC, Bellevueberget (≈ Bellevue Hill), NL309
- Veidekke, Albano and Teknikhöjden (≈ Technology Hill), NL306
- Oden Anläggningsentreprenad, Fiskartorpsvägen, NL304
- Skanska, Norrtull, NL 101

In Albano and Teknikhöjden, the works are continuing generally from where they were terminated in 1997, apart from the slashing of existing tunnels.

At Bellevueberget, the entrance tunnel to the Ormen surge chamber will be widened so that it can be used as a works access tunnel. A new entrance tunnel to the chamber will be blasted out next to the old one.

The works access tunnel on Fiskartorpsvägen starts at the entrance to an old rock chamber. The one at Norrtull starts north of Norra Stationsgatan.

The works access tunnels are between 175 and 250 m in length.

The main and ramp tunnels will be constructed in:

- 2 contracts (NL11 and NL12) at Norrtull
- 1 contract (NL21) north of the Wenner-Gren Center (WGC)
- 1 contract (NL31) through Bellevueberget (≈ Bellevue Hill) and under Roslagsvägen
- 3 contracts (NL33, NL34) under AlbaNova (the old Roslagstull Hospital area) and Teknikhöjden (≈ Technology Hill) to Frescati
- 1 contract (NL35) under Lill-Jansskogen (a

wood) and the Royal Institute of Technology (KTH) to Fiskartorpsvägen

The various rock-excavation contracts vary in size from about 50,000 to 400,000 m^3. Total excavation will be 1.1 million m^3 of rock and 0.4 million m^3 of earth. The tunnels will have between one and four lanes. Tunnel widths will vary from 12 to 20 m; heights from 8 to 9.5 m.

In Frescati and Värtan the expressway will be located in concrete tunnels. Rock excavation is required at both places.

NCC has negotiated bulk-haulage under a separate contract (NL308), whereby rock from the larger contracts will be received at predetermined places. The contract also covers the re-delivery of crushed rock to Northern Link project according to need.

The following chapters report progress in the ongoing contracts for the works access tunnels, and give brief descriptions of the forthcoming rock-excavation contracts.

3. RISK ANALYSES FOR VIBRATION-GENERATING WORKS

Blasting work for the Northern Link is subject to restrictions on vibration and structure-borne sound, and to fixed blasting-times. Structure-borne sound will not be dealt with in this paper.

In the Norrtull area, the blasting work must take into account the activities and vibration-sensitive equipment in the Karolinska Hospital, existing tunnels and underground installations in the immediate vicinity and housing north of Cederdahlsgatan and Norra Stationsgatan.

The tunnel contract through Bellevueberget must take into account the listed buildings on the hill, as well as the activities of the Graduate School for Social Work and Public Administration (formerly Sveaplan Secondary School) and the Wenner-Gren Center. The latter contains both apartments and offices. The traffic on Roslagsvägen and Värtabanan (an overland suburban railway) must also be considered.

At Albanoberget (≈ Albano Hill), which used to be the old Roslagstull Hospital area, big changes have taken place since 1997. The site is now home to the AlbaNova University Center, which conducts research and teaching activities and belongs to both Stockholm University and the Royal Institute of Technology (KTH) The activities take place mainly in the newly built physics centre, completed in 2001, but also in the older buildings, which have been renovated.

The outer main tunnel will run about 7 metres underneath the part of the physics department where the research activities most sensitive to vibration take place.

The research at AlbaNova focuses mainly on three fields: biotechnology, physics and astronomy, for which very advanced equipment is used. Among the equipment most sensitive to vibration are lasers and electron-beam lithography equipment. Certain experiments with vibration-sensitive equipment can take whole days to complete and are subject to a vibration limit value of 1μm/s (0.001 mm/s), measured in the third octave-band filter.

Representatives of the AlbaNova University Center and the National Road Administration, Vägverket, are agreed that measures should be carried out in the operation to make it possible to dimension the tunnel blasts in accordance with the vibration limit values for the building.

For the operations to be conducted in the normal way, therefore, comprehensive insulation from vibration will be required using optical tables equipped with self-levelling pneumatic dampers. In spite of such precautions, the most vibration-sensitive experiments must be halted during blasting. Tunnelling operations are therefore subject to fixed blasting-times.

On Albano Hill there are also two homes for the elderly, as well as housing on Ruddammen, which the tunnelling operations must take into consideration.

The Stockholm Metro and Roslagsbanan (another overland suburban railway) also pass through AlbaNova and Teknikhöjden (Technology Hill). The Northern Link will cross both under and over the Metro in two and four places respectively. The rock cover to the Metro varies from zero to approximately 7 metres. The crossing points in the Metro were reinforced in 1996 prior to the first start-up of the Northern Link project (see next chapter).

The blasting work is subject to the vibration restrictions in the Metro, and to fixed blasting-times so that train traffic can be stopped when vibration levels are going to be greater than 10 mm/s.

East of the AlbaNova area, the tunnels will pass under the so-called Maskiningenjören quarter. On the site are buildings in which take place activities of both the Machine Design Department (KTH-Maskin) of the Royal Institute

of Technology (KTH) and the University College of Dance. KTH research there includes hologram manufacturing. The activities are very sensitive to vibrations and will have to be moved before blasting starts in the main tunnels in contract NL35.

Further to the east, the blasting work will be dimensioned by a utility tunnel that crosses underneath the Northern Link at Fiskartorpsvägen. Reinforcement of the rock in the utility tunnel is currently under way. The vibration limit value is 100 mm/s, measured on the nearest tunnel wall.

4. WORKS ACCESS TUNNEL, NL306 TEKNIKHÖJDEN

At Teknikhöjden (Technology Hill), the access tunnel starts east of Roslagsvägen and west of the buildings called Teknikhöjden, at Björnnäsvägen 2. The access tunnel passes over the Metro at a distance of about 9 metres. During 1996 and 1997, the open cut and about 50 metres of the access tunnel were blasted. Due to new demands on ventilation, the tunnel cross-section must be increased to 65 m^2. Slashing of the existing tunnel walls and floor was therefore necessary.

The Metro is subject to the same general limit values that apply to SL (the Greater Stockholm Public Transport Company Limited). The limits are 10 mm/s when the traffic is moving and 30 mm/s when shut down. In this contract, however, SL has approved an increase in the limit value to 60 mm/s in accordance with SL General Regulation FÖ-I-365 when the traffic is shut down. The regulation came about following tests (normally called the Hjulsta Tests) that were carried out by SL and the National Road Administration (Vägverket) in 1996-1997 prior to planned blasts at several points where the Northern Link crosses the Metro.

Increasing the limit value has been possible thanks to the reinforcement work done in the tunnel prior to the previous start of the Northern Link project. The reinforcement consists of systematic bolting in the roof and down to one metre below the spring line. Systematic bolting was carried out using Ørsta bolts 4metres in length at 2-metre spacings centre-to-centre. There are a total of 7 bolts in each section. The rock was also reinforced with ø8-mm galvanized wire mesh. The mesh was fixed using threaded anchor rods with nut and washer. The reinforcement is installed along a stretch about 20 metres long.

Vibration measurement is carried out in accordance with General Instruction FÖ-I-364, which requires triaxial geophones to be placed in the centre of the tunnel roof and at both spring lines. Outside the reinforced area, vibration levels are measured using vertical geophones in the tunnel roof, about 10 metres either side of the reinforced section.

In the Metro there is a relay station about 80 metres north of the crossing with the works access tunnel. The relay station is subject to a limit value of 15 m/s^2.

Instruments of types Infra Mini and UVS 600 are used to measure vibration. Registrations (readings) over a pre-set threshold value are displayed on a project page at www.ncvib.com.

Blasting is carried out at the fixed times of 10:30 – 10:40, 12:30 – 12:40 and 21.30 to 21:40.

In general, the tunnelling work is subject to a maximum damage zone of 0.3 m in the walls and 1.1 m in the floor. The grout holes are drilled to a length of 22 m. The total number of holes in the grout shield varies. Depending on the sealing class, hole-point distances (the distance between hole bottoms) of 3 or 4 metres are used. This means that for an access tunnel with a cross-section of 65 m^2 and sealing class 2 (hole-point distance 4 metres), for example, 34 grout holes are drilled. Every second hole is drilled with a look-out of 4 or 5 metres. Thus for sealing class 1 with a hole-point distance of 3 metres, the number of holes is increased.

Veidekke is doing the drilling with an Atlas Copco 3-boom drill jumbo. Due to the closeness of the Metro and the buildings in Teknikhöjden, all charging has been carried out using cartridge explosives of type Dynorex (ø25-mm) at the bottom and Kemix (ø25-mm) and Dynotex (ø17-mm) as a pipe charge. The Nonel LP initiation system is being used supplemented with Nonel SL to increase the number of intervals and reduce the simultaneously-acting charge weight. Later on, when the tunnel passes the critical installations and buildings, the holes will be charged with site-sensitized bulk emulsion (SSE).

