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Comparison of Legislation on the Safe Utilisation of Explosives and its Application in some European Mines

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Abstract

Blasting operations form a central part of any hard rock metal mining operation and are, given its inherent hazards, critical in ensuring safe mine working environments. In order to improve workplace safety in such operations, it is important to select the right explosives and technologies, to issue rules and procedures and to offer adequate training. Because multinational mining companies work under different jurisdictions, they have to comply with different rules with different regulators. Given that the aim is to have no Lost Time Injuries (LTI's) at any operation within New Boliden, it is important to develop working practices that both comply with various legal requirements, are practically usable and lead to a safe working environment. The aim of the research is therefore to identify applicable legal requirements, technologies and working methods, in order to see if different working practices are compliant with these legal requirements, and whether these requirements and practices can help to meet the requirements of different regulators and Boliden's mission objectives.

This research has identified the legal requirements applying to mining operations in Sweden, Finland and Ireland, and compared working practices in several mines, operated by Boliden Mineral AB in these countries. With a comparable number of relevant legal sources, the legal structure on explosives safety requirements is generally similar. However, Nordic legislation puts more generic responsibilities on the employer, whereas Irish regulations are more specific. Blasting requirements in Finland and Sweden are mostly similar and apply to underground and surface mining operations and civil engineering, whereas Irish legislation is tailored specifically to underground mining operations. Significant differences can be seen when comparing explosives handling, in particular explosives storage, Ireland has a very different approach in this respect.

Technologies influencing the explosives handling and blasting safety performance are considered to be the initiation systems used, the reliability of explosives and successful implementation of a digital track&trace system. No events leading to human injury have occurred following the utilisation of explosive materials in Boliden Mines in the past ten years. Using both Boliden and international data, it was found that the main types of explosives- and blasting related incidents are misfires, flyrock, toxic fumes and early detonation. Fault Tree Analysis, adapted forms of reliability modelling and the bow-tie method have been used to identify critical parts of the explosives handling and blasting process. Critical activities are these surrounding evacuation of the blasting area, material failures and explosives materials being unguarded. Most incidents appear to be caused by failures in communication between different departments and insufficient awareness of safety procedures.

Considering that there is overlap between the various operations in terms of legal requirements and practices, it is judged to be useful to more closely align these practices, since learning from each other's practices might improve safety levels. Also, alignment of track&trace systems, and the adoption of electronic initiation systems are recommended. It is deemed less useful to align more national requirements and practices, such as permitting and licensing procedures. In order to exchange best practices, company-wide safety guidelines and reporting based on a clear distinction of responsibilities per activity are recommended. The main conclusion is that alignment of existing safety practices and technology use is achievable given the various legal and operational constraints and is expected to ensure a zero-LTI explosives handling and blasting safety performance.

Keywords Mining, Risk Engineering, Blasting, Safety, Health & Safety, Law, Regulations

Comparison of Legislation on the Safe Utilisation of Explosives and its Application in Boliden Mines

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II. Table of Contents

III. List of Figures

IV. List of Tables

V. Nomenclature

Abbreviations

Abbreviation	Description
ADR	Accord européen relatif au transport international de marchandises Dangereuse par Route European Agreement concerning the International Carriage of Dangerous Goods by Road
AFS	Arbetsmiljöverkets Författningssamling Swedish Work Environment Authority Law Collection
ANFO	Ammonium Nitrate Fuel Oil
AML	Arbetsmiljölagen Swedish Working Environment Act
AV	Arbetsmiljöverket Swedish Work Environment Authority
CLR	Comprehensive Legal Requirements (Own work)
EC	European Commission
ECJ	European Court of Justice
FTA	Fault Tree Analysis
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
HSA	Irish Health and Safety Authority
HSE	Health, Safety & Environment
IFC	International Finance Corporation
ILO	International Labour Organization
ISO	International Organization for Standardization
LTI	Lost Time Injury
MSB	Myndigheten för samhälsskyd och Beredskap Swedish Civil Contingencies Agency
MSHA	Mine Safety & Health Administration (United States of America)
PPE	Personal Protective Equipment
RBD	Reliability Block Diagram
RSAA	Regionalförvaltningsverket Regional State Administrative Agency (Finland)
RfSU	Rådet för sprängteknisk utbildning Council for blasting engineering education (Sweden)
SIS	Swedish Standards Institute
SOP	Standard Operating Procedure
UN	United Nations
US	United States of America

Glossary

Word	Meaning
Act	*See* Statute
Blasthole	Hole drilled in rock to be filled with explosive material
Blasting	To blow up rocks by explosion.
Blasting Agent	Substance that in order to transport, handle and store safely is separated from the other substance together with whom it forms an explosive material.
Blasting Cap	*See* Detonator
Case Law	Law introduced by the judicial branch of government.
Charge	Filled Blasthole.
Code	*See* Regulation
Convention	*See* Treaty
Deflagration	Subsonic form of combustion
Detonation	Supersonic form of combustion
Detonator	Component of an initiation system, used to turn a low-energy pulse into a detonation. Usually equipped with a delay.
Drillhole	*See* Blasthole
Explosion	Rapid expansion of matter into a volume much larger than the original.
Explosive	Material intended to quickly expand and release energy when initiated
High Explosive	Explosive with a detonation speed faster than the speed of sound.
Initiation	Commence a detonation
Jurisdiction	Practical authority granted to a legal body to administer justice within a defined area of responsibility.
Law	Set of rules and customs that have binding force in a certain jurisdiction.
Loading	*Either* putting blasted material in a truck *or* charging a blasthole with an emulsion
Low Explosive	Explosive with a detonation speed slower than the speed of sound.
Muck	Loose rock material, produced by blasting.
Nitrate	Agent in a blasting mixture that serves as the fuel for the explosive reaction.
Oxidiser	Agent in a blasting mixture that provides the oxygen component.
Primary Explosive	Explosive that is sensitive to detonators
Primer	*See* primary explosive
Pyrotechnics	Explosive material based on a burning process
Regulation	Law introduced by the executive branch of government. Usually more specified, but of lower legal weight, than a statute.
Round	Two or more shots fired in one operation.
Safety	Being protected against natural events or accidents
Secondary Explosive	Explosive that requires a primary explosive to detonate
Security	Being protected against intentional threats
Shot	Explosion of a single unit of explosives
Statute	Law introduced by the legislative branch of government, usually in collaboration with the executive branch.
Treaty	Binding international agreement between sovereign states.
Winze	(Usually small) vertical connection in a mine of small size without a winding system, when constructed upwards usually called a raise, when constructed downwards a sump.

VI. Preface and Acknowledgments

Over the past months, I have been working on this work, which gave me a great opportunity to further develop my skills in blasting practices, safety management and legal issues, and make a few very interesting site visits. I expect these experiences will be very helpful to me to further direct me in the right career direction. The research itself, at the crossing of these three different disciplines, made it a challenging topic to approach, but I hope the result will be of use to people involved in any of these three fields, and hope will contribute to safer mining operations in Europe.

Importantly, I would like to thank Malin Söderman for offering me the opportunities to do this work properly, including the very interesting and useful mine visits. Also, the large number of people, both managers and miners, that welcomed me at the various Boliden Mines to show me around, provide me with documents and answer my questions. I would also like to thank Mike Buxton for his critical comments that further helped me to direct my research and Marco Keersemaker, both for his supervision and suggestions to improve my work. Last but not least, I would like to thank my family and friends, who took the effort to review some of my proposals and writings, accompany me during breaks and in other ways helped to improve this work.

Ottomar Brussee

Delft, 12 December 2017

1. Introduction

This chapter will shortly discuss the utilisation of explosives in mining, and the relevance of explosives safety and legislation in this field. It defines the problem that will be analysed, followed by a definition of objectives and research questions.

1.1. Explosives Handling and Blasting Safety in Mining

Traditional extraction and development operations in hard rock mining use explosives to loosen and fragment rock masses. This technique is relatively cheap for the given environment, and the knowledge of and experience with explosive usage makes it a solidly proven method. Safety always remains a central concern however, given the extremely hazardous nature of the materials used.

Prevention of unwanted explosions is one of the major factors in the selection of an explosive, together with reliability when working in the physically challenging mining environment. Since explosives are in themselves a safety hazard, special care is necessary regarding storage, transport, charging and blasting itself. Explosives safety does also influence overall mining operations however, for example, areas where explosives are used may not be accessible for certain types of equipment or operations, and it is in some cases even necessary to evacuate an entire mine during blasting. For these reasons, safety measures around explosives utilisation play an important role in mining operations since these, partially determine the overall technical and economic performance of a mine, and the extent to which people working in a mine are exposed to workplace hazards.

Considering the major hazards involved in the storage, transportation and usage of explosives, public authorities are setting standards and overseeing its use to ensure safe working environments. As early as in the 19th century, when workplace safety law was still a rare phenomenon, workplace regulations where adopted around the world on various levels of government regarding mine safety, and explosives safety in particular (Karmis, 2001, p. 2). Nowadays, every stage in the utilisation of explosives is subject to safety policies and regulations. Both national and international legislators and mining authorities, and also private organisations, have developed extensive regulations and standards that aim to set safe standards explosive usage and blasting in mining.

1.2. Problem Analysis

The approaches taken regarding explosives safety vary per country, and may also vary from mine to mine. Given the many different sources of legislation, it may not always be clear what the legal requirements are, and when they apply and when not. This also raises the question to what extent safety standards overlap, and where they are different. It would be useful information, especially for companies operating in different (legal) environments such as Swedish miner Boliden Mineral AB, to get a better overview of these conditions, because this would make it easier to develop uniform policies and monitor compliance and possible incidents and other deviations at different mine sites.

Given that it is the aim of Boliden to have “zero accidents resulting in absence from work (LTI, Lost Time Injury) at all units by 2018” (New Boliden, 2017, p. 8) it is essential to ensure a very high level of workplace safety, compliant with all applicable safety requirements.

Subsequently the question is how these legal requirements can best be applied, learning from other jurisdictions and operations. Boliden already has internal policies issued by the Health, Safety and Environment (HSE)-department, but this one has only been based on Swedish legislation and practical conditions so far. Since Boliden is a multinational company, it would be practical to find out if different jurisdictions and operations have very different standards, or that they could be combined more easily.

1.3. Objectives and Research Questions

The objective of this thesis is to find out what is legally required of mining companies operating in Sweden, Finland and Ireland regarding explosives safety, in what way the different Boliden mines apply, and comply with, these requirements, and if it is possible to formulate a consistent blasting policy that applies to all the countries and mines that Boliden operates.

The main research question of this project is:

Is it possible to align multinational legal safety requirements on explosives and blasting and will this help to meet Boliden's safety mission objective?

In order to answer this main question, several sub-questions have to be answered:

Objective 1: Find out what legal requirements apply to explosives safety in Boliden mines.

Sub-research question 1.1: What law is applicable to mining operations in Sweden, Finland and Ireland regarding explosives safety?
Sub-research question 1.2: What do international and national regulations in Sweden, Finland and Ireland require regarding explosives safety in mines?
Sub-research question 1.3: Is it possible to align the explosives and blasting safety legislation of Sweden, Finland and Ireland?

Objective 2: Identify the main issues relevant to explosives safety in mining, the way in which Boliden mines take care of these issues and the complications that occur with this implementation.

Sub-research question 2.1: What are the key safety issues and prevention and mitigation measures and practices when storing, transporting and using explosives in mining?
Sub-research question 2.2: What rules, guidelines and practices does Boliden have regarding explosives safety?
Sub-research question 2.3: What are practical complications and incidents that pose a threat to the fulfilment of safety requirements?

Objective 3: Find a way to develop an explosives and blasting safety policy for Boliden mines of the highest standards compliant with legal and safety requirements and practical conditions.

Sub-research question 3.1: How can legal requirements, existing and recommended practices be aligned to ensure no LTI's occur in Boliden's blasting operations?

1.4. Methodology

First, a literature study is undertaken in order to understand the main safety issues surrounding usage of explosives in mining. The goal of this literature study is to identify the main types of explosives and detonation systems used in mining, and the associated safety hazards. Also, general data regarding explosive usage specifically used in Boliden will be gathered, in order to see in what environment and in what quantity the explosives are used.