Slashing was done in two-metre rounds within a distance of approx. 20 metres from the nearest measuring point in the Metro. Floor, helper and stope holes were charged with approx. 0.2-0.5 kg as the bottom charge and about 0.3-0.4 kg in the pipe charge. The biggest slashing rounds consisted of about 60 holes with a total charge weight of 25-30 kg. The specific charge was approx. 0.9 kg/m^3.

There has been only one transgression of the limit value in any measuring point. The highest reading was 73 mm/s, which was registered in a horizontal direction in the roof centre. The distance to the Metro was about 21 metres. Generally, the highest readings from the slashing rounds have been in the horizontal direction in the roof centre.

To be able to maintain an advance of 2 to 3 metres per round when blasting within 10 metres of the Metro, Veidekke has drilled, at the most, 210 holes in the full tunnel cross-section rounds. When the distance to the Metro was greater (approx. 30 m), Veidekke increased the hole depth to about 5 metres. The charge weight in the boreholes varied from approx. 1.2 kg in the contour holes to 3.1 kg in the floor holes. The total charge weight in the rounds was about 400 kg, with a specific charge of 1.4 kg/m^3.

The tunnel face has recently passed the south gable of Teknikhöjden, Björnnäsvägen 23, where the rock cover was at least 6 meters, without exceeding the vibration limit in the building. The distance to the Metro is at present about 45 metres. The vibration levels in the Metro are just over 10 mm/s, which means that blasting may take place at fixed times only.

Figure 2 below shows a regression analysis of readings taken at all measuring points on the rock in the Metro in the vertical direction. The readings are from blasts within approx. 10 m of the Metro.

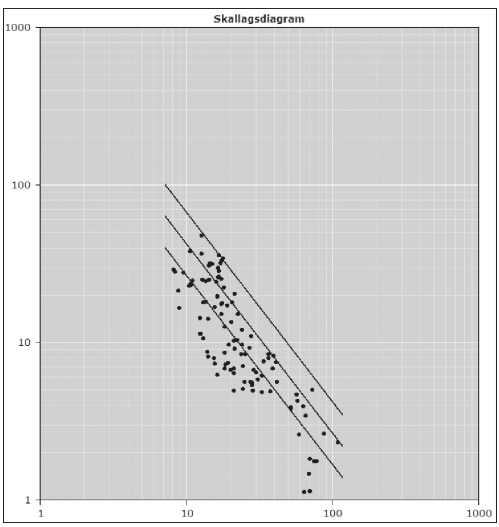

Figure 2. Regression analysis of blasts within 10 metres of the Metro. Measuring points on rock and in vertical direction.

When calculating the simultaneously-acting charge weights, one can normally use an 84 % confidence level, i.e. the middle of the three lines shown in Figure 2, but due to the high penalties for exceeding the limit value, a higher confidence level is applied.

Figure 3 (below) shows readings in the same measuring points as in Figure 2, but when tunnelling away from the Metro. The regression lines are significantly steeper, which means that distance damping increases with increased distance. But due to relatively few readings in the 30 to 60 mm/s range, the curve becomes steeper and the distance damping probably somewhat greater than in practice.

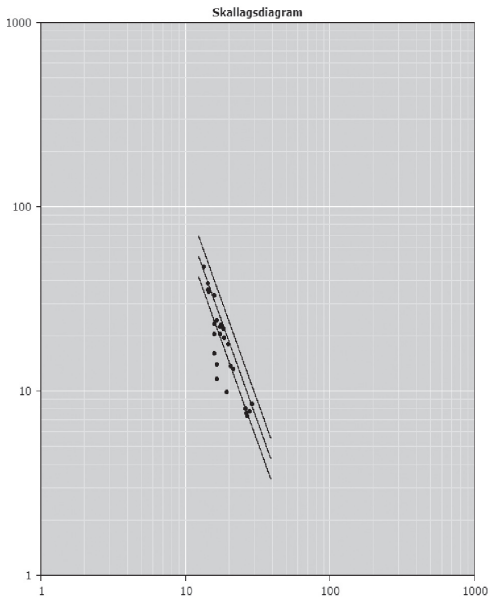

Figure 3. Readings from measuring points 10-65 metres from the Metro when tunnelling away from the Metro. Measurements taken in vertical direction.

5. WORKS ACCESS TUNNEL NL306, ALBANO

The access tunnel is approx. 180 metres long, of which about 100 metres had been blasted out previously. Veidekke has completed the preparatory blasting work on the surface, which is part of the contract, and the slashing of the access tunnel has been under way for a couple of weeks.

The distance to the most vibration-sensitive

equipment in the Physics Center and Building 10 is about 100 metres and 27 metres respectively. The tunnel will pass under the latter building. Blasting of the full tunnel cross-section will start shortly. The blasting on the surface is restricted to the fixed blasting-times applicable to the Värtabanan railway and AlbaNova operations. While four blasting times have been available to the contractor, in practice only three have been used: 10:00 – 10:15, 14:00 – 14:15 and 15:30 – 15:45. Blasting in the works access tunnel will be subject to two blasting times: 07:00 - 07:15 and 21:45 - 22:00.

6. WORKS ACCESS TUNNEL NL 304, VÄRTAN

The access tunnel is about 250 m long and starts at the eastern part of Uggleviksvägen. The contractor is Oden Anläggningsentreprenad AB (Oden).

The open cut for the access tunnel is situated at the entrance to an old air-raid shelter. The blasts will take place at a relatively long distance from buildings etc. The closest infrastructure are the Värtabanan, a water tower and two water pipelines (ø300 to 600 mm), one of steel and the other of nodular and grey cast iron. The distance to the welded pipeline, situated directly above the access tunnel, is about 20 metres. It is subject to a guideline of 100 mm/s. The distance to a lead-caulked grey cast iron pipeline is about 50 metres. For it, the guideline limit value is 30 mm/s.

The portal of the access tunnel has been adapted to minimize the impact of the open cut on the environment. As a result, the tunnel portal has been moved out about 5 metres. The tunnel profile has been lowered and modified to give approx. 2 metres of rock cover above the portal. The rock mass nearest the portal has been grouted and reinforced with two rows of spiling bolts. In the first row, the centre-to-centre distance is 0.6 m above the roof and 1.0 m outside the wall just below the spring line. The 6-metre long bolts are installed with a 'look-out' of about 15 degrees from the horizontal plane. The second row consists of 3-metre long spiling bolts spaced accordingly. After bolting, the portal face was sprayed with shotcrete. The brow above the tunnel roof was sprayed with 30 mm fibre-reinforced concrete.

The reinforcement work is now complete and Oden will shortly start slashing the first part of the tunnel. Slashing of the existing tunnel is divided into 8 rounds in order to protect the remaining rock. The order of excavation is as follows: lowering of the floor, roof slash, roof contour, side slash left, contour left wall and roof, side slash right and, finally, contour right.

When blasting of the full tunnel cross-section begins, the contractor will use SSE explosive. The initiation system is Nonel LP.

7. WORKS ACCESS TUNNEL NL309, ORMEN SURGE CHAMBER

The Ormen access tunnel contract is divided into three tunnels. The existing entrance tunnel to the surge chamber will be slashed out for a distance of about 100 m. A new 200-m long tunnel for the surge chamber will be excavated. Finally, a small tunnel (approx. 80 m long), will be excavated to connect existing stormwater pipes on the surface to the surge chamber.

The contractor NCC will start work on the first grout shield shortly, after which slashing of the existing tunnel will commence.

Blasting must take into account the buildings on Bellevueberget (Bellevue Hill), as well as the activities in the Graduate School for Social Work and Public Administration (formerly Sveaplan Secondary School) and the AlbaNova University Center. Also to be considered are the traffic on Roslagsvägen, buried utility-lines and existing tunnels in the immediate vicinity.

8. WORKS ACCESS TUNNEL NL101, NORTULL

The contract for the access tunnel in Norrtull is divided into two sub-sections. The first involves tunnelling down to the future ramp tunnel and the second to a future utility tunnel. The lengths of the sub-sections are 215 and 85 metres respectively. Existing buried utility lines affected by the Northern Link will be re-routed through the utility tunnel. Blasting work for the open cut and tunnels is expected to start in April 2007. Sheet pile driving and excavation work must be completed before that time.

The blasting work must adapted to the operations and equipment in the Karolinska Hospital, as well as to an existing utility tunnel, an existing road tunnel (Eugeniatunnel), a railway (Värtabanan), buildings and buried utility lines.

9. ROCK AND CONCRETE TUNNELS, KAROLINSKA, NL11 AND NL12

Each of the contracts involves excavation of approx. 50,000 m^3 of rock. Tunnel blasting will be carried out under the eastern part of the Karolinska University Hospital (KUS) area. Activities in the area include neurosurgery and patient examination. The vibration-sensitive equipment comprises PET and MR scanners. The MR scanner manufacturer stipulates a limit value of 20 m/s^2. The MR scanner is housed in a building situated directly above the ramp tunnel. KUS is planning to install an additional MR scanner in the same building. At present, the client, Vägverket, does not believe it will be possible to isolate the MR scanner from vibration.

The ramp tunnel will pass under the road tunnel, Eugeniatunnel, which will remain in operation throughout the contract. There will be no rock cover at the crossing. Preparatory work must therefore be carried out in the Eugeniatunnel, and it must be complete by the time the contract for NL11 starts.

The Eugeniatunnel is subject to a vibration limit value of 60 mm/s while traffic is flowing. When traffic is shut off, the limit value can be raised to 100 mm/s.

10. NL 31, ROCK AND CONCRETE TUNNELS, BELLEVUE

The rock tunnels will run from the west side of Bellevueberget (≈ Bellevue Hill) to Roslagsvägen, a busy thoroughfare. The rock volume is approx. 70,000 m^3. Blasting will be subject to the same restrictions as for the Bellevue works-access tunnel (NL309) mentioned earlier and must also take into account the offices and apartments in the Wenner-Gren Center.

11. NL 33, ROCK TUNNELS, ALBANO

The contract comprises the main tunnels from Roslagsvägen, which will run west to the Machine Design Department (KTH-Maskin) of the Royal Institute of Technology (KTH), and two ramp tunnels from the roundabout at Roslagstull. Total rock excavation will be about 250,000 m^3.

Under the bastion at AlbaNova where the experiments most sensitive to vibration are conducted, the rock cover is about 7 metres at least. The sensitive equipment will be insulated from vibration as much as possible so that the buildings (guide value, v10, limit for 10m distance, 84 to 100 mm/s) become dimensioned for the blasting work. In spite of this, however, fixed blasting times will apply. Since AlbaNova is also a place of teaching, the tunnelling working will be subject to restrictions on structure-borne sound.

The tunnels in this contract will cross the Metro in 6 places. The distance to the Metro varies from 0 to approx. 7 metres. In 1996, the Metro tunnel was reinforced with bolts (centre to centre 1.0 – 1.7, lengths 2.4 – 4 m) and wire mesh. At two of the crossing points, bolting was supplemented with wire-mesh reinforced shotcrete (60 – 160 mm). The reinforcement was intended to make safe the operations in the Metro, but also to permit a limit value higher than 30 mm/s, which applies generally when the traffic is shut down. Fixed blasting-times will apply to the Metro as well. See description of Teknikhöjden works access tunnel (NL306) above.

In the east, the contract boundary lies directly under KTH-Maskin. The blasting work must therefore take into account the department's buildings and activities.

In addition to the buildings mentioned above, the tunnelling work must take into account a home for the elderly situated in the western part of Albanoberget, as well as the Ruddammen housing area. The ramp tunnels from Roslagstull roundabout will pass directly under the old-people's home, with rock cover of about 7 metres.

12. NL34, ROCK TUNNELS, TEKNIKHÖJDEN

The contract comprises the excavation of two ramp tunnels with offshoots. The rock volume is estimated to be about 300,000 m^3.

The contract boundary for the western offshoot is north-west of the main AlbaNova building, just before crossings with the Metro. The boundary of the eastern offshoot is directly under the Mechanical Engineering quarter (Maskiningenjören), where both KTH-Maskin and the University College of Dance have premises. The blasting work must take into account the equipment and activities in AlbaNova and the KTH. The rock cover under KTH-Maskin is about 30 m. Restrictions on structure-borne sound must be observed.

Blasting will also be subject to restrictions for the Metro and Roslagsbanan, an overland suburban railway. The latter runs almost directly above the ramp tunnels. In a couple of sections, there is very little is very little rock cover (approx. 3 to 5 metres).

13. NL35, ROCK TUNNELS, VÄRTAN

The contract comprises two tunnels: main tunnels that transform into ramp tunnels toward Värtan. The total rock volume is about 400,000 m^3. The western boundary of the contract is under KTH-Maskin. In the east, it is about 50 metres east of Fiskartorpsvägen. In addition to the buildings and activities of the KTH – and the installations described in connection with the Värtan works access tunnel (contract NL309) – the blasting work is subject to restrictions in respect of a utility tunnel, buried utility lines and the buildings east of Fiskartorpsvägen.

14. CONCLUSIONS

By liaising closely with the client and all affected parties, implementing protective measures, dimensioning their blasts carefully, using the right explosives, charging techniques and initiators, and observing fixed-blasting times where necessary, contractors on the Northern Link project in Stockholm are managing to make good progress in difficult conditions without exceeding the prescribed limits. The fact that in all of the contracts currently under way, there has so far been only one transgression of the vibration limit value is testimony to their skill. The use of quality measuring instruments and taking advantage of the project page facility at www.ncvib.com is also helping all concerned to achieve their goals. In view of the iron will of Stockholmers to protect their environment to the greatest extent possible, it is remarkable that very few complaints have been received so far. It goes to show that by listening carefully, adopting an open approach, engaging talented people, using the right equipment and taking sensible precautions, even extremely challenging projects can be completed harmoniously.

Vienna Conference Proceedings 2007, P. Moser et al.
 ISBN 978-0-9550290-1-1

Studies on flyrock at soapstone quarry for safe working

S.S. Rathore & E.S.C. Jain
Dept. Mining Engg., CTAE, MPUAT, Udaipur, India

ABSTRACT: Flyrock due to blasting is currently a serious problem in surface mines. Many accidents happen outside the blasting danger zone. Thus, a study was carried out in soapstone mines to predict the flyrock safety distance for man and machinery. In this study observed flyrock distances for 10 blasts at a soapstone quarry along with blast design parameters are presented. The influence of blasthole diameter, burden, stemming length, powder factor and the initiation systems on the generation of flyrock is analyzed and the most critical parameters for flyrock control are identified. Based on the analysis of results, suggestions are given to minimize the flyrock hazards at this soapstone quarry.

1. INTRODUCTION

During blasting operations in general, the rock gets fragmented and the centre of gravity of the ground is moved forward. In addition to desirable displacement of broken fragments in case of surface mine blasting for excavation blast, some stone pieces get turned and travel very large distances. Usually, this undesirable movement of rock debris from the blast area is called flyrock. In recent years, blasting technology has improved greatly but danger and damage from flyrock in rock blast has been a serious problem. Not only have men been killed and injured but also buildings, equipment and materials have been damaged (Lundborg et al. 1975). Flyrock, which travels beyond the protected blasting area, caused 25% of the blasting accidents in U.S. surface mining (Fletcher & D' Andrea 1986). An analysis of blasting accidents in Indian mines indicated that more than 40% of fatal and 20% of serious accidents were caused by flyrock (Bhandari 1997). The major causes of flyrock are inadequate burden, inadequate stemming length, drilling inaccuracy, excessive powder factor, unfavourable geological conditions (open joints, weak planes, cavities etc.), inappropriate delay timing and sequence, in-accuracy of delays, back break and loose rock on top of the bench (Fletcher & D'Andrea 1986, Workman & Calder 1994, Kopp 1994, Bhandari 1997, Adhikari 1999, Rathore & Lakshminarayana 2000).

The energy spent in creating flyrock during blasting is less than 1% of the total energy transmitted to the rock (Berta, 1990), hence the wastage of explosive energy in this form may be insignificant. However, the risk of damage due to flyrock is so high that it merits serious consideration in blast design. Keeping this in view field investigations were conducted at soapstone quarry to study the flyrock from blasting. This study was carried out to analyze effect of various parameters of blasting in soapstone, host rock dolomite and intrusions of quartzite at few places.

2. FIELD STUDIES CARRIED OUT

The soapstone quarry selected for this study produces about 60,000 tonnes of soapstone annually. The quarry was developed in five to seven benches and deployed similar types of equipment. There is no residential area within 500 m of the site. In that quarry a fatal accident occurred at a distance of 620 m from blast site. After that incident the owner of the soapstone quarry approached our department of mining engineering to request help to establish a proper blasting pattern to control flyrock within the 500 m danger zone of blasting.

The density of soapstone and host rock dolomite varied between 2.2 and 2.6 g/cu.c. The mineral soapstone was very soft and host rock dolomite was medium hard at quarry. At that soapstone quarry, study was carried out during the month of April 2005 to find out the route cause of the fatal accident and also to suggest an appropriate blast design to control the undesired movement of the rock or flyrock for safety of the men and machinery.