Subsequently, a legal analysis is carried out to map applicable legislation and its requirements. The sources used for this research will be legal literature, specific legislation provided by government authorities and if necessary inquiries at relevant authorities. The objective of this study is to clearly define what the specific legal rights and obligations are for explosives usage and blasting in mining in the studied jurisdictions. The focus of this assessment will be to map whether the legal requirements in the different studied jurisdiction are the same, whether some may require higher or more precise standards or whether they even contradict each other.

In order to find out about the application of explosives safety in practice, staff overseeing safety and working with explosives in Boliden will be interviewed, and internal documents will be studied. This is done in order to get a good insight in the internal policies that have been defined already on a corporate level and by mines individually. The aim of this is to see what practices exist and whether these vary significantly from mine to mine.

Some of the mines considered will also be visited, and if this is not feasible longer interviews will be undertaken, in order to find out in greater detail what the practices in place are and to what extent this practical application is comparable with theory. Materials provided and experiences shared by professionals in the field of health & safety and blasting will be used to get a clear and detailed overview of the reality, and main difficulties surrounding compliance with the given legislation that face people working with explosives and blasting in mining, such as blasting engineers, chargers and other miners.

The results of this field research are then finally compared with the findings of the legal study, in order to answer the final research sub-questions and research main question. The goal of this part is to critically assess what the main challenges would be in the drafting and implementation of a company-wide internal explosives safety policy. See Figure 1 for a diagram of the research structure.

1.5. Outline

This work is divided in four main parts; the introductory part laying out the engineering and legal environment is the first part. This is also a useful part for people who are either not yet familiar with either

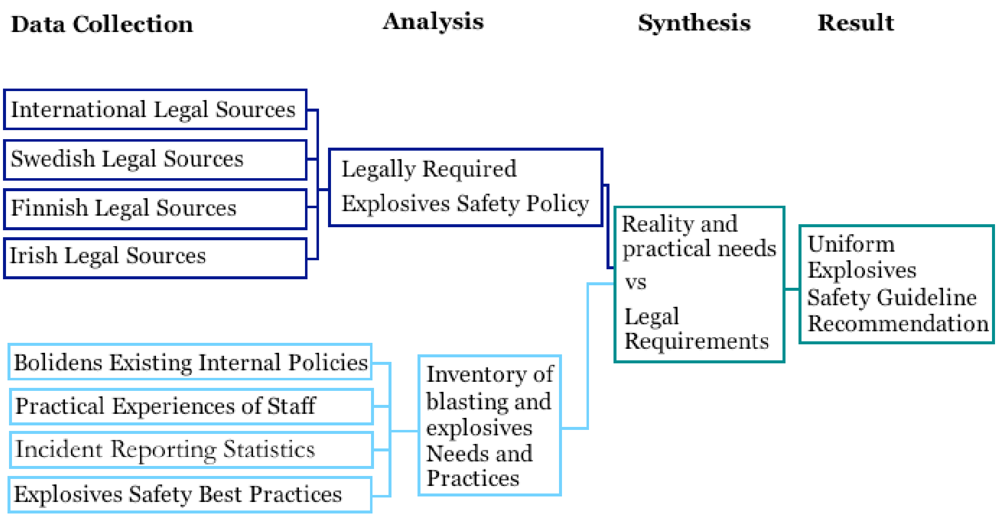


FIGURE 1: RESEARCH STRUCTURE

health and safety regulation or explosives- and blasting practices. Then, a detailed legal analysis, intended to clearly define the legal standards that apply to this topic follows. In the third part a study of the application of safety standards in practice composed of two chapters is discussed.
In the fourth, and final, part a synthesis with a comparison of legal requirements and existing mining safety practice is made. Suggestions on how to achieve a uniform explosives policy that is in accordance with the various legal requirements and practical implications concludes the research. This final part is composed of three chapters.

An overview of the specific chapters and their function in this thesis is given below; the first four chapters serve to introduce the reader to the respective topics, chapters 5-7 form the legal study and chapters 8-10 form the study of actual blasting techniques, practices and its complications. Chapter 11 combines the findings of the previous chapters, and chapter 12 gives the conclusion of the research.

1 Introduction
The current chapter; definition of the objective and scope of the research, definition of the research questions, the way in which the research will be structured.

2 Introduction to Explosives and Blasting
An overview of general explosives theory, commonly used explosives and detonation systems and the types of safety hazards that are associated with the usage of explosives in mining.

3 *Utilisation of Explosives in Boliden Mines*
General characteristics of explosives utilisation in Boliden Mines are given; the goal is to find out what the practical engineering environment of explosives utilisation in the studied mines is, to consider what legal requirements and practical conditions are relevant for the subsequent legal and practical assessments.

4 Regulatory Framework of Mining Safety
This chapter will provide an introduction to law and the legal framework regarding workplace safety in which mining companies operate in Sweden, Finland and Ireland.

5 Law Applicable to Explosives Safety in Mining
It is identified what the relevant sources of law applying to explosives- and blasting safety are for the three studied jurisdictions, and the extent to what they apply to the studied mines.

6 Comparison of Requirements on Explosives Safety per Stage
Outlining the specific legal requirements with regards to explosives- and blasting safety in the studied countries, on the basis of the different aspects in the process of the storage, internal transportation of explosives and blasting. Based on this outline, a comparison of the compatibility of these legal requirements can be made.

7 Recommended Explosives Safety Practices
Methods recommended and techniques available to ensure safe storage, handling and blasting of explosives are considered in the context of the mines studied, in order to make an assessment whether hazards can effectively be prevented and/or mitigated.

8 Application of Explosives Safety Policies in Boliden Mines
It will be determined what safety rules, guidelines and practices are in place in Boliden mines. It will be established whether and if so in what way the applied safety policies of the different mines differ, what the background of these differences is, and how they relate to the legal requirements.

9 Complications and Incidents
In order to find out if there are matters that deserve special attention, or would even require a completely different approach it is studied what matters typically cause problems, or even have led to incidents.

10 Suggestions for a Boliden Explosives Safety Policy
This chapter suggestions will be given on how explosives and blasting safety policies in the various mines can be improved, by both establishing the highest legal standard and learning from the various different practices.

11 Conclusion and Recommendations
Finally, the most important findings of this research will be presented in the final chapter. Comments on the research, recommendations to take and suggestions for further research will be given as well.

1.6. Scope and Limitations

Based on the objectives of this research and the questions that have to be answered, the quality and availability of sources and data, the main difficulties that were expected prior to the research and the time given, the boundaries of this work have been defined.

In general, working environment safety legislation and its application regarding explosives from the moment the explosives enter the mine site to the moment right after blasting is discussed. The research includes the following topics:

- Working environment hazards associated with explosives usage.
- International law applicable to explosives safety.
- National legislation applicable to explosives safety.
- Agreements between mining authorities and researched mines on explosives safety requirements.
- Inventory of explosives and related materials used by Boliden.
- Internal policies of Boliden regarding explosives safety.
- Application of explosives safety policies by Boliden staff.
- Compliance of explosives safety policies and practice with relevant law.
- Best practices used to ensure safe explosive utilisation.

This research does not address:

- Legislation regarding acquisition of explosives and transportation to the mine site.
- Environmental law regarding explosives usage.
- Explosives safety legislation applicable to non-mining purposes.
- Ventilation and air quality requirements following blasting.
- Private law regarding liability for damage and injury due to explosives use.
- Fields of working environment legislation that do not apply to explosives safety.
- Legislation and practice regarding explosives and techniques that are not used by Boliden mines.
- Blasting performance optimization insofar not directly affecting safety levels.
- Drilling processes prior to blasting, unless it directly affects the blasting process.
- Legal comparison with mines not part of Boliden.
- Economic analysis of various blasting methods.
- Safety issues that may be an issue for people involved with explosives handling and blasting activities but are not particular to these operations.

2. Introduction to Explosives and Explosives Safety

In order to familiarize the reader of this research with some of the underlying physical and chemical characteristics of explosives and the terminology used, this chapter gives a brief overview of the main aspects of explosives theory. The most important aim of this is to provide definitions of the terminology used, since this can have important consequences for both legal requirements and its practical application. Definitions given in this chapter will be consistently used throughout the whole research, even if different terminology is used locally in practices or legislation, in order to ensure consistency. Also, general approaches to deal with explosives in a safe manner are discussed, in order to give a short background of the regulations in the next chapter.

2.1. General Theory and Use of Explosives

An explosive is a substance that tends to explode under certain condition. An "explosion" is "The action or an act of bursting or flying into pieces with extreme violence and noise; ..." (Brown, 1993), or "any rapid expansion of matter into a volume much larger than the original" (Persson, et al., 1994). In a mining context, the purpose is to get rock masses, that are otherwise hard to loosen and extract, to be "flying into pieces" so that they can be excavated and possibly processed. An “explosive” is “any chemical compound, mixture, or device, the primary objective of which is to function by explosion” (Hopler, 1998, p. 742). The activity of using explosives to fragment rock for extraction purposes is called "blasting", the verb in this context literally means "to blow up (rocks etc.) by explosion; ..." (Brown, 1993). As such, the handling of explosives to blast rock lies at the heart of any hard rock mining operation.

In order for an explosion to occur, it is necessary that energy is released at a very high rate, leading to the expansion of gases and usually a loud bang. An explosion can be caused by many different sources, and also occurs incidentally in nature. Examples of various kinds of explosions include nuclear explosions, caused by the splitting of unstable atoms in atomic bombs; physical explosions such as sudden phase changes from water to vapour, as for example occurs with the outburst from a steam boiler; or chemical explosions, such as the sudden explosion of kerosene (a fossil fuel) after a plane crash. It is noteworthy that in all cases it is also possible to have a similar energy release process, where the air also expands, but at a slower rate. Examples would be nuclear electricity production, the regular functioning of a steam engine and the slow burning of coal respectively. The difference is speed of the energy release, which can make the process uncontrollable. From a safety perspective, it is clear that in two of the three examples explosions are undesired by the operator. In the mining context however, explosions are desired, but only at a specific time and location, and with certain precisely described expected results. Also, mining explosives used are always of the chemical explosion category, which means that there will always be a reaction between different elements that cause the sudden energy release.

Explosives will be "charged" into boreholes that have been drilled in the rock to be blasted. For safety reasons, this charge will require a detonator and primer to explode. The detonator turns a relatively low energy pulse into a detonation. A primer then bridges the gap between the detonator and insensitive explosives used for the charge. The process of inserting the detonator and primer into the blasthole is referred to as “priming”. A single explosion is called a "shot". Usually, more than one shot is fired in an operation, this is called a blasting round. There are four main effects of blasting in a mining context (Tamrock, 1999), rock fragmentation, rock displacement, ground vibration and an air blast. For mining

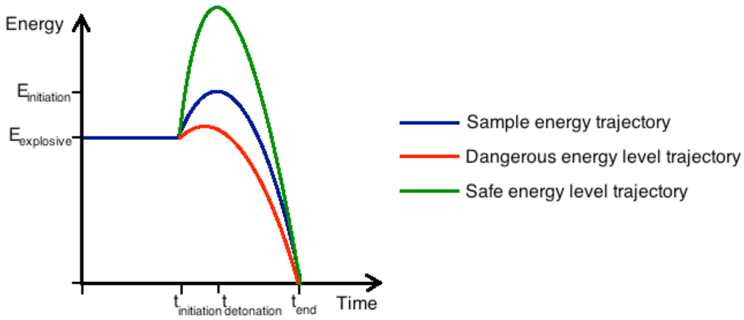


FIGURE 2: CHARACTERISTICS OF SAFE EXPLOSIVES

purposes the selection of explosives therefore primarily depends on its effectiveness in blasting rock, but also on practical considerations such as its workability in wet environments and, perhaps most importantly, safety requirements. The main parameters that determine the impact, safety and usability of an explosive in mining are its effective energy, velocity of detonation, detonation pressure, sensitivity and water resistance (Tamrock, 1999).