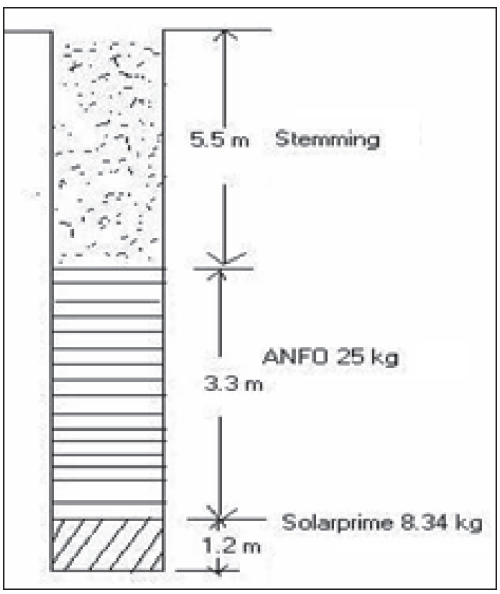

Figure 1. Charging pattern of deep holes.

Blasthole diameter, burden, stemming length and condition of the holes were recorded for 10 blasts at soapstone quarry along with the maximum distance traveled by the fragments (Table 1). The actual burdens were recorded for the front row of holes. Drill cuttings were used as stemming material. Subgrade drilling was used maximum upto 5% of the bench height. The charging patterns of bench blasthole and toe holes are given in Figures 1 & 2. The general view of the quarry and flyrock movement are also given in Figures 3 & 4. The powder factor of soapstone quarry was varied from 0.24 to 0.51 kg /m^3. Other parameters at soapstone quarry were:

- Bench height: 6.0 to 9 m
- Spacing: 2 to 3.5 m; Burden : 1.5 to 3.6 m
- Number of holes per blast: 5 to 40
- Number of rows: 1 to 2
- Explosive used: Solarprime (cartridge slurry): ANFO = 1: 3
- Initiation System: Detonating cord in downline & trunkline with delay detonators

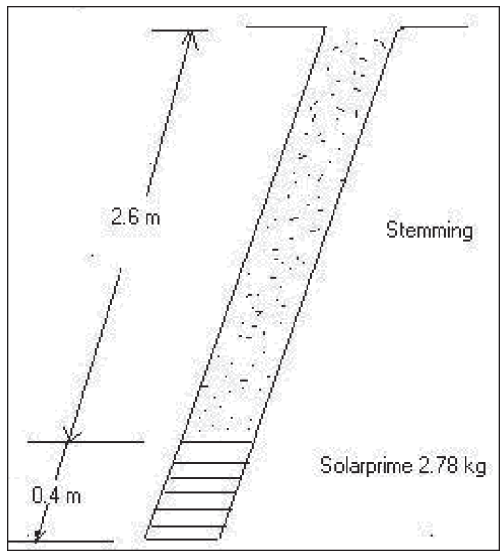

Figure 2. Charging pattern of toe holes.

Figure 3. General view of soapstone mines.

Figure 4. Flyrocks in blast number.6.

Quantities of explosives used in various blasts were carried out and fragmentations obtained are given in Table 2.

3. RESULTS AND DISCUSSIONS

Field studies carried out for flyrock distances are used to determine the safe distance for flyrock. The field data are analyzed to determine correlation between flyrock distances and the blast design parameters.

3.1 Flyrock safe limits

Flyrock safe limit is the minimum distance beyond which the throw of fragments does not appreciably affect the surroundings. The metalliferous mines regulations, 1961, prescribes a danger zone of 300 m for surface blasting. As the accidents related to flyrock did occur outside this zone the Director General of Mines Safety, Dhanbad recommended an increase in the radius of the danger zone to 500 m for surface blasting (DGMS 1982).

Despite some attempts to estimate flyrock distance (Lundborg et al. 1975, Roth 1979, Chiappetta & Borg 1983, Workman & Calder 1994), it is extremely difficult to predict flyrock, both in terms of distance and direction. From Table 1 it is noted that the maximum flyrock distance was observed upto 210 m in main blasts with toe

Table 1. Base data on flyrock observations at soapstone quarries.

Blast no.	Type of Rock	d (m)	B (m)	l_s (m)	l_s /B	B/d	l_s /d	Flyrock distance (m)	q (kg/ m^3)	q/q^0	Remark
B-1	Ferrugenous Quartzite	0.115	3.5	1.8	0.51	30	15	30	0.40	1.0	
B-2	Ferru. Quartzite	0.115	2.6	5.0	1.92	23	43	40	0.51	1.27	
B-3	Soapstone + dolomite	0.115	3.2	4.0	1.25	28	35	210	0.30	0.75	Main blast with toe holes
B-4	Dolomite	0.115	1.5	2.4	1.09	13	21	108	0.26	0.65	Toe holes
B-5	Soapstone	0.115	3.2	5.0	1.56	28	43	150	0.25	0.62	Main blast with toe holes
B-6	Quartzite + Soapstone + Dolomite	0.115	3.6	5.0	1.38	31	43	132	0.33	0.82	
B-7	Soapstone	0.115	1.5	2.4	1.6	13	21	150	0.30	0.75	Toe holes
B-8	Dolomite bands	0.115	1.5	2.4	1.3	13	21	175	0.24	0.60	Toe holes
B-9	Dolomite bands	0.115	1.5	2.4	1.3	13	21	105	0.25	0.62	Toe holes
B-10	Dolomite bands	0.115	1.5	2.4	1.2	13	21	112	0.25	0.62	Toe holes

d – blast hole diameter; B - burden; l_s - stemming length; q - powder factor;
q^0 - optimum powder factor (0.40 kg/ m^3 for quarries)

Table 2. Details of blasting parameters of soapstone quarries

Blast No.	Burden (m)	Spacing (m)	Blasthole depth (m)	No. of holes	Total Explosive used (kg)	Powder factor (tonne/kg)	Fragmentation type
B-1	3.5	2.8	2.75	9	97	7.5	Average
B-2	2.6	3.0	8.35	16	536	5.8	Average
B-3	3.2	3.5	6.7	17 + 8 toe	457	7.8	Average
B-4	1.5	2.5	2.8	6 toe	16.68	9.8	Average
B-5	3.2	3.0	10	9 + 17 toe	317	8.6	Average
B-6	3.6	3.3	9.6	20	666.8	8.8	Average
B-7	1.5	2.0	3.0	40 toe	111.2	7.1	Good
B-8	1.5	2.5	3.0	8 toe	22.24	10.5	Large Fragments
B-9	1.5	2.5	3.0	5 toe	13.90	10.4	Average
B-10	1.5	2.5	3.0	15 toe	41.70	10.4	Good

Note: Specific gravity of Ferrugenous quartzite = 3.0., Dolomite = 2.6, Soapstone = 2.2

holes. Thus, in toe holes flyrock travels for longer distance and precautions are required even beyond the danger zone of blasting prescribed in Indian regulations.

3.2 The influence of burden

In all the quarry blasts, blasthole diameter (d) used was 115 mm. the burden (B) was kept 1.5 m in dolomite bands and 2.6 to 3.6 m was kept in ferruginous quartzite and soapstone. On the basis of results, flyrock distances are plotted against the burden to hole diameter (B/d) ratio (Figure 5). It should not be interpreted that burden has no influence on flyrock from single hole tests (Bilgin 1991), it is known that flyrock decreases as the burden increases. In the present study, the flyrock observed was also less with increase of burden distance.

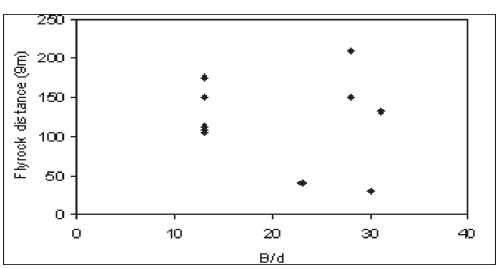

Figure 5. Influence of burden (B) to blasthole diameter (d) ration on flyrock.

It is possible to obtain crater effects from the front row of holes if burden is inadequate. This may be due to incorrect design, drilling errors and geological weakness. Proper care and precautions are to be taken while marking and drilling the holes, particularly for the front row of holes.

3.3 The influence of stemming length

The stemming length (l_s) is also expressed as multiples of blasthole diameter (d) and plot of flyrock distance against stemming length to hole diameter (l_s/d) ratio as shown in Figure 6. The maximum flyrock distance does not have definite relation in soapstone, dolomite and intrusions of ferruginous quartzite. Generally, the decreasing trend of flyrock distance with increasing stemming length is obvious from the role of confinement in controlling premature venting of high pressure gases.