2.2. Types of Explosives and Initiation Methods

Whereas traditionally gunpowder was used for this purpose, more advanced and safer explosives have been developed over the years, such as dynamite, Ammonium Nitrate Fuel Oil (ANFO) and other slurries and emulsions. In this part, the various ways to classify different types of explosives are discussed. This classification intends to give a quick look on the advantages, disadvantages and typical risks associated with the types of explosive materials discussed.

2.2.1. "Low" vs "High" Explosives

A main distinction between types of explosives can be made between "low" and "high" explosives. Low explosives are explosives of which the blast wave travels slower than the speed of sound. This process is called deflagration, which compares to a regular burning process. The most famous example of this type of explosive is gunpowder. High explosives are explosives of which the shock wave, which is defined as a blast wave moving faster than the speed of sound (Anderson, 1984), in the medium from ignition travels faster than the speed of sound. This process is called "detonation". Examples of these type of explosives are dynamite, TNT and the emulsions used commonly in mining nowadays.

When a wave travels at exactly the speed of sound, a so-called "sonic boom" will occur, since the sound waves that have been released at times t_1 to t_6 will all reach the same point at the same time as the actual shock wave causing the sound waves. The best-known example of this phenomenon are airplanes breaking the sound barrier. See Figure 3. The reason that high explosives have a sharper bang, distinct from low explosives, is this sonic effect. It is important to distinguish the different waves associated with the detonation of high explosives; Apart from the shock wave, the blast wave in general and the sound wave there is the detonation wave, which is the wave throughout the explosive medium itself. In Chapter 7 the importance of an understanding of the interference of different waves will be discussed in further detail.

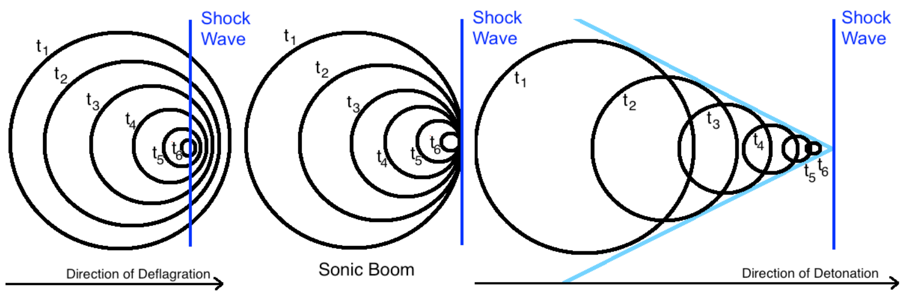


FIGURE 3: DEFLAGRATION VS DETONATION

2.2.2. Categories of Explosives

The three main categories that are therefore distinguished are propellants, which are materials used to propel bullets and rockets, pyrotechnics, which are primarily used in various forms of fireworks and other artistic uses and high explosives, the main category of interest for mining purposes. See Figure 4. The legal classification of explosives is discussed in Chapter 5. Another distinction is made between civil and military explosives; each explosive material has a certain “expiry date”, because of the components reacting to states of lower energy. Since military explosives are used in smaller quantities, but generally need to be stored much longer and may involve more difficult and different sorts of logistics and working conditions they will generally have much longer half-life’s and much more expensive. Composite explosives are therefore the main field of interest for mining purposes.

Depending on the requirements at a given mine site, different explosives are commonly used. The most commonly used explosives nowadays are ANFO, slurries and emulsions. Given more difficult conditions,

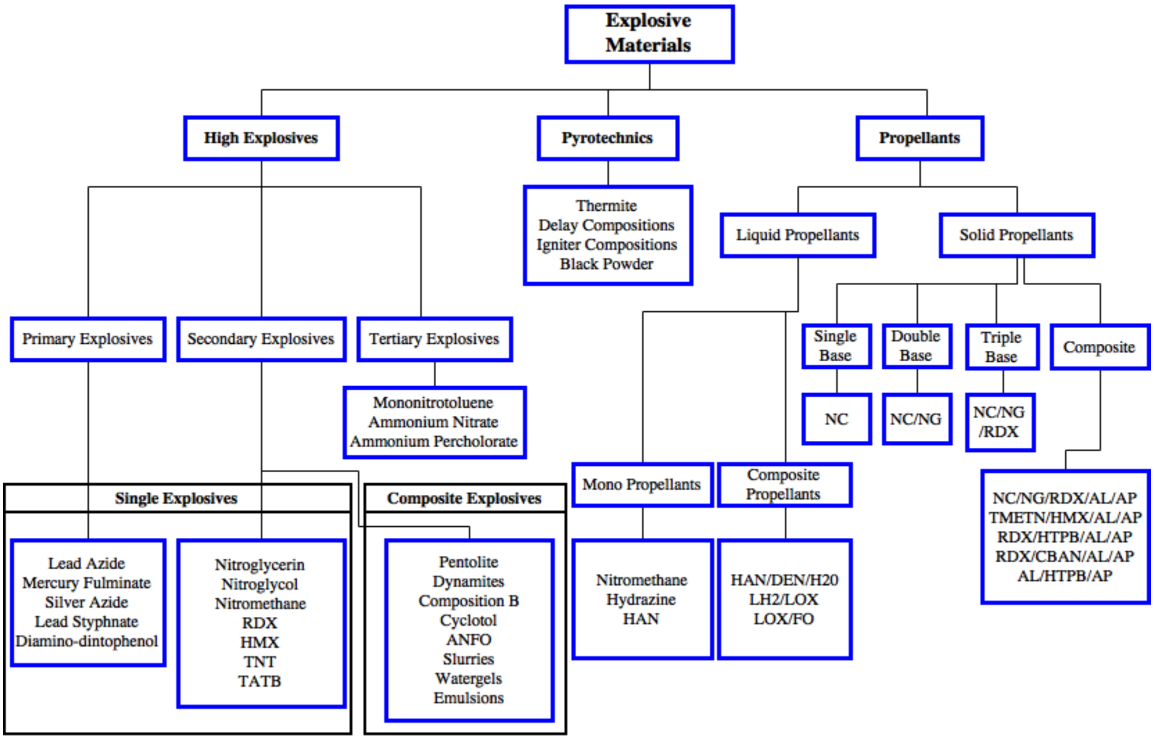


FIGURE 4: CATEGORISATION OF EXPLOSIVES

the use of emulsions has increased (Tamrock, 1999). Emulsions consist of two components, a super-saturated oxidiser solution component, which is dispersed in an oil phase. A gaseous component is mixed with this liquid, on a micro-droplet scale. The small droplets ensure close physical connection, which leads to a high velocity of detonation. It is inherently safe, since the mixing is carried out just before charging (or loading, as it is referred to in this report, to avoid confusion with the charging process in general), this makes the emulsion harmless until that point. Also, mixing just prior to loading allows for adjustment of the density of the emulsion and thereby power of the blast, by varying the amount and type of gassing agents added, ensuring that blast designs can be executed more precisely (Zhao, et al., 2000, p. 121).

2.2.3. Initiation of Explosives

Initiation system consist of several parts; the blasting machine sending out the electrical signal or pulse; the wire or cord, which connects the blasting machine to the detonator, and the detonator or cap, which initiates the actual detonation (Jimeno, et al., 1987, p. 123). Various different systems of combinations of wires and detonators exist, each with their own advantages and disadvantages. For the purpose of this research, three types of detonators are judged to be most relevant; electrical-, NONEL- and electronic detonators. As seen in Figure 5, there are fundamental differences in the way the initiation is turned into detonation. To the left is a section view of an electrical detonator, then section views of a NONEL-detonator and to the right an example of an electronic detonator is given. The initiation is carried by an electric pulse in the case of electrical detonators, by a detonation in the cord in the case of NONEL-detonators and by a digital signal in the case of electronic detonators. Electrical- and NONEL-detonators both have powder to ensure the required delay, whereas electronic detonators use digital delays. Therefore electronic detonators have significantly smaller delay time deviations. Their advantages and disadvantages are listed in Table 1 (Persson, et al., 1994, p. 171). Since the initiation methods to a great extent influence workability and safety performance this topic will be discussed more detailed in Chapter 7.

TABLE 1: ADVANTAGES AND DISADVANTAGES OF DETONATOR TYPES

	Electrical	NONEL	Electronic
Risk for unwanted detonation	--	+	+
Fragmentation	-	-	++
Check prior to blast	+	-	+
Costs	+	+	--

2.3. Topics in Explosives Utilisation Safety in Mining

The ultimate goal of this research, by means of the legal requirements in place and technologies and methods available, is to improve explosives handling and blasting safety. To this extent, it seems useful to have a more functional approach, which can later be used to compare both the legal requirements and practices of the different stages in the blasting process, and the inherent risks.

2.3.1. Safety Risks

The hazard of using explosives in a mining operation leads to various risks. Three main risk types are unintended detonation, detonation failure and unintended damage following blasting. There can be many different root causes to these problems; since each chain is as strong as the weakest link, all these possible roots will have to be addressed. Therefore, a structure will be outlined; a more specific outline with possible causes for safety risks per blasting stage has been given below.

2.3.2. Structure of Topics

In order to ensure safe working with explosives, different aspects of explosives utilisation need to be taken into account. For the purpose of this research, a classification has been made, based on the structure of applicable legislation and the underlying theory on explosives safety. The purpose of this classification is to make it possible to compare the various legal safety requirements among themselves and their applications

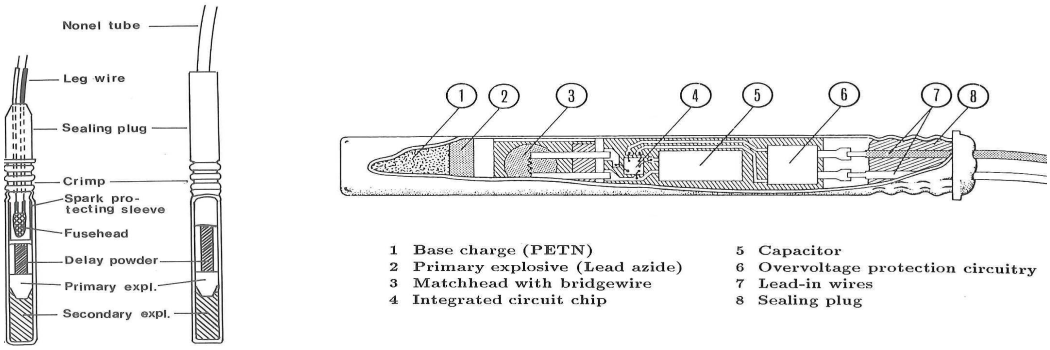


FIGURE 5: DETONATOR TYPES (PERSSON, ET

in practice in a structured manner, and also to serve as a basis for the definition of a uniform safety policy in such a way that it is easy to understand what rule is relevant to which person. The following categories have been defined:

- Responsible Persons
  Since it is in the end the people working with explosives and related topics that determine the safety of the operation there are certain requirements on these people, in terms of their qualifications and experience. Other people, such as the employer or governmental authorities, can have certain requirements they should meet as well. The assignment of responsibilities should also be very clear.

- Explosives Standards
  Explosives safety starts with the characteristics of an explosive; this is primarily the responsibility of the manufacturer, but since a mining company has to work with the product it is important to be aware what the characteristics of a utilised explosive are, and what standards are to be followed. This includes markings and traceability of explosives, to avoid confusion.

- Storage
  Hazards of unintended ignition during storage should be dealt with in a responsible way. Furthermore, knowing how much and what type of explosive materials are stored is important, given capacity restraints and security risks of theft. In general, unauthorised access is to be avoided.

- Transportation
  Moving the explosives into the mine and through the mine poses a safety hazard, given the risk for accidents, contact with other hazardous materials or loss of materials.

- Charging

  For the purpose of this report charging is defined as the stage between the materials having been delivered to the blast site until the moment the charge is ready for initiation. Irresponsible charging methods may cause unintended ignition. More importantly, the quality of charging determines the quality, and thereby safety, of the blast. Also, charging may occur simultaneously as for example drilling or loading, and this also requires extra care.

- Blasting

  Blasting for the purpose of this report is defined as the stage from connection of the initiation system to initiation and detonation. During the blast rock will be flying around, the main concern is therefore to protect people and equipment and keep them away from the blast, or cover them.