Field experiments carried out in Sweden using high speed photography indicated that the throw length increased with decreasing stemming length. The maximum throw was achieved for l_{ess}/d ~15; and then it decreased again. Person et al. (1994) had provided an explanation for this phenomenon. When the stemming length is short, shock wave component of the explosive energy is sufficient to fragment the rock at the collar.

It is noted that stemming is the most neglected

blast design parameters at soapstone quarries. Some considerations are given to the stemming length but no consideration is given to the stemming material and particle size of the material. Hence, there is scope for reducing flyrock at these quarries by ensuring $l_s/d > 20$ and by using suitable stemming material, such as angular gravel (Konya and Walter, 1990).

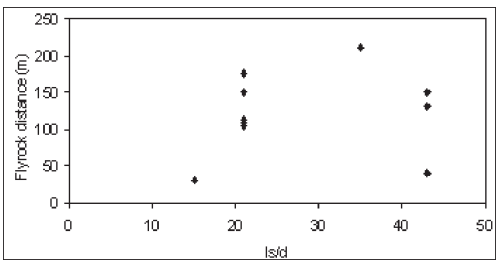

Figure 6. Influence of stemming length (ls) to blasthole diameter (d) ration on flyrock.

3.4 *The influence of powder factor*

Based on the observations of powder factor of quarries, optimum powder factor was taken as 0.4 kg/m3. The powder factor data for soapstone quarry (Table 1) are expressed as the ratio of q/q_0, where q is the powder factor used in the blast and q_0 is the optimum powder factor and the relationship between flyrock and q/q0 is shown is Figure 7. It can be seen (Figure 7) that flyrock is upto 30m when $q/q_0 = 1$. Previous study (Lundborg et al. 1975) also shows that flyrock can be avoided if the powder factor is smaller than a critical value. However, it is not recommended to reduce the powder factor significantly because it will adversely affect the fragmentation and displacement.

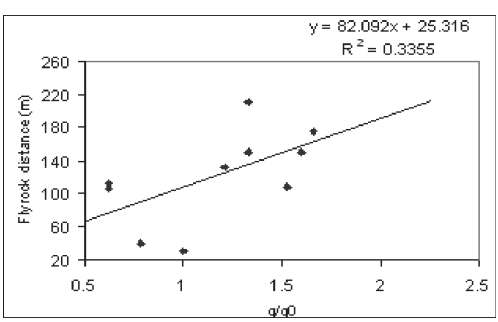

Figure 7. Trends of flyrock with powder factor.

3.5 *The influence of stemming length to burden ratio*

Taking flyrock distance as a dependent variable, stemming length to burden (l_s/B) ratio (a dimensionless parameter) as independent variable, three types of regression analysis (linear, exponential and power curve) were carried out. The correlation between flyrock distance and l_s/B ratio is shown in Figure 8 (a), (b) and (c) for the combined data of all blasts. The correlation is positive, showing an increasing trend of flyrock distance with increasing l_s/B ratio.

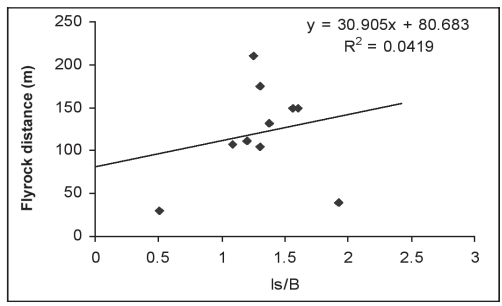

Figure 8a. Linear curve.

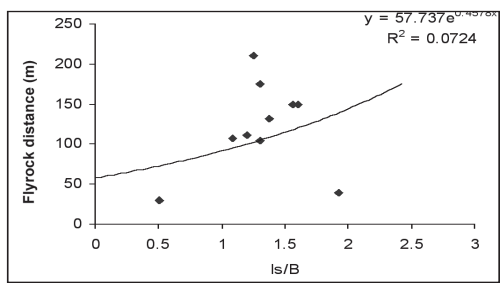

Figure 8b. Exponential curve.

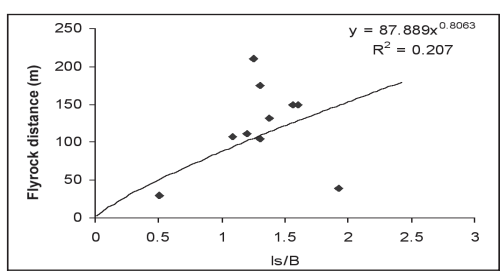

Figure 8c. Power curve.

Figure 8 a-c. Trend of flyrock with stemming length (ls) to burden (B) ratio.

The linear, exponential and power curves show that flyrock distance increases with increasing l_s/B ratio. The reason for this was the single row and toe holes blasting carried out simultaneously. Thus, it was pointed out that toe holes blasting with single row may be avoided to control the flyrock.

4. CONCLUSIONS

The charge in the holes of first row should be based on the profile of the face. Profile can be drawn with the help of survey instruments. The main stress should be given on toe burden and explosive charge may be kept higher for more toe burden and less for less toe burden. Maximum flyrock distance observed at the soapstone quarry was 210 m and the safe distance of 500 m prescribed is on the higher side for well controlled blast but extra precautions are required outside the danger zone in routine blasts.

This study aimed to determine the blast design parameters responsible for flyrock at a soapstone quarry and identify the areas for immediate attention. In this soapstone quarry, blasthole diameter, burden and power factor are common causes of flyrock, whereas poor stemming with drill cutting is the major cause of flyrock. Due to inclined toe holes, flyrock travels for a longer distance. Thus, toe holes blasting with first row of blast holes may be avoided. The risk of flyrock is less in air deck blasthole. Using bottom hole non-electric initiation system, flyrock can controlled.

REFERENCES

Adhikari, G.K. 1999. Studies on flyrock at limestone quarries. *Int. J. Rock Mech. & Rock Engg.*, 32 (4) pp. 291-301.

Berta, G. 1990. Explosives and engineering tool. Italesplosivi, Milano.

Bhandari, S. 1997. Engineering rock blasting operations. *A. A. Balkema, Rotterdam*, 315 - 325.

Bilgin, H.A. 1991. Single hole test blasting at an open pit mine in full scale: a case study. *Int. J. Surf. Min. Reclam.* 5(4), 191-194.

Chiappetta, R.F. & Borg, D.G. 1983. Increasing productivity through field control and high-speed photography. *Proc. 1st Int. Symp. on Rock Fragmentation by Blasting*, Lulea, Sweden, 301-331.

DGMS 1982. Directorate General of Mines Safety. Technical Circular No. 8. Dhanbad, India.

Fletcher, L.R. & D'Andrea, D.V. 1986. Control flyrock in blasting. Proc. 12th Conf. on *Explosives and Blasting Technique*, Atlanta, Georgia, 167-177.

Konya, C.J. & Walter, E.J. 1990. Surface blast Design. *Prentice-Hall, Englewood-cliffs*, 190 – 200.

Kopp, J.W. 1994. Observation of flyrock at several mines and quarries. *Proc. 20th Conf. on Explosives and Blasting Technique*, Austin, Texas, 75-81.

Lundborg, N., Persson, A., Ladegaard-Pedersen, A. & Holmberg, R. 1975. Keeping the lid on flyrock in open-pit blasting. *Engg. Min.* J. 176, May, 95-100.

Mead, D.J. Moxon, N.T. Dannel, R.E. & Richardson, S.B. 1993. The use of air-decks in production blasting. *Proc., 4th Int. Symp, Rock Fragmentation by Blasting, Vienna, Austria*. 437-443.

Person, P.A., Holmberg, R. & Lee, J. 1994. Rock blasting and explosives engineering CRC, Atlanta.

Rathore, S.S. & Lakshmi-Narayana, V. 2000. Control of flyrock in opencast mines. *Proc. Nat. Sem. on Mining Technology of new millennium, organized by* MEAI, Himalayan Chapter, June 10-11, 54-62.

Roth, J. 1979. A model of the determination of flyrock range as function of shot conditions. *A report for the U. S. Bureau of Mines by Management Services Association,* Los Altos, California, NTIS, PB81-222358.

Workman, J.L., Calder, P.N. 1994. Flyrock prediction and control in surface mine blasting. *Proc. 20th conf. on Explosives and blasting Technique*, Austin, Texas, 59-74.

Worsey, P. 1990. Stemming ejection comparison of conventional stemming and stemming incorporating blast control plugs for increasing explosion energy use. *Proc., 3rd Int. Symp. on Rock Fragmentation by Blasting, Brisbane*, 361-367.