- Post-blasting

  The post-blasting stage primarily applies to people who are responsible for checking a blasted rock mass just after the blast. Safety concerns here are the hazards of misfires, unstable rock masses, including an assessment of the need for rock reinforcement, toxic or otherwise damaging blast gases and loading hazards insofar related to misfires. Carrying out this professionally is important to ensure that subsequent tasks in the mining process, such as loading, hauling, crushing and drilling can be carried out safely without, or with the smallest possible, risks of misfires.

2.4. Conclusion

In this chapter, an introduction to the theory of explosives and blasting techniques was discussed, in order to familiarise the reader with some core concepts on explosive materials and rock blasting. The reader has also been introduced to the terminology that will be used throughout this report. Furthermore, a brief overview has been given of safety risks associated with explosives utilisation. The three main risks that have been discussed are unintended detonation, detonation failure and unintended damage following blasting.

Most importantly, following the introduction to explosives utilisation, this chapter has outlined the structure that will be followed in the rest of this research. The following topic-classification will be used throughout this research in order to compare both relevant legislation and practice:

- Responsible Persons
- Explosives Standards
- Storage
- Transportation
- Charging
- Blasting
- Post-blasting

For each of these categories some typical risks have been named, for which regulations and practices have been put in place to prevent them from becoming reality. It is now possible to zoom in on Boliden's mining operations and their explosives utilisation.

3. Utilisation of Explosives in Boliden Mines

Prior to the more in-depth research, data around the mines studied and the explosives and blasting procedures they have, have been assembled. The purpose of this is to see to what extent the different mines are similar in size, type of deposit mined and commodities produced. Also, it is important to know the mining method, explosives and blasting procedures used in order to see if the techniques used make a more uniform policy feasible. This will help a more guided research in the subsequent chapters, and introduces the reader to the general characteristics of the mines operated by Boliden.

3.1. Mines operated by Boliden

Following a gold rush in 1924, the area around Boliden developed into a thriving mining area. Over the years, the company that was founded following this gold rush expanded, and developed to the company it is nowadays, with an annual turnover of approximately SEK 40 billion (~EUR 4.2 billion) and 5500 employees, headquartered in Stockholm. Apart from several smelters, Boliden currently operates 6 different mines in Sweden, Finland and Ireland, making it one of the major metal producers in Europe. Exploration rights have been acquired for the traditional Outokumpu mining area, Finland, in 2014 and Boliden also continues to undertake exploratory activities in Sweden (Boliden, 2017).

FIGURE 6: MINES CURRENTLY OPERATED BY BOLIDEN

Currently, individual mines operate to a large extent independently, which means they can develop their own policies, including explosives safety policies. However, central policies and techniques are developed as well. The central mining office, intended to support the individual mining operations with for example technological challenges, research and development and HSE-matters is located in the Boliden area (New Boliden, 2017). See Figure 6 for the location and names of the mines that are currently operated by Boliden.

3.1.1. Boliden in Sweden

Being the home of Boliden, Swedish mining operations still form the backbone of Bolidens operations. Note that the Boliden Area "mine" extracts resources from the Skellefteå-field, and currently consists of three smaller underground mines, Renström, Kristineberg and Kankberg, and two small open-pit mines near Maurliden. General data on the three Swedish mining operations are given in Table 2 (New Boliden, 2017). Underground mines have a yellow instead of blue background.

Table 2: Boliden Mines in Sweden

Mine	Aitik	Boliden Area	Garpenberg
Mining Technique	Open Pit, 20-meter bench blasting	Sublevel stoping using backfill	Sublevel stoping, backfilling
Commodities Mined	Copper, Silver, Gold	Zinc, Copper, Lead, Gold, Silver, Tellurium	Zinc, Copper, Lead, Gold, Silver
Ore Production (kT/a)	36,361	2,139	2,622
Number of Employees	647	580	430
Year Established	1968	1925	357BC/1957
Mining Depth (m)	450	140-1445	1250

3.1.2. Boliden in Finland and Ireland

Recent expansions of Boliden operations were primarily in Finland, and further expansions in Finland may be ahead; Tara mine in Ireland is the biggest zinc mine in Europe and the 9th biggest zinc mine in the world, and was acquired by Boliden in 2004. General data on the Finnish and Irish mining operations are given in Table 3 (New Boliden, 2017).

Table 3: Boliden Mines in Finland and Ireland

Mine	Kevitsa (Finland)	Kylylahti (Finland)	Tara (Ireland)
Mining Technique	Open Pit, 12-meter bench blasting	Sublevel stoping using backfill	Stope & Pillar, drift & slash technique
Commodities Mined	Copper, Nickel, Gold, Platinum, Palladium	Copper, Gold, Zinc	Zinc and Lead
Ore Production (kT/a)	6,700	2932	2197
Number of Employees	380	114	586
Year Established	2012	2012	1977
Mining Depth (m)	500	600	1000

3.2. Type and Quantity of Materials used

Considering that all of Boliden's mining operations work in a hard-rock environment, all mines use drill & blasting techniques for both development and ore extraction. As seen previously, production rates between the mines differ, and this is also translated in different blasting techniques and sizes applied. In this part, a quick-scan is made to identify the different materials used in the blasting process.

3.2.1. Materials Used

In the Boliden area, Kankberg has been taken as an example of a typical operation. The other mines in this area are also relatively small underground mines, under supervision from Bolidens central office. It turns out that the materials used are fairly similar, even though there are of course differences in practices between the size of operations. There are no major differences in material usage.

Table 4: Materials Used in Sweden

Mine	Aitik	Kankberg	Garpenberg
Secondary Explosives	Emulsions	Emulsions	Emulsions
Special charges	Pre-blasting: Riogur		
Primers	1,7kg booster	X-pipe 25g	X-pipe 15 mm, SLP-primer, 1 kg booster
Ignition Systems	NONEL, 1000ms delay	Firex electronic detonators, Austin Indetshock, riocord 5g fuses	NONEL, electronic detonaters, 5g, powder fuses
# primers/blasthole	2	1	1
# detonators/blasthole	2	1	1
Emulsion supplied by	Forcit	Forcit	Forcit
Blastholes ø (mm)	311	45	45-65

Table 5: Materials Used in Finland and Ireland

Mine	Kevitsa (Finland)	Kylylahti (Finland)	Tara (Ireland)
Secondary Explosives	Senatel, Presplit with Maxam 45mm packaged product	-Kemiitti 810 (~90%) -ANFO (~10%)	Emulsion+gas agent, use Non-L primed
Special charges	Powder chords, electrical detonators	Pipecharges for smooth walls/wet conditions	Powder chords, cartridges
Primers	500g & 1000g Fortis Extra emulsion	Forprime	Rio primers
Ignition Systems	NONEL detonators and surface delays	Millisecond non-electronic and electronic detonators	Bunch connectors-primer chord, Electric detonators
# primers/blasthole	2	1	1
# detonators/blasthole	2	1	1
Emulsionsupplied by	Orica	Forcit	Orica,
Blastholes ø (mm)	165-225	45	45 (dev) 65 (prod)
Blastholes depth (m)	24		5 (dev), 20 (prod)
Stemming height (m)	3.5-4.5	-	-

3.3. Blasting Procedures

In this part, the general explosives handling and blasting procedure is laid down. The goal is to see if the different types and sizes of mining operations also translate into different working practices.

3.3.1. Blasting Procedure in Sweden

All mines have developed their own blasting safety policies according to Swedish safety legislation, usually in coordination with Boliden's central office.

Table 6: Blasting Practice in Sweden

Mine	Aitik	Kankberg	Garpenberg
Frequency of blasting	1-2 times per week	Daily at 1am	Daily at 4.05 am and 4.05 pm
Evacuation procedure (people)	-600m (staff involved) -1200m (other)	Entire mine is evacuated until 6 am	Entire mine is evacuated
Evacuation procedure (equipment)	-300m (heavy equipment) -600m (light equipment)	Protected Area	Protected Area
Storage of explosives	All systems are stored in a certified storage on site	Certified underground storage	3 certified underground storages
Total number of people involved in regular charging activities	12	4	48
People involved per shift	3	1-2	24

3.3.2. Blasting Procedure in Finland and Ireland

Kevitsa and Kylylahti have both developed their own safety policies independently, over the course of the life of mine. In the case of Kylylahti this is a mixture of Australian, Finnish and Swedish mine safety cultures, and within the requirements of Finnish legislation. Tara Mine has a safety policy based on (implementations of) European law and specific Irish regulations, together with SOP's (Standard Operating Procedures) developed on site, given their long time of operations.

TABLE 7: BLASTING PROCEDURE IN FINLAND AND IRELAND

Mine	Kevitsa (Finland)	Kylylahti (Finland)	Tara (Ireland)
Frequency of blasting	1-3 times per week	Daily	2 times daily
Evacuation procedure (people)	Entire pit is evacuated	Entire mine is evacuated	Entire mine is evacuated
Evacuation procedure (equipment)	Minimal 300 meters	Protected Area	Protected Area
Storage of explosives	-Steel containers modified according to Finnish legislation for packaged products and detonators -Insulated and heated storage tanks for emulsions	Dedicated storages are mined out, or in after-use tunnels	Dedicated storage with restricted access, reserve station
Total number of people involved in blasting	13	10	66
People involved per shift	2	2	22

3.4. Comparison of Operations

Although the commodities produced vary somewhat from mine to mine, all mines are operating in hard rock environments mining for base metals and incidentally gold and other high-value byproducts. The materials used for regular operations are also similar; emulsions are used as the main explosive in all operations, detonated either by NONEL-system (still the majority) or electronic initiation systems. Main suppliers are in Sweden always Forcit, outside Sweden Orica has a larger role. There are three main distinctions to be made in terms of the mines studied, in terms of the size of operations, but also in terms of the types of blasting practices and for example evacuation procedures;

- Large Surface Mines: Aitik, Kevitsa
- Large Underground Mines: Tara, Garpenberg
- Small Underground Mines: Kankberg, Kylylahti
-

This distinction may influence the practices studied; for now, all mining operations will be assessed according to the same standards however, because in general the materials used make similar safety measures seem reasonable.

3.5. Conclusion

Boliden currently operates three different open pit mines (in Finland and Sweden) and six underground mines (in Sweden, Finland and Ireland). It has been found that there are significant differences in terms of size, but that materials used are similar. A distinction can be made between large surface mines, large underground mines and small underground mines, a distinction that sometimes can be of importance in the Part 3 of this research. Now the factual characteristics of the operations studied have been identified, the legal landscape in which these mines operate can be studied.

4. Regulatory Framework of Mining Safety

The purpose of this chapter is to identify the sources of law and authorities that have jurisdiction over mining operations, in order to define the legal and regulatory framework under which the considered mines have to work. Basic legal concepts are also explained, in order to provide clear definitions for the subsequent chapters. An overview of the abbreviations and definitions used can also be found on page x.

4.1. Sources and Types of Relevant Law

In order to know what applicable legislation is with regards to a certain topic, it is necessary to know what the sources are that determine what the law is. Law can have various sources; the various sources that can apply to workplace safety are considered below.

4.1.1. International Treaties

Generally international law relies significantly on international custom and soft law. The most important source of hard binding law are treaties. Treaties exist between two or more countries, and oblige the parties to conform to a certain agreement, they can loosely be compared to a contract. In the context of workplace safety, international treaties can serve as the basis for worker's protection rights. International treaties are generally hard to enforce globally, but also need to be taken into account by national courts and authorities when they bind states and offer rights to individuals within their jurisdiction (Janis, 2003, p. 9).

The most important other source of international law is customary international law; this implies that long maintained practices between states hold legal power. Most other sources of international law are considered to be "soft law". This means that they tend to be more generic and hard or even impossible to enforce. Soft law can however be taken into account as a guideline in court cases where the law is unclear (Janis, 2003, p. 52). Companies and governments violating soft law may also come under attack from NGO's and the press.

4.1.2. Directives and Standards Issued by International Organisations

When countries are party to a certain international organization, such as the United Nations, European Union or International Labour Organization (ILO), this will generally mean they also give certain (usually very limited) law-making powers to these organizations, so they can develop consistent legislation in their field for their members. For the context of this research, the most important organisations will presumably be the European Union and the ILO. Sweden, Finland and Ireland are all a member of both the EU and the ILO.

The EU, and more specifically the European Commission, frequently issues so-called directives. These directives need some form of implementation in all EU-member states, either by the introduction of independent statutes that require the same as the directive or by accepting direct legal effect of EU-directives in the national constitution, but since all states have different legal systems the resulting law can look slightly different per member state (Obradovic & Lavranos, 2007). In the context of mining safety, directives can be issued in the fields of worker's rights/labour law and product standards (Watson, 2014).

4.1.3. (International) Industry Standards

Not all law needs to be public by nature; specific industry sectors may voluntarily draft their own standards that apply to companies in their field. This can be done in order to ensure fair competition, to take into account the needs of the wider public in the form of Corporate Social Responsibility (CSR) agreements, or because it may simply be more effective to exchange certain practices.

4.1.4. National Statutes and Acts

The central source of national law in countries with a civil law-tradition, such as Sweden and Finland, are statutes and acts. These lay out the foundations of regulation in a certain sphere of interest. Enactment of statutes requires that the legislative branch of a government, for example parliament, writes the law, and that the executive branch signs it into law (Black, 1990). The more common name in Anglo-Saxon countries for this source of law is an Act, in Ireland formally called the Act of the Oireachtas after the Irish' name of the parliament. Since both the legislative and executive branch of government are involved in this type of law it generally holds the highest value, but will usually also be relatively generic.

This source of law, together with regulations, is probably the most important source of law however, since governments usually consider workplace safety such an important topic to oversee that a binding and relatively detailed body of law is introduced and maintained (Smith & Thomas, 2003, p. 866).

4.1.5. National Regulations, Codes and Mine-Specific Standards

Since statutes and acts tend to offer room for discretion, executive government bodies tend to draft more specific legislation. Examples of this are the many sector- and topic-specific regulations that are drafted with regards to workplace safety by working environment authorities, that form part of ministries of economy and labour. Also, local government bodies may have the opportunity to issue specific regulations and codes. The aim of these regulations is always to be sure that the worker is well protected, and therefore usually comes accompanied with close oversight (Smith & Thomas, 2003).

Government authorities, specifically Mine Authorities, may make specific arrangements with mines depending on their specific conditions and needs. Generally, these standards will form part of the permitting procedure.

4.1.6. Case Law

The primary source of law in the common-law tradition, which is the tradition of law that is dominant in Anglo-Saxon countries such as the United Kingdom, Canada and Ireland, is case law. Case law relies on legal precedent and, in this way, ensures legal certainty over time. Cases dealt with by lower courts generally hold a lower legal value, but cases settled by supreme legal bodies such as national supreme courts need to be considered in order to obtain clarification on the law. Case law also serves as a clarification of law in countries with a civil law tradition, when statutes, acts and regulations leave legal specifics open for debate. Traditionally this field of law is the most important in Ireland. It should be noted however that over the years, following the influence of the introduction of a body of workplace safety statutes and regulations and the emergence of European law, the importance of case law in the field of health & safety law has significantly decreased (Smith & Thomas, 2003, p. 868).

4.1.7. What is the law?

The question what the law exactly requires with regard to a specific topic can be a complicated one to answer, especially when different sources may give different outcomes. There is however a hierarchy in law; if a country has signed up to a treaty, legislation that would go against the requirements of this treaty would generally be held to be void. Similarly, statutes rank above regulations, since they have a more solid democratic backing and have generally been considered more thoroughly. Sources of soft law, private industry initiatives and sometimes even foreign legislation can also help to clear uncertainties on a specific legal question, but only when this is not contrary to more "hard" law. Parallel to this, the higher-ranking sources of law tend to be much more generic. Regulations, but also case law, will provide answers to more specific questions, and will therefore form the bulk of relevant legislation in many specific legal questions. See Figure 7 for the general legal structure of types of law considered.

To be consistent with this general legal structure, this research will follow this pattern as well; first the more generic international and statutory legal requirements will set the general framework for the legal assessment, followed by a more detailed analysis based on specific regulations and industry standards. Also, considering that the goal of this research is to compare different legislations, foreign legislation will be taken into account insofar it could help to form a uniform legal approach.

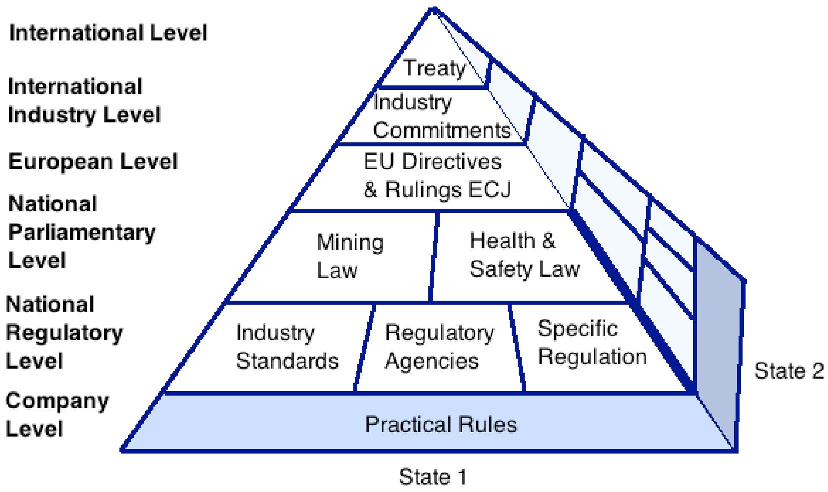


FIGURE 7: LEGISLATION PYRAMID

4.2. Relevant Authorities

Below an overview is given of the governmental authorities that have been identified that can introduce legislation regarding explosives safety in mining and oversee these.

4.2.1. International

The main international organisation in the world is the United Nations (UN). In a mining context, its primary activities deal with environmental matters, human rights and public health. One subsidiary, the International Labour Organization (ILO) is the most important organisation. Its aim is to protect workers globally, especially those working in hazardous conditions such as miners. Another important, private, international institution is the International Standards Organization (ISO), issuing industry standards around the world and via its national partners.

Furthermore, the EU is the main authority in Sweden, Finland and Ireland that deals with economic matters. It therefore regulates matters related to explosive materials and equipment standards. The European Court of Justice (ECJ) can settle disputes between EU member states when there are conflicts regarding EU-law. Individuals and companies can however also report a suspected violation of EU-law to the European Commission, which in turn can start a case against the member state responsible for the violation. As such, the ECJ and the European Commission can be considered as the enforcers of compliance with European safety standards, in case the member states would fail to do so, and can undertake inspections if necessary (Obradovic & Lavranos, 2007, p. 27).

4.2.2. Sweden

The Swedish Civil Contingencies Agency (Myndigheten för samhällsskydd och Beredskap, MSB) is responsible for public safety, when it is not covered by other institutions, and as part of this deals with issues around hazardous materials, such as explosive materials (MSB, 2017). This includes activities around acquisition, storage, transport and preparation of explosives.

The most important authority regulating and overseeing workplace health and safety in Sweden is the Swedish Work Environment Authority (Arbetsmiljöverket, AV). The difference with the MSB is that the MSB focusses on the dangerous goods themselves and serves the general public interest, whereas the AV aims to protect workers and oversees any type of working place.

Swedish Standards Institute (SIS) is the national standardisation body of Sweden. It is a member of the International Organization for Standardization (ISO) and such also implements worldwide ISO-standards (ISO, 2017).

SveMin is the main industry organization for the Swedish mining industry. Its goal is to serve the interests of Swedish mining, but also sets out internal standards for mining activities in Sweden, also in the field of Health, Safety and Environment (HSE). It does not regulate issues related to explosives- and blasting safety however (SveMin, 2017).

Municipalities where the mine is located need to give permission for certain activities, such as transportation and storage within their borders.

4.2.3. Finland

In Finland, the Ministry of Social Affairs and Health is responsible for occupational safety, including the developing of applicable legislation. It works together with the Ministry of Employment and Economy and other relevant ministries (European Agency for Safety and Health at Work, 2017). The governmental body responsible for executing this task is the Finnish Work Environment Protection Agency (Tyosuojelu /Arbetarskyddsförvaltningen).

The Regional State Administrative Agency, RSAA(Aluehallintovirasto/Regionalförvaltningsverket) administers various issues in Finland that are related to mining, such as occupational health and safety topics, environmental permits and rescue services and preparedness (RSAA, 2015). It issues blasting licenses, and do this in accordance with the requirements of the Work Environment Protection Law 44/2006 (§28 3.6.2016/423).

The Finnish Safety and Chemicals Agency (Tukes/Säkerhets- och kemikalieverket) carries out oversight on sites handling and storing hazardous chemicals, such as explosives, and issues for example permits for explosives transfers (Tukes, 2017).

4.2.4. Ireland

In Ireland, the most important authority dealing with workplace safety is the Health and Safety Authority (HSA). This body was set up in 1989 under the Safety, Health and Welfare at Work Act, 1989. The HSA has the duty to ensure workplace safety standards for all people working in Ireland, and does this by issuing regulations for specific sectors and surveillance. It also regulates the production, transport and use of chemicals and explosives. The HSA reports to the Minister for Jobs, Enterprise and Innovation (Health and Safety Authority, 2017).

Local authorities have to deal with permit requests for the storage and handling of explosives (§7 Stores for Explosives Order 2007).

Importantly, the Mine Inspector carries out close supervisions of mining activities, in particular in regards to explosives safety. The Mine Inspector does so under authority of the Mines and Quarries Act 1965.

4.3. Conclusion

In this chapter, the main types of sources of law have been identified. It has been found that the most important sources of law for the topic of workplace safety are national statutes and acts and regulations, since national governments have prioritised this in order to ensure worker's safety, but many other types of law from many different levels need to be considered as well, in order to lay down the legal framework of explosives and blasting safety. The main bodies introducing specific legislation and inspecting and overseeing explosive utilisation in mining have been identified as well. It is therefore now possible to commence finding out what law exists that applies to explosives safety in mining in the three countries.

5. Law applicable to Explosives Safety

This section lists legal documents that have been judged to be of (possible) relevance to the legal framework surrounding explosives safety in mining, including a short description of its source and scope. It also outlines the general duties that mining companies have in the discussed jurisdictions, and its legal basis.

5.1. International and European Law

The main treaty worked out by the ILO in the field of mine workplace safety is the Safety and Health in Mines Convention, 1995 (No. 176) which has been ratified by Sweden, Finland and Ireland (ILO, 2016). Article 2(1) states that the convention applies to all mines, which, following Article 1(1), includes both underground and surface mines. The main purpose of the convention is to put requirements on the employer to guarantee safety and worker's right of people working in a mine. As an addition to this convention, R183 - Safety and Health in Mines Recommendation, 1995 (No. 183) has been adopted as well. The preamble of this Recommendation states that the purpose of this document is to add training advice supplementing the Convention. It should be noted that this is a recommendation, and therefore should be treated as soft law.

The Environmental, Health & Safety Guidelines for Mining (December 10, 2007, World Bank Group) issue a general guideline on explosives handling and blasting safety. The guideline has been issued by the International Finance Corporation (IFC), which is an international organisation resorting under the World Bank, which is part of the UN. The IFC aims to advice and set global standards and code of conducts for governments and private institutions such as banks, not necessarily mining companies (IFC, 2017). However, since members to the IFC are required to only finance mining projects that comply with these standards, IFC and World Bank standards can therefore indirectly apply to mining companies as well. Guidelines by international organisations can generally be qualified as soft law.

Directive 2014/28/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market and supervision of explosives for civil uses (Directive 2014/28/EU) is the main European source of law with regards to regulation of the explosives market. It is intended specifically for civil uses, not including fireworks (Article 1). It is primarily intended for manufacturers and transportation, but impacts actual operations as well since it sets health and safety standards for the actual explosives. Also, it is common that explosives manufacturers also have a role in the storage- and usage phase at a mine site, and can sometimes even carry out most of this work. Considering it is European law it therefore applies to all three studied countries. Connected to this main directive are various harmonised standards, which will however not be discussed in greater detail, since it is the responsibility of the supplier to ensure conformity.