Vienna Conference Proceedings 2007, P. Moser et al
 ISBN 978-0-9550290-1-1

The influence of the oxygen balance on the chemical reaction of explosives

G. Kamburova
University of Mining and Geology, "Ivan Rilski", Sofia, Bulgaria

ABSTRACT: A widely held belief is that the most complete reaction and formation of high oxides H_2O and CO_2 occurs with zero oxygen balance explosives, where the least quantity of toxic gases is released. Based on a new study of the chemical reaction on contemporary industrial explosives performed according to the EU's new requirements and world tendencies, it was found that apart from the examined gases, a considerable group of hydrocarbons C_XH_Y are released as the oxygen balanced explosives become unbalanced with an oxygen surplus. Based on the results obtained from this study we developed a new equation for the chemical explosive reaction of industrial explosives, which reflects more completely the detonation process and created products from the blasting. The new equation will find application in the creation and evaluation of new explosives for civil use, as well as revision of existing explosives allowed for use in industrial blasting.

1. INTRODUCTION

The modern blasting industry is as concerned with effectiveness and output as with minimizing the harmful effects caused by the blast-generated seismic vibrations, flyrock, airwave and harmful gas-dust emissions released in the environment.

The seismic impact, flyrock and airwave can be and are in fact successfully mitigated through the latest implementations of various blasting technologies. It can be argued that these problems have already been contained and are successfully managed by leading experts. The harmful effect on the environment is based on the discipline, experience and knowledge of blasting engineers rather than blasting technology.

The situation with the harmful gas-dust emissions generated during all types of blasting is completely different. Although studied since the inception of industrial blasting, the implemented measures thus far have not brought about satisfactory resolution to the problem. Moreover, driven by the increased rate of blasting its implications are even greater.

A common practice at larger construction projects, surface mines and quarries is to detonate 20-100 to 200-300 tons of explosive at a single blasting. As a result, up to tens of millions of liters of harmful gas emissions are released in the environment, negatively affecting nearby communities and significantly reducing the air, soil and water quality. The introduction of most coarse booster sensitive explosives (ANFO, emulsions, slurry or "wet bag" explosives, coarse ammonites, etc.) complicates matters further as the chemical explosive reaction varies greatly even at the same composition of the explosive materials.

The majority of theoretical and experiential studies of the chemical explosive reaction are performed on chemically pure compounds such

as trinitrotoluene and nitroglycerin as well as the blasting cap sensitive, higher explosives. Those studies have utilized small chambers with volume 20 to 50 liters, such as those of Bichel- USA, Dolgov- Russia and others, and the charges detonated in their original packaging have a mass of 50 to 200g (Baron and Kantor 24-25; Dubnov, Bakharevich and Romanov 26-40; Lazarov 51-67). More recent studies performed in chambers with volume 10-15 m^2 equipped with a mortar with diameter of the central opening 50mm, detonated charges of 600 to 1000g.

The only subject of these studies have been the blasting cap sensitive explosives. Furthermore, because of the prevailing concept of the chemical explosive reaction, only carbon monoxide (CO), mono-nitrogen oxides (NO_x), carbon dioxide (CO_2) and oxygen have been subject to measurement. It is presumed that no other gas-dust emissions have been studied.

The problem of pollution to the environment as a result of the harmful gas-dust emissions is magnified by development of large open mines and quarries performing large scale blasting operations. In 2002 in compliance of EU's Directive 93/15 EEC a completely new standard for measuring gas-dust emissions resulting from blasting in chambers with volume greater then 15m^3 was developed. In the USA, NIOSH has undertaken new studies aiming at the reduction of toxic gas emissions from emulsion ANFO explosives used in large open mines. The tests utilized charges with a mass of 4.5-5kg and volume of the testing chamber to 274m^3 (Rowland and Mainiero 163-174). Clearly, the study of the chemical explosive reaction and the emitted gas-dust emissions during blasting is more important than ever.

2. CURRENT EQUATION OF THE CHEMICAL REACTION

The equation for the chemical explosive reaction has a great importance because it serves as a basis for determining the composition of the industrial explosives used and from there the type and volume of the gas-dust emissions from the blast, thus assuring compliance to the Directive 93/15 EEC.

All else being equal, the chemical explosive reaction is determined mainly by the explosive's composition and especially by the proportion of the elements C, H and oxygen, i.e. by the oxygen balance. The explosives are commonly divided into two-three groups based on the oxygen in their composition. The first group refers to explosives with a positive oxygen balance, the second (and third) explosives with zero and negative oxygen balance.

It is also well known that balanced explosives with zero or near zero oxygen balance have the greatest heat formation and form the high oxides H_2O and CO_2. The chemical transformation of an explosive with a composition CaHbNcOd is as follows:

$$CaHbNcOd \rightarrow aCO_2 + b/2\ H_2O + c/2\ N_2 + 1/2\ (d - 2a - b/2)\ O_2 \quad (1)$$

This equation of the chemical explosive conversion based on maximum heat generation does not reflect the real make-up of the gaseous products of the blast. As evident in the tests performed in small chambers utilizing smaller charges as well as the new studies performed in the EU and the US on various types of explosives, including balanced ones, the released CO and NO_x are dependant on numerous factors.

Brinkley and Wilson, working off of the assumption that explosives with zero oxygen balance convert their entire hydrogen H_2 to water H_2O with no excess left, propose the following equation for the chemical reaction (Andreev, Baum and Orlenko 125-132):

$$CaHbNcOd \rightarrow b/2\ H_20 + (d\text{-}a\text{-}b/2)\ CO_2 + (2a\text{-}d + b/2)\ CO + c/2N_2 \quad (2)$$

The equation proposed by Brinkley and Wilson, however, does not allow for any formation of nitric oxides, which greatly disagrees with reality.

The same analysis can be performed using the method of Le Châtelier for maximum gas release at which the carbon dioxide is first oxidized to CO as the remaining oxygen divides equally between H_2 and CO until they are converted to H_2O and CO2.

The equation of the chemical explosive reaction by Le Châtelier looks like this:

$$CaHbNcOd \rightarrow aCO + b/2H_2 + c/2\ N_2 + 1/2(d\text{-}a)\ H_20 + 1/2(d\text{-}a)\ CO_2 + 1/2(3a\text{-}d)\ CO + 1/2(a + b - d)\ H_2 + c/2N_2 \quad (3)$$

The equations for maximum gas release of the chemical reaction to convert TNT with constituents $C_7H_5N_3O_6$ and hexogen with constituents $C_3H_6N_6O_6$

are as follows:

$$C_7H_5N_3O_6 \rightarrow 6CO + C + 2{,}5H_2 + 1{,}5\ N_2 \quad (4)$$

$$C_3H_6N_6O_6 \rightarrow 1.5CO_2 + 1.5\ CO + 1{,}5\ H_2O + 1{,}5\ H_2 + 3N_2 \quad (5)$$

The Brinkley -Wilson equation is commonly used for explosives with negative oxygen balance. At first the hydrogen is converted to water after which the remaining oxygen oxidizes the carbon dioxide to CO. Finally, the excess, non-oxidized carbon dioxide is released freely. The equation for explosives with a negative oxygen balance by Brinkley –Wilson is as follows:

$$CaHbNcO_d \rightarrow b/2\ H_2O + (d - b/2)\ CO + (a - d + b/2)C + c/2N_2 \quad (6)$$

At this equation the chemical reaction for TNT and Hexogen is (Dubnov, Bakharevich and Romanov 26-40):

$$C_7H_5N_3O_6 \rightarrow 2{,}5H_2O + 3{,}5CO + 3{,}5\ C + 1{,}5\ N_2 \quad (7)$$

$$C_3H_6N_6O_6 \rightarrow 3H_2O + 3CO + 3N_2 \quad (8)$$

Although this equation reflects much better the reality of the blast as it provides for the freed excess carbon dioxide, it still does not take into account the creation of cumulative nitric oxides.

The methods and concepts for the chemical explosive reaction discussed so far have the following shared shortcomings:

- The methods for maximum gas and heat release do not account for the possibility for endothermic chemical reactions which create nitric oxides or hydrocarbons, for example the Ethylene C_2H_4, both of which absorb heat
- The methods do not account for the interaction of some chemical elements creating combined hydrocarbons or liberating excess carbon and hydrogen. These interactions considerably alter the proportions of oxygen and the burning elements as a result of the chemical reaction
- The discussed equations for chemical explosive reaction have been developed mostly for the chemically pure substances and do not apply to mechanically derived explosive compounds, which have much more complicated chemical reaction. This realization is especially important for the booster sensitive explosives ANFO, emulsion mixtures and slurry or "wet bag" explosives
- The methods ignore the fact that due to the altered oxygen balance the explosives do not follow the sequence of decomposition assumed in the equations

3. NEW STUDIES OF GAS EMISSIONS

To mitigate the problem and reduce gas-dust emissions resulting from blasting operations, new studies using innovative methods have been undertaken in the EU and USA.