Commission Directive 2008/43 EC, setting up, pursuant to Council Directive 93/15/EEC, a system for the identification and traceability of explosives for civil uses, lays down requirements regarding the identification and traceability of explosive materials. Its application to explosives used in mining follows Article 1. It does however not apply to explosives transported in pump trucks for their unloading into a blast-hole, and explosives manufactured at blasting sites that are loaded immediately (Article 2).

The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) aims to provide a worldwide standard for various chemicals, including explosives, and rules and techniques to decide in what category a certain chemical substance falls. Chapter 2.1 in ST/SG/AC.10/30/Rev.4 outlines the various classifications of explosive materials (United Nations, 2011). In this report, this classification is also referred to as the "UN Classification System". The system has been applied in the latest version of the United Nations Convention Accord européen relatif au transport international de marchandises Dangereuses par Route/European Agreement concerning the International Carriage of Dangerous Goods by Road (UNECE, 2015), in this report referred to in this report as “ADR”. This Convention, issued under the umbrella of the UNECE, which is the European zone of the UN, which includes Europe, Russia, Turkey and countries in Central Asia (UNECE, 2017), regulates transport of hazardous materials, including explosives, on the road.

5.2. Swedish Law

The main law that applies to workplace safety in Sweden is the Swedish Working Environment Act (Arbetsmiljölagen, SFS 1977:1160). It sets out the general duties on employers and employees with regards to the working environment. The act has been adopted in 1977, but revised several times since then. Whereas working environment legislation initially only dealt with physical safety, the act now also regulates mental well-being. The general purpose of this law is to oblige the employer to take responsibility, and to oblige him to undertake a "systematic" approach towards working environment safety.

The main document regarding mining workplace safety can be found in the Swedish Mining Work Regulation (Berg- och gruvarbete, AFS 2010:1). This document stipulates general safety rules around workplace safety in rock excavation works and mines, including two sections related to blasting activities. It aims to avoid accidents in mining work environment, and it applies to any working activity in any mine, both surface and underground, following §1 and 2.

The main document outlining the requirements around working with explosives in Sweden can be found in the Swedish Work Environment Authority regulations and general advice around blasting activities (Sprängarbete, AFS 2007:1). An update has been issued in 2014, AFS 2014:1, this update has been implemented in AFS 2007:1. Article 1 states that the regulation applies to all works where explosives, gunpowder, detonators or gas-generating compositions are being used, except for military applications. This document is specifically developed for blasting activities on site, and covers all types of explosive utilisation and blasting activities, including those in rock excavation and mining. Article 2 defines the employer, who is the main responsible party to apply this law. A more extensive guidance is added, further elaborating on most requirements. This is intended as a recommendation, and will be used to this extent in this research as well.

The Swedish law on flammable and explosive Goods (Lag om brandfarliga och explosiva varor 2010:1011) is a statute outlining general requirements for flammable and explosives goods. It outlines general definitions, oversight and permitting requirements. On top of this, the MSB has issued the Regulations on handling of explosive goods (Föreskrifter om hantering av explosiva varor", MSFB 2016:3). In this regulation, standards with regards to explosives handling and storage are outlined. It applies to any explosives except for explosives used for military purposes or weaponry following §1 to 4. It is an implementation of Directive 2014/28/EU.

The Swedish law on transport of dangerous goods (Lag om transport av Farligt Gods, 2006:263) deals with the transportation, unloading and handling of explosive materials in industrial areas, underground and on public roads, following §3 and §5. Its applicability however stops when the materials have reached the final area where they will be utilised, following §3. In this context, its applicability is therefore limited to transportation into the mine.

The Swedish Work Environment Authority regulations and general advice around working in explosive sensitive environments (Explosionsfarlig miljö, AFS 2003:3), does not apply to mining safety, following section 1. Also, the Swedish Mining Act (Minerallagen, 1991:45) does not contain requirements related to explosives, blasting or workplace safety, and is therefore not considered relevant to this research.

5.3. Finnish Law

The main document outlining obligations and rights with regards to mining activities in Finland is outlined in the Finnish Mining Act (Kaivoslaki/Gruvlagen, 10.6.2011/621). In it, the rights and duties of investors in mining in Finland are laid down, including in Chapter 12 the "Regulations pertaining to mining safety permits".

The State Council Order on Mining (Valtioneuvoston asetus kaivostoiminnasta/Statsrådets förordning om gruvdrift, 28.6.2012/391) lays down provisions on mineral exploration and the acquisition of a mining permit, and can be considered as a further elaboration on the Finnish Mining Act. Apart from a general requirement on the procedure of requesting a mine safety permit (§20), as required by the Finnish Mining Act, it does not specify mine safety requirements in the field of explosives and blasting safety.

The main document with regard to explosives safety in the working environment in Finland is the State Council Order on Blasting and Extraction Safety (Valtioneuvoston asetus räjäytys- ja louhintatyön/Statsrådets förordning om säkerheten vid sprängnings- och brytningsarbeten, 16.6.16.6.2011/644). It applies to blasting and rock extraction activities, and should be read together with law on the manufacturing and storage of explosives, and is a way to further elaborate on the duties of care of the employer in this field (§1).

A more detailed document laying out requirements on people having responsibility in blasting activities is laid out in the Charger's Law (Panostajalaki/Lag om laddare, 3.6.3.6.2016/423). §1 states that this document regulates the "charger's rights and duties, conditions to issue, renew and withdraw blasting licenses for chargers and the duration of the license" (§1, Charger's Law, 3.6.2016/423). §1 also explicitly excludes blasting licenses for police, emergency services and the military.

The Finnish Statute on safety with handling of dangerous chemicals and explosive goods (Laki vaarallisten kemikaalien ja räjähteiden käsittelyn turvallisuudesta/Lag om säkerhet vid hantering av farliga kemikalier och explosiva varor, 3.6.2005/390) is applicable to explosive standards, manufacture, import, use, transport, storage and destruction of these explosive goods (§2(2)).

A further elaboration on this statute can be found in the State Council Order on Safety of manufacturing, handling and storage of explosive materials (Valtioneuvoston asetus räjähteiden valmistuksen, käsittelyn ja varastoinnin turvallisuusvaatimuksista/Statsrådet förordning om säkerhetskraven vid tillverkning, hantering och upplagring av explosiva varor, 20.8.2015/1101). It applies to safety requirements manufacturing, handling, storage and destruction of explosive materials, and storage of emulsions in mobile aggregates to manufacture explosive materials.

Connected to this law is the State Council Order on the guarding of production and storage of explosive goods (Valtioneuvoston asetus räjähteiden valmistuksen ja varastoinnin valvonnasta/Statsrådets förordning om övervakning av tillverkningen och upplagringen av explosiva varor, 25.6.2015/819), laying down more specifications in the field of explosives storage. It applies to the manufacturing, storage and destruction of explosive goods as mentioned in the Finnish Statute on safety with handling of dangerous chemicals and explosive goods (§1). It does however not apply to the manufacturing and usage of explosive goods at the working place for immediate use for the part that is covered by State Council Order on Blasting and Extraction Safety. It does therefore apply to contractors and suppliers that produce and store explosives to supply mines, but not to mining operations and short-term storage sites at mine sites.

The State Council Order on Explosive Goods Compliance with Requirements (Valtioneuvoston asetus räjähteiden vaatimustenmukaisuudesta/Statsrådets förordning om explosiva varors överensstämmelse med kraven, 21.12.2016/1440) is closely connected to EC Directive 2014/28/EU, and applies to explosives used for civil purposes (§1). It does not apply to powder fuses and other non-detonating fuses, or to small detonators used as propellants (§2). The main aim of the document is to set standards to explosives goods, and can be considered as an implementation of EC Directive 2014/28. It is therefore sufficient to notice that Finland has effectively implemented this Directive by allowing its direct functioning by means of this Regulation, and that its main aim is to regulate manufacturers of explosive materials.

The Finnish Law on the transport of dangerous goods (Laki vaarallisten aineiden kuljetuksesta/Lag om transport av farliga ämnen, 2.8.1994/719) is comparable in scope to the Swedish Lag 2006:263. Its goal is to prevent and avoid damage and risks in the transport of dangerous goods, and applies to transport on the road, railway, airplanes in Finland (§2(1,2,3)), but not transports of less than 45-meter distance, but also to packaging, tanks and vehicles for the transport of dangerous goods (§2(3)). It is an implementation of several European standards.

The Finnish Worker's Protection Act (Työturvallisuuslaki/Arbetarskyddslag, 23.8.2002/738) is the main source of law regarding general workplace safety. Its aim is to improve the working environment and employment relations in order to prevent and avoid accidents at work, diseases or other matters that harms workers (§1), and it applies to any type of regular employment relationship (§2).

5.4. Irish Law

General Irish workplace regulation is outlined in the Safety, Health and Welfare at Work Act, 2005. Its aim is to ensure a safe working environment in any type of Irish working place, and it applies to both employers (§8) and employees (§13).

The Mines and Quarries Act 1965 is the main piece of law regarding mining activities in Ireland. It is applicable to mining activities, with "Mine" being

"an excavation or system of excavations made for the purpose of, or in connection with, the getting, wholly or substantially by means involving the employment of persons below ground, of minerals (whether in their natural state or in solution or suspension) or products of minerals." (Section 3)

Since Tara mine is an underground mine the articles insofar relevant to mines are therefore applicable to Tara mine.

S.I. No. 123/1972 - Mines (Explosives) Regulations, 1972, does apply to underground mining in the Republic of Ireland. It aims to provide detailed regulation regarding the storage, handling and usage of explosives in mine sites in Ireland. Article 4 states: "These Regulations shall apply to every mine." The regulation is drafted as a more specific detailed addition to the previously mentioned Mines and Quarries Act 1965.

The Guidance on the Safe Use of Explosives in Quarries (Doc. No 1396/2/01 EN) gives detailed information regarding explosives usage and blasting in a mining environment. However, the Guidelines to the Safety, Health and Welfare at Work (Quarries) Regulations 2008, that also provide regulations on explosives utilisation in mining environments, state in Section 3(2)a that "quarry" does not include a "mine within the meaning of section 3 of the Mines and Quarries act 1965". This regulation is therefore not applicable to Tara Mine, but since it is a much more recent piece of legislation it could provide a general impression of more recent approaches in the regulatory environment of explosives and blasting and environment.

S.I. No. 423/2016 - European Union (Making Available on the Market and Supervision of Explosives for Civil Uses) Regulations 2016, stipulate the requirements on explosives and manufacturers and transporters of explosives. It is an implementation of EC Directive 2014/28, required to make the directive directly functioning under Irish law, but contains the exact same requirements in terms of content as the EC Directive. Differences can be found in for example the rules on legal procedure (Section 2) and different legal terminology. It will therefore not be worked out in detail in the next chapter, it should however be remembered that in Ireland it is this document, and not the EC Directive, that gives the requirements in the directive force of law.

S.I. No. 133/2009 - European Communities (System For the Identification and Traceability of Explosives For Civil Uses) Regulations 2009 is the Irish implementation of Directive 2008/43 EC. Its requirements are therefore the same as in this directive.

The Explosives Act 1875 is the main document in Irish law elaborating on requirements on manufacturers and users of explosives. It contains some provisions applicable to the preparation and storage of explosives on a mine site. Since the Act is from 1875, it was issued by the British government who at that time still was the government in charge in Ireland, it should therefore be noted that references to British authorities nowadays instead refer to Irish authorities.

S.I. No. 804/2007 - Stores for Explosives Order is a regulation that further works out details regarding the storage of explosives. The regulation follows the UN-classification of explosives, following §4, and aims to elaborate on the more general requirements following from the Explosives Act 1875 (preamble).

5.5. Health and Safety Requirements in Mining

The starting point with regards to workplace safety are statutes and acts drafted by national governments that impose general liabilities on employers to ensure that their employees are safe and stay in good health. The following paragraphs outline the general requirements with regards to mining working environments in Sweden, Finland and Ireland that form the foundation of more specific explosives safety legislation outlined in Appendix IX.A.

Since Swedish is an official government language in Finland and all Finnish legislation therefore has to be published in Swedish, this work will always use the Swedish version. In practice Finnish is the language spoken in Finnish mining environments.

5.5.1. Safety and Health in Mines Convention and Recommendation

The two ILO-documents regarding mine work safety, the C176 - Safety and Health in Mines Convention, 1995 (No. 176) and the R183 - Safety and Health in Mines Recommendation, 1995 (No. 183). C176 Safety and Health in Mines Convention 1995, since it is a treaty and therefore meant to bind states and not individuals, contain a general duty on states to introduce appropriate laws and regulations, possibly supplemented by technical standards, and an authority to oversee compliance with these laws (Article 4, 5(1)). However, these requirements on state will into indirect requirements on private parties. The most important requirements are given below:

Article 6 requires the employer to assess the risk and deal with it in this order:

a) eliminate
b) control at source
c) minimize by means that include the design of safe work systems
d) if there still is a risk, provide the use of personal protective equipment

Article 7(e) requires the monitoring, assessment and regular inspection of the working environment to identify hazards. In respect of zones susceptible to particular hazards, operating plans should be drawn up and implemented to ensure safe workings. Article 7(i) requires that operations are stopped when there is a serious danger to the health of workers.

Article 10 requires workers to be trained in an understandable manner, at no cost to them. It is also required to report all accidents and dangerous occurrences.

In the Safety and Health Recommendation, 1995 it is again stated that employers should undertake hazard assessment and risk analysis, and following this, develop and implement, and if necessary systems to manage the risk (§12). §17 requires that employers prohibit persons from carrying underground any object that could initiate a fire, explosion or dangerous occurrence. Special attention should be paid to, among others, flammable, toxic, noxious and other mine gases, fumes and hazardous substances, noise and vibration when estimating hazards (§20(b, c, g)).

5.5.2. Swedish Working Environment Act

The most relevant general requirements related to this topic are the following. First of all, it is emphasised that both the employer and the employee are responsible for a good working environment (Section 1a Chapter 3, Arbetsmiljölagen, SFS 1977:1160). Section 2 requires that the employer takes any measures necessary to prevent harm. The starting point of any safety approach should take as a starting point that the hazard be eliminated or replaced. Special care is required when people have to work alone. Proper maintenance of workplaces and equipment is also required. It is the responsibility of the employer to plan, lead and oversee the activities of the employee and to take necessary action in case hazardous situations or risks are discovered. The employer shall keep a written documentation regarding these activities (Section 2, 2a Chapter 3, Arbetsmiljölagen, SFS 1977:1160). Section 3 demands that the employer ensures that employees are well-qualified to do their job, informed about the risks involved and not allow people to work if they are not qualified instructed properly. It is also necessary that an employer reports any lethal or severe accident in his workplace, without outside pressures (Section 3a Chapter 3, Arbetsmiljölagen, SFS 1977:1160). Chapter 4 outlines the opportunities of the government or relevant governmental authorities to outline specific guidelines, require medical checks, increase oversight or even stop activities that are expected to cause harm to workers. Chapter 7 specifically assigns oversight tasks to the Swedish Work Environment Authority (Arbetsmiljöverket).

5.5.3. Swedish Mining Work Safety Regulation

Swedish Working Environment Regulations and General Advice on Rock- and Mining Works Arbetsmiljöverkets föreskrifter och allmänna råd om berg- och gruvarbete, AFS 2010:1) contains two relevant general safety requirements with regards to mining companies. Section 3 requires companies that want to start a mining operation to undertake a written comprehensive risk assessment plan including all aspects relevant for the mining operation, before actual operations can begin. Section 6 requires any people working in the mining operation to have knowledge of all relevant traffic and work safety rules before they can start working in the mining operation. §5 requires that also time-planning is done such that all work can be carried out carefully and safely.

5.5.4. Swedish Statute on Flammable and Explosive Goods

In Lag 2010:1011, §7 it is demanded that anyone who has obtained a permit to work with explosives is required to undertake risk assessments on the possible impacts on workers' safety and health, environment and third parties.

5.5.5. Finnish Mining Act

The Finnish Mining Act (Gruvlagen, 621/2011) contains general safety requirements for mining companies. §112 states that the "mining operator is obliged to ensure mining safety", by the prevention of dangerous situations and accidents, alongside with limitation of the consequences thereof. This means that elements of danger and threats of accident need to be identified, subsequently eliminated, or if that is not possible limited. Measures need to be implemented to prevent accidents. (§113(1)(2)(3), 621/2011).

Importantly, §113(4), 621/2011 states that "generally effective measures" need to be implemented prior to individual ones. Also, the development of technology needs to be taken into account when implementing safety measures (§113(5), 621/2011). It is necessary to undertake a *systematic* identification of elements endangering mine safety, in order to eliminate them. If it is not possible to eliminate these elements, their significance shall be assessed. This assessment is to be written down, kept and kept up to date, and changed fundamentally when necessary (§114, 621/2011).

In general, all employees shall be trained and instructed on mine safety (§117, 621/2011). The mining operator shall assign a person that is in charge of mining safety. This person shall be employed by the mine and be present at the mine site. This person shall be competent with regards to mining regulations and measures necessary for mine safety, and ensure compliance with these requirements. This competence shall be tested by the mining authority (§118, 621/2011). The issuance and extension, or alteration, of a mining safety permit necessary to operate a mine relies on compliance with these safety requirements (§121, 122, 124 621/2011). According to section 125, the permit will contain measures required to implement mining safety, training, guidance and instruction of the person in charge and other key person in mining safety, among other things.

5.5.6. Finnish Worker's Protection Act

The first issue that is important to notice in the Finnish Worker's Protection Act is that this law applies to both regular workers as well as "hired work" (contractors) in the same way (§3). The consequence of this is that work safety requirements should be exactly the same for "own" staff as well as contractors. It also requires that it is the responsibility of the employer/contracting party to provide clear requirements on competency of the hired worker, and to provide clear instructions on the task, and subsequently assure that the worker/contractor fulfils these requirements and understands his task and responsibilities. The law also applies to for example students and/or interns working at the employer's site (§4). General duties of the employer are to take the measures to ensure the safety and health of the worker at his job. These duties exclude matters that lie beyond the control of the employer or are unavoidable. The employer shall plan, choose, dimension and execute the measures that are necessary to improve working conditions. The following principles shall be used in this regard:

- The occurrence of risks and accidents shall be prevented.
- Risks and accidents shall be removed, when this is not possible replaced with something less dangerous or damaging.
- General worker's protection measures shall be prioritised over individual measures.
- The development of technology and other methods shall be taken into account.

The employer shall ensure that all these measures are applied everywhere in the organisation (§8). The employer shall have operational programs in place to ensure workplace safety and develop them together with employees (§9), and identify and judge risks in the work taking into account personal characteristics of the people involved (such as the typical types of accidents, age and gender of the employee, the workload etc.). If the employer lacks specific knowledge he shall hire external parties (§10). If the work to be carried out has a special risk it shall only be carried out by competent people that are suitable for the job (§11). It is the responsibility of the employer to provide the employee with sufficient information on the risks of the job, and it is the duty of employees to contribute to a safe working environment (§17). Several more requirements that are applicable to mining work, such as night shifts, lighting of the workplace, ventilation and working space are included in this act as well, but judged outside the scope of this research.

5.5.7. Irish Safety, Health & Welfare at Work Act

The most important requirements following the Irish Safety, Health and Welfare at Work Act 2005 are discussed here. Article 8 of the Safety, Health and Welfare at Work Act 2005 states in paragraph 1 that "Every employer shall ensure, so far as is reasonably practicable, the safety, health and welfare at work of his or her employees.". It subsequently elaborates how this is to be done in the subsequent paragraphs; work activities have to be managed and conducted to ensure health and safety and prevent improper conduct putting safety and health at risk. The employer should also provide and maintain systems to be used that are safe and healthy. He is also required to train and oversee employees in order to ensure their safety. If hazards cannot be prevented, suitable protective clothing and equipment needs to be provided, see §8(2)(i). There is also a duty to provide information on their safety and working methods in an understandable manner, including the hazards identified, the measures to be taken and the names of the people responsible for safety (§9). This information in any case always needs to be provided prior to the start of any employee's commencement of the working contract. The subsequent articles further work out the requirements on understandable preparations and trainings. Section 19 requires employers to identify the hazards in the place of work and the risks presented by those hazards. Then he has to assess these hazards, and in doing this, he has to take into account the duties imposed by the relevant provisions. On the basis of this assessment the employer shall take steps to implement any improvement considered to be necessary, and ensure that this improvement is implemented at work. This three-stage approach (identify risk, assess risk, take protective and preventive measures) is to be followed for any significant hazard.

5.5.8. Irish Mines and Quarries Act

Sections 12 and 13 of the Mines and Quarries Act 1965 stipulate that it is the responsibility of the owner of a mine and on his behalf the Mine Manager to ensure compliance with relevant safety law. The owner is the person that has obtained the right to exploit a certain mining license (section 4). If the person working the mine is a contractor this person is assumed to be the owner (section 4(2)). It is therefore essential to comply with all relevant mining safety requirements in order to obtain and maintain a mining permit, and it is the responsibility of the Mine Manager to practically ensure this.

5.6. Duty of Care

The most important finding of the previous subchapter is that mining activities and the working with explosives in all three jurisdictions have a consistent approach in dealing with workplace hazards, namely to actively identify hazards, prevent risks, or if this is not possible, to mitigate them. More broadly speaking, employers have a duty of care towards their employees, meaning that negligence in taking effective safety measures imply a breach of the law, even though no specific law has been broken.

In common law, this concept was established in *Donoghue v Stephenson* [1932] UK House of Lords 100 as a general concept, being part of the duties towards "one's neighbour". In Ireland, this approach has been followed in *Ward v McMaster, Louth Co. Council and Nicholas Hardy & Co. Ltd.* [1985] IR 29. The Irish Supreme Court held in this case that a duty of care arises from 1) the proximity of the parties, and 2) the foreseeability of the damage. This should be balanced against "absence of any compelling exemption based on public policy", but it is unreasonable to assume that any public policy arguments could be used by mining companies in this regard. It is good to know that this does not mean that an employer will always be held liable, as was the case in *Industrial Chemical Industries Ltd v Shatwell* [1965] AC 656, where two shotfirers were injured during their blasting work in a quarry because they themselves had not taken the necessary precautions. Given that employers and employees always work closely together and damage is reasonably foreseeable in mining operations, it therefore is reasonable to assume there is always an active duty on the employer to identify any sort of workplace risk and deal with this.

The duty of care traditionally is part of private law on liability (Lunney & Oliphant, 2013), and therefore not the scope of this research. It is however a concept closely connected to this scope, since it lays down a duty on the employer, in that it requires employers to not just not breach existing specific regulations, but also act pro-actively in regards to workplace safety. Measures such as systematic risk identification would fit in this category. The duty of care is a principle developed in common law, but similar duties exist in civil law countries. In civil law countries, this duty is expressed by statutory law and interpretations case law, in the case of Sweden and Finland this is called the "omsorgsplikt", and is mentioned in e.g. §8 of the Finnish Worker's Protection Act and is expressed in §2 of the Swedish Working Environment Act.

This concept, together with the specific regulations discussed in the previous subchapter, means that the legal duties of mining operators in the field of explosives safety always extend well beyond the specific regulations, but should also actively identify issues that are reasonably foreseeable to cause damage to people or for example contractors, and develop methods to deal with them.

5.7. Concluding Remarks

There are a few international documents applicable to mining workplace safety and explosives safety in particular. These documents have different backgrounds, and scopes of application, since they stem from a global public international organization, a European public organization and a global private organization. In relation to national legislation, it turns out that all three studied countries have a similar set of legal sources applying to explosives safety in mining, the backbone of which are general work environment safety statutes, added by specific regulations regarding working in mining. All three countries have specific regulations regarding working with explosives in mining environments. In addition, some more specific documents related to explosives and transportation standards have been identified.