3.1 Testing chambers

The new methods utilize testing chambers with considerably larger volume. In order to determine the actual gaseous emissions at large blasting operations conducted with coarse, booster sensitive explosives ANFO, emulsion compounds, and their mixtures created by a government mandate in NIOSH, Pittsburgh, USA, a large underground chamber with 274m^3 volume is being used. (Figure 1)

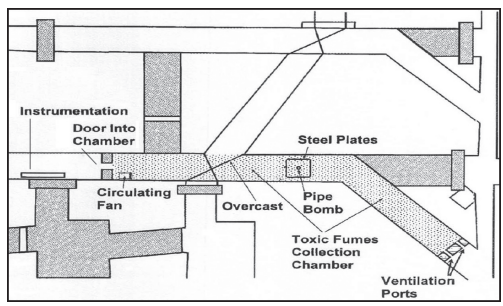

Figure 1. Scheme of the underground testing chamber at the laboratory of NIOSH, Pittsburgh, Pennsylvania, USA.

The new EU standard EN 13631-61 for toxic gas formation and measurement requires these studies to be performed in testing chambers with volume larger than 15m^3, as the chamber's volume determines the quantity of explosive compound to be used in the testing.

In the Republic of Bulgaria, complying with the requirements for labor safety, the studies of gas emissions resulting from blasting operations in civil uses are conducted in a specially equipped testing chamber with parameters 5x5x5m and volume 142m^3. (Figure 2) (Kamburova, New Research on the toxic gases, 2005)

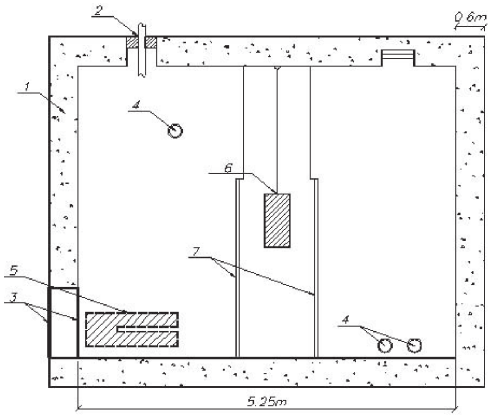

Figure 2. Profile of the chamber 1-reinforced concrete, 2-opening for ventilation, 3-two armored doors, 4-steel pipes, openings for test samples, 5-mortar for the cap sensitive explosives, 6-charge of explosive in suspended position in a steel pipe, 7-safety equipment.

3.2 Parameters of the explosives tested

EU's new standard calls for test sample over 500g as the sample can go up to 950-1000g for booster sensitive explosives combined with a donor charge. Additionally, there is a requirement for 70cm maximum length of the sample in its original factory packaging. The studies performed in the US utilize testing samples with a mass between 4.5 and 5kg, as the test sample can go over 1000g in a pressure test chamber.

These new requirements regarding the parameters of the tested samples provide for considerably more complete detonation and as a result more accurate results.

3.3 Testing methods and analysis

EU requires the test samples to be placed in a thick walled mortar designed for multiple uses with central opening in diameter of 150mm and depth 1400mm. The cartridges of explosives are placed in the mortar in their factory packaging. The non-cartridged, loose explosives are first placed in a small PVC pipe before being positioned on the mortar. The tests intend to measure CO, CO2, NO, and NO2. (EN13631-16)

Listed below are the most substantial shortcomings of this methodology.

3.3.1 The loose, non-cartridged explosives need to be tested in PVC pipes which interact with the chemical explosive reaction and alter, due to their strong negative oxygen balance, the emitted gases. In the field these explosives are used in their original unpackaged state without any covering.

3.3.2 The mortar with a central opening of 150mm is heavy equipment that is cumbersome to work with. Additional complications arise when testing explosives for which the manufacturer recommends mortars with diameter less than 150mm. Those explosives are placed on the axis of the central opening and require difficult to come up with mass. Furthermore, when testing explosives with various recommended diameters, the conditions of their detonations and the gas emissions differ greatly.

3.3.3 Explosives with a larger maximum diameter require tested sample with a minimum length of 70cm and have mass from 6,700 to 10,000kg, which makes it difficult to execute.

NIOSH, USA successfully uses a different method when testing coarse, loose explosives. The explosives are placed in a single strong steel pipe with diameter 100mm and required charge is between 4500-5000g, eliminating the shortcomings of test with PVC pipes (Rowland, Mainiero 163-174; Hurd, 2001). Studies of the gas emissions in the Republic of Bulgaria are performed using single-use pipes generating accurate results. (Kamburova, New methods for detection 21-24).

3.4. Test outcomes based on the new methodology

The study conducted on coarse ANFO and emulsion explosives using the new EU and US methodologies shows drastically different chemical explosive reaction.

Listed below are the more notable differences:

3.4.1 All explosives, both cap and booster sensitive, have shown to discharge much larger quantity nitric gases than currently thought. The emitted quantity by various explosives is in the range of 10 to 30 l/kg and these results have been validated and confirmed in tests performed in Bulgaria, USA, and Poland (Kamburova, New Research on the toxic gases 2005; Sapko et al 317-330, Jerzy at al 12-15).

Table 1. Gas emissions of booster sensitive explosives.

Explosives	gas emissions, l/kg			
	$\sum NO_x$	CO	$\sum NO_x + CO$	$\sum C_xH_y$
1. Coarse ammonite				
GDA 79/21 (zero % OB)	29	14	43	59
GDA-LM (negative 1% OB)	23	17	40	42
modified GDA-LM (negative 7.5% OB)	15	13	28	50
GDA 70/30 (negative 8.2% OB)	14	11	25	59
2. Fuel oil and ammonium nitrate				
ANFO-L (zero % OB)	21	22	43	80
Modified ANFO-L (negative 7.5% OB)	11	20	31	70
ANFO, USA 6% fuel oil (negative 1.78% OB)	37	17	54	11(H_2)
3. Mixture ANFO 6% and emulsion 50/50	31	18	49	7(H_2)

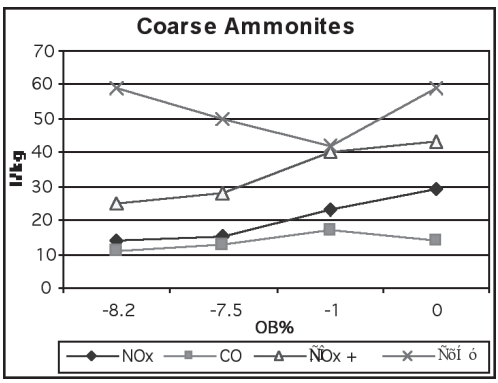

Figure 3a.

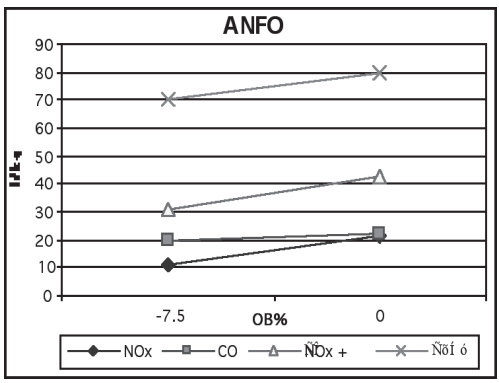

Figure 3b.

Figure 3. Correlation between the OB and toxic gasses: a) Coarse ammonias, b) ANFO L

3.4.2 Contrary to the current belief, the tests showed that balanced explosives (with zero or near zero oxygen balance) emit large amount orange nitric oxides 20-30 l/kg. These emissions are considerably reduced when explosives with minus 8 to minus 12 percent oxygen balance are used (Kamburova, New research on the toxic gasses, Kamburova and Mitkov, 2006).

3.4.3 All explosives tested emitted hydrocarbons C_xH_y due to the interaction of portion of the hydrogen with the carbon and the release of excess quantities. This is observed on all types of explosives regardless of the oxygen balance. The emission of hydrocarbons is correlated to the emissions of toxic gases and obviously has a strong impact on the chemical reaction. The new studies performed in the USA confirmed the substantial emission of hydrocarbons (Sapko et al 317-330).

3.4.4 The creation of the hydrocarbons leads to a considerable change in the ratios of the remaining elements and the oxygen. As a result the originally balanced explosives become unbalanced with various amounts of excess oxygen. During the extreme conditions of the blast, the excess oxygen connects to some of the nitrogen and nitric oxides at which there is a loss of heat. The process is endothermic.

3.4.5 Freed hydrocarbons have been noticed in the gas-dust emissions and in the blasted material in industrial studies conducted at surface and underground mines.

Table 1 presents the recorded gas – dust emissions produced in blasting of the widely used in Bulgaria and Eastern Europe trinitrotoluene coarse ammonias with various oxygen balances, as well as ammonium nitrate- fuel oil mixture, ANFO L, in its classic and updated composition. Given for comparison are the results of the studies conducted by NIOSH.

Figure 3 graphically represents the results of the tests conducted on Bulgarian explosives.

4. NEW EQUATION FOR CHEMICAL EXPLOSIVE REACTION

Based on the studies conducted in accordance with the new EU standard and those performed by NIOSH on booster sensitive explosives for civil uses, it was concluded that the balanced explosives emit considerable quantity nitric orange gases. It was also established the existence of large amount of hydrocarbons and freed carbon hydrogen.

When explosives with oxygen balance of minus 8 to minus 12% are used, the emitted toxic nitric gases are decreased by over 2-2.5 times. The combination of portion of the hydrogen to the carbon or their free release leaves excess oxygen, thus transforming the balanced explosive to one with a positive oxygen balance as a result of which more nitric gases are produced. Using explosives with a negative oxygen balance counteracts this process.

The previously discussed equations of the chemical explosive reaction do not apply and do not reflect accurately the chemical conversion of explosives for civic uses. In order for those explosives to remain balanced during the chemical reaction, it is necessary a certain amount of negative oxygen balance in the range of 8-12% to be build into their production. This will considerably decrease the harmful gasses emitted in the atmosphere.

Tests on blasting cap sensitive explosives with zero or near zero oxygen balance allowed for use in underground condition emit nitric gases in the range of 20-30 l/kg. More comprehensive studies need to be performed in order to establish the optimal negative oxygen balance for their production. This will sharply reduce the negative effects of released toxic gases and in particular the nitric gases produced as a result of the chemical reaction in underground condition.

Based on the results of the new studies, the equation of the chemical explosive reaction needs to be modified in order to reflect the emitted free and combined hydrocarbons as follows:

$$CaHbNcOd \rightarrow eXO_2 + fCO + g/2H_2O + h/2\ N_2 + iNO + jNO_2 + kC1H + 1/2\ (d - 21 - f - g/2 - i - 2j)\ 0_2 \quad (9)$$

where: $a = e + f + k$ (10)

$b = g + l$ (11)

$c = h + i + j$ (12)

The newly developed equation for the chemical explosive reaction has to be taken into consideration at the planning, development and production of new and the modification of existing explosives for civil uses. This will assure compliance to the EU Directive 93/15 EEC/15, issued April 1993, for harmonization the condition for trade and control of explosives for civil uses.

5. VERIFICATION OF EQUATION IN REAL CONDITIONS

The conclusions drawn form the proposed equation, were validated in real conditions. Performed were industrial testing on the original ammonium nitrate-fuel oil mixture, ANFO L, as well as on the modified version of the explosive. The original ANFO L has a zero oxygen balance; the modified ANFO L was manufactured with a minus 7% oxygen balance obtained thru the increase of the fuel oil from 5.5% to 7.5%.

The industrial test was conducted at quarry Studena on a beanch with boreholes with diameter 105 mm and depth 12-15m. The beanch was divided onto two sections as the section to the left was charged with balanced ANFO L and the one to the right with the modified minus 7% ANFO L. The two sections were blasted together as the modified minus 7% ANFO L was blasted with 50 ms delay after the balanced ANFO L.

Figure 4 shows the visual effect of the blasting. It is clearly visible that the gaseous cloud on the field to the right is much smaller and lighter.

Figure 5 shows the development of the studied blasting, as the effects produced by the two explosives are even better visible. Each picture shows both sections of the beanch.

Similar industrial tests were conducted with the widely used coarse ammonite GDA-LM, which is allowed in underground blasting operations and is traditionally manufactured with a minus 1% OB, as well as with the modified GDA-LM with an OB of minus 7.5%. The industrial tests were conducted at the quarry of A&B Corporation, Klokotnica and at the open pit mine Republica, Pernik. Consistent with the results of the previous testing, the gas cloud at the detonation of GDA-LM with a minus 7.5% OB is considerably smaller and clearer then the one with the balanced GDA-LM, negative 1% OB. The gas cloud for the modified GDA-LM at the open mine was invisible.

Figure 4. Visual effect of the gas-dust clouds at detonation of ANFO-L. The section to the left has a zero % OB, the section to the right has minus 7 % OB.

Figure 5. Fragments of the developing blasting of ANFO-L, Studena quarry.

The industrial tests conducted completely confirm the lab tests and the accuracy of the new equation for chemical conversion at blasting.

6. CONCLUSIONS

Based on the performed studies of the correlation between the oxygen balance and the emission of toxic gases we can draw the following conclusions:

Because of the wide spread usage of coarse booster sensitive explosives for blasting operation at the larger mines, quarries and construction sites, it is imperative that steps are taken to reduce the harmful gas-dust emissions in the environment.

The current methods for measurement of gas emissions in small chambers utilizing small charges are unacceptable for the widely used booster sensitive explosives. The new methods in the EU and USA call for large 15m^3 chambers and charges between 500 and 5000g.

The discussed equations for the chemical explosive reaction are accurate for chemically pure compounds and partially for some blasting cap sensitive explosives and are not applicable to booster sensitive blasting agents.

Our studies have shown that the chemical explosive reaction produces large amounts of hydrocarbons, or free carbon and hydrogen, causing the creation of excess oxygen when explosives with zero or near zero oxygen balance are used. Consequently, an oxygen-balanced explosive becomes unbalanced and there is a release of large quantities of highly toxic orange nitric gases.

Analysis of the results of the studies conducted show that the nitric gases decrease over 2-2.5 times when the explosives have been modified from zero to minus 7-8% OB. This claim has been qualitatively confirmed in industrial conditions.

The results obtained have led us to develop a new equation for the chemical explosive reaction, taking into consideration the interaction between the elements and their liberation.

It is strongly recommended that all explosives approved for use, including the blasting cap sensitive explosives for underground conditions, are studied and modified to an optimal negative oxygen balance so that the toxic gas emissions and more specifically the nitric oxides are significantly reduced.

REFERENCES

Andreev, S.G, Baum F.A. Orlenko L.P. Blasting Physics. Third edition, pp125–132. Physamlit, 2002.

Baron V. L. and. Kantor V. Kh. 1989. Blasting Equipment And Technology in the United States. pp 24–25. Nedra M.

Bieganska J&Kwiatkowski Sl&Olek J An overview of modern explosives applied in mineral materials mining. Explosive magazine- SBIB, issue. 5, pp 12–15 S. 2007.

Dubnov, L.V., Bakharevich, N.S., & Romanov, A.I. (1988). Industrial Explosives, pp 26–40. Nedra M.

Consul Directive 93/15/EEC of 5 April 1993 on the harmonization of the provisions relating to the placing on the market and supervision of explosives for civil uses (OJ No L 121/20 of 1993-05-15).

Kamburova G. New research on the toxic gases emitted during blasting from chemical reactions according to the new requirements of the European Community European Federation of Explosives Engineers, World Conference on Explosives and Blasting, Brighton U.K.,pp 15-20. 2005.

Kamburova, G. New methods for detection of toxic gases emitted during chemical explosive reaction, Explosive magazine. SBIB, issue 1, pp 21–24 S. 2004.

Kamburova G&Mitkov V New examinations of the toxic gas emissions released during blasting of emulsion and Anfo explosives, Annual Conference on Explosives and Blasting, Slovakia, pp 43-51 .2006.

Lazarov, Sl.B. 1988. Blasting Operations, pp 51-67 – Texnica S.

EN 13631 – 16 .Explosives for civil uses - High explosives – Part 16: Detection and measurement of toxic gasesq CEN, B-1050 Brussels. 2002.

Rowland Y.H.& Mainiero R.Y. Factors affecting ANFO fumes Production. Proceedings of the 26th Annual Conference on Explosives and Blasting Technique (Anaheim, CA, Feb. 13-16, 2000). 1. Cleveland, OH: International Society of Explosives Engineers, pp. 163 – 174.

Rowland III J.H, Mainiero R.J, Hurd D.A (2001). Factors Affecting Fumes Production of an Emulsion and ANFO/Emulsion Blends. Proceedings of the 27th Annual Conference on Explosives and Blasting Technique (Orlando, FL, Jan. 28-31, 2001). Vol. 2. Cleveland, OH: International Society of Explosives Engineers.

Sapko M.J, Rowland III J.H, Mainiero R.J, Zlochower I.A (2002).Chemical and Physical Factors that Influence NOx Production During Blasting – Exploratory Study. Proceedings of the 28th Annual Conference on Explosives and Blasting Technique (Las Vegas, NV, Feb.10-13, 2002). Vol. 2.Cleveland, OH: International Society of Explosives Engineers, pp. 317-330.

Author index