It turns out that all the three studied jurisdictions regard mine safety and the responsibility of employers to ensure a safe working environment as an essential prerequisite for any form of commercial operation. A lack of knowledge of safety requirements, and subsequent failure of employers to ensure safe working environments can potentially lead to the withdrawal of mining permits under all three jurisdictions. An important aspect of all three jurisdictions is that they maintain that it is the duty of employers to identify and deal with workplace hazards. These hazards include those are not discussed in specific regulations, and also the mitigation measures suggested in the regulations may not be sufficient.

Furthermore, it is important to recognise that all three jurisdictions require employers to implement their safety measures in a manner that is understandable to and executable by all employees. This implementation includes the duty to provide information and training on these working place hazards and mitigation measures.

It is therefore necessary to establish what the exact legal requirements are, and if Boliden does comply with these. This will be done in the following chapter. Subsequently, it will need to be assessed what other rules should be introduced to ensure a safe working environment.

6. Comparison of Applicable Legislation

This chapter will discuss the contents of the applicable legislation discussed in the previous chapter, reviewing both international and national legal sources. The aim is to compare the various legal requirements, in order to assess whether it is possible to align these requirements and combine them to achieve the highest standards. The detailed comparison and the resulting Combined Legal Requirements (CLR) can be found in Appendices and IX.B.

6.1. Approach

In order to find out what the specific legal requirements are, all relevant laws and regulations have been studied, and assembled in Appendix IX.A. Colours have been used to highlight how the different regulations can be compared. See Table 8 for a legend of the colours used for the different specific requirements.

TABLE 8: LEGEND OF COMPARISON OF SAFETY REQUIREMENTS

Contradicting Requirement	Lacking Requirement	Similar Base Requirement	Similar Requirements, but Additional/Stricter	Different Requirement

Based on this comparison, it will be considered in the next chapter to what extent the requirements of the different legislations can be aligned. For this purpose, the first column of the tables will be coloured, based on a judgment of the extent to which the different safety requirements can be aligned. See Table 9.

TABLE 9: LEGEND OF INTEGRAL REQUIREMENT ASSESSMENT

Requirements can be copied one on one.	Requirements are different but could be combined.	Requirements are different and may be impractical to combine.	Different legislations need different rules.

The next subchapter comments on some of the main issues that should be noted when reading this outline of legal requirements. Subchapter 6.3 discusses in further detail the main differences and possible overlap of these requirements. The result of this study and comparison is outlined in the Comparative Legal Requirements, that can be found in Appendix I.IX.B.

6.2. Content of Legal Requirements

An outline and detailed comparison of all legal requirements can be found in Appendix Appendix IX.A. Below, a brief overview of the key requirements is given.

6.2.1. Comments on International and European Legal Requirements

The international documents that were judged to be relevant to this research have very different backgrounds, and also have different fields of application. It should be remembered that normally these international requirements should have been implemented by the respective states, with the exception of the IFC-guidelines, which are applicable to financial institutions instead of states. There is a clear difference in implementation procedures between the different states, with Ireland working with "indirect implementation", meaning that a specific act implementing the Directive requirements is necessary, whereas the Scandinavian countries appear to (partially) rely directly on European standards. For the actual practice this does not matter however, and it is therefore not discussed further. Given that the European standards on explosives standards, road transport and track&trace systems are the same, they also do not require extensive further comparison.

A central recommendation in the explosives management practices formulated by the IFC is that the utilisation, handling, and transporting explosives should always be in accordance with local and national explosives safety regulations (Environmental, Health, and Safety Guidelines Mining, December 10, 2007 16 World Bank Group).

In the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), explosives are ranked according to the hazard they pose, with explosive materials in category 1.1 posing the greatest hazard, and those in 1.6 the smallest. See Appendix IX.K for a full overview of the different classes of explosive materials, and the associated signs. This categorisation forms the basis for the legal requirements related to the storage, transportation and handling of explosives. The signs assigned to the different categories (see for example Figure 8) are to be used on packaging and vehicles transporting the materials, following the requirements of the ADR. Together with this risk-based classification, there is an associated classification based on the type of explosive material. The classification is important because it determines what materials can be transported, handled and stored together, and which ones not.

FIGURE 8: EXAMPLE OF SIGN TO BE USED ON PRODUCTS WITH A MASS EXPLOSION RISK

Requirements in EC-Directive 2014/28 are only applicable to government authorities or manufacturers. The Directive is implemented in MSFBS 2016:3 (Sweden), Statsrådets förordning om explosiva varors överensstämmelse med kraven (21.12.2016/1440) (Finland) and S.I. No. 423/2016 - European Union (Making Available on the Market and Supervision of Explosives for Civil Uses) Regulations 2016. Directive 2008/43/EC is implemented by the S.I. No. 133/2009 - European Communities (System For the Identification and Traceability of Explosives For Civil Uses) Regulations 2009. It should be noted that the main document regulating explosives standards in the EU is EC Directive 2014/28, which has been implemented in various forms in national legislation. Since the requirements should be the same, even though the national documents of implementation may be different, these requirements, in so far relevant to mining companies, have been listed in the international subchapter of this chapter. The following requirements on explosives and storage standards are therefore only those that are not an implementation of this Directive. It is important to remember that EC Directive 2014/28 provides detailed requirements on the marking and packaging of explosives, and EC Directive 2008/43/EC on track & trace systems.

6.2.2. Comments on Content of local Legal Requirements

There are some key issues worth mentioning. The central figure in overseeing blasting activities is called the "sprängarbas" in Sweden and Finland, and "shot-firer" in Ireland. Other people responsible for, or involved in, the blasting process are the employer (Sweden and Finland) or Mine Manager (Ireland), chargers under supervision and explosives storage managers. The exact requirements to be eligible to have this position appear to be different per country, but their responsibilities in the blasting process appear to be comparable.

Regulations on the transportation of explosives and other dangerous materials are usually intended for longer distance transports from the manufacturer or importer to consumer, and not within mine sites. Two types of explosives transportation legislation are therefore considered in this part; transportation regulations that form part of mine explosive safety regulations in their entirety, and regulations stemming from explosive transportation law only insofar it would apply at mine sites. Storage is an issue where legal requirements differ significantly between jurisdictions and even in between different permits. Irish legislation requires different storages for long- and short-term storage, and separate responsible people for managing the storage. The charging and blasting itself is less densely regulated, generally employers are required in general terms to ensure safe and healthy working conditions, with sufficient lighting and effective evacuation procedures.

6.3. Comparison of Regulatory Approach

It is noteworthy to point at the different approaches the regulators in the three studied countries have taken; this subchapter will discuss the different approaches by the three states, the consequences this has for the definition of a uniform resulting recommendation.

6.3.1. Legal Backbone of Mining Safety Legislation

Already in Chapter 5, the approach of the legislator to general mining safety was discussed. It turned out that the approaches are fairly comparable, with the legislator in all cases having introduced a duty of care to employers in statutory law, and a duty on the relevant ministries to develop further detailed regulations to more specifically define what this duty implies. The type of act serving as the main basis to this extent is different however; in the case of Sweden and Ireland this is the general Work Safety Act, in the case of Finland the main document was the Mining Act, including safety as part of the mine permit.

6.3.2. Specific Explosives Safety in Mining Legislation

All three countries have specific regulations, issued by the working environment authority, to regulate safe working with explosives in mining environments (AFS 2007:1 Sprängarbete, 16.6.2011/644 Säkerheten vid sprängnings- och brytningsarbeten and the Mines (Explosives) Regulations 1972 respectively). In Sweden and Finland this document is intended for both underground and surface mines, and also for civil engineering, in other words for all forms of rock blasting. In Ireland, the regulation has been developed specifically for underground mining. However, an important notion here is that some of the regulations seem particularly intended to coal mining and associated explosion risks. This is understandable given that at the time coal mining was the most common type of underground mining in Ireland, but it is irrelevant to this research.

6.3.3. Explosives Standards

Since all three countries are EU-members, they have to have the same requirements when it comes to product standards, which is an essential component of the internal free market which lies at the heart of the EU. For the purpose of this research, this means that explosives standards, albeit the methods of implementation differ. Given that the substantive requirements of these national requirements should be the same following EU law, EC-Directive 2014/28 is assumed to be the best legal standard to be followed directly for all three jurisdictions. This does not mean that for example oversight structures cannot be different, but since this law is intended to regulate explosives manufacturers and transporters, this has been judged to lay outside the scope of this research.

Although the requirements have been phrased as a duty on explosives manufacturers, this should be interpreted for the purpose of this research as a duty on a mining operator to not utilise explosives that have not been brought onto the market according to these requirements. The legal reason for this is that if a mining company would not ensure that the explosives have been manufactured and marketed in a safe manner this may also affect safe workings in the mine, which means the employer would breach its duty to ensure a safe working environment.

6.3.4. Miscellaneous Requirements

On top of the general safety requirements, mining explosives safety requirements and explosives standards there are additional requirements on the storage and transport of explosives, or regulations applicable to other mining activities that do however have a relation with explosives safety.

6.4. Comparison on Specific Topics

In this subchapter, issues that require more elaboration than a general and quick comparison or simple addition of different rules is discussed. The more complicated issues per stage in the cycle of explosives utilisation have been identified and marked orange or red in the previous chapter, and are discussed in this order below. Other issues that may be problematic are discussed as well. The results of this analysis will be used in subchapter 6.5 to define the resulting legal requirements.

6.4.1. Main Specific Difference

The biggest difference between the various legal requirements on explosives handling and blasting appears to be on the method of storing explosives; Ireland knows a distinction between a "magazine" and a "reserve station", following §17 of the Mines (Explosives) Regulations 1972. The main requirements following this approach of storage security is that the magazine is much more restricted and only accessible to an exclusive set of people (the "powdermen"), and that the reserve station cannot store more than 2 days of explosive materials. The concept of the magazine is that explosive materials for long-term storage in large quantities are stored in the magazine, which is an extremely restricted site. From there explosive materials can be delivered by the powdermen to the reserve station. This reserve station is also accessible by regular Blasting Foremans (at least this is legally allowed), and is the place from which explosive materials are distributed to the blast sites. Such a distinction is not made under Swedish and Finnish law.

6.4.2. Responsible Persons

The main issue on this topic that is very hard to compare in the field of responsible persons, given that each country has their own set of rules regarding blasting qualifications, blasting licenses that are valid in one jurisdiction are not valid in another, and the involved agencies are different. It therefore seems appropriate not to try to develop a uniform policy and leave this a national matter. It is however possible to compare the rights and responsibilities different responsible people have according to the law in the various jurisdictions.

6.4.2.1. Responsibilities Blasting Foreman

In Swedish, the Blasting Foreman appears to have a rather large responsibility, including the responsibility to "verify storage and dealing of explosives and associated equipment", in Finnish law this is not mentioned, and under Irish law another person is responsible for this task. It therefore seems best to make this Swedish requirement conditional on the question if there is not another (in the case of Ireland legally required) person responsible to maintain the storage of explosive materials. Apart from that it is clear that in all three jurisdictions the Blasting Foreman has a three-fold task regarding blasting, namely by involvement of the blast planning, in managing charging works and in verifying if these works have been executed correctly prior to the blast.

6.4.2.2. Eligibility of the Blasting Foreman

The exact procedures on obtaining blasting licenses are regulated nationally, and a blasting license for one jurisdiction is not valid in another jurisdiction. It therefore seems useless to formulate a uniform rule for this purpose. All jurisdictions essentially have a two-fold requirement for people to be eligible as Blasting Foreman, namely an experience requirement and the need to have blasting license.

6.4.3. Explosives Standards

The bulk on requirements on explosive materials themselves is regulated by European law, since equal product standards form part of the European single market for goods (European Commission, 2017). The main standards can therefore be retrieved from the two main Directives that are applicable to this topic; however, there are some specific aspects, that primarily aim to specify the duty of care with regards to the mine operator on checking the materials used. The general approach when drafting the list of requirements in this regard therefore is to see in what way the mine operator can see if materials used comply with European and national standards in order to act as a responsible employer, and not with the explosive materials themselves.

6.4.3.1. Quality Requirements on Detonators/Blasting Machines

It should be noted that there are some problematic issues with these requirements; first of all, does Swedish law explicitly refer to other Swedish law. However, in a European context should product standards and certifying bodies be held to the same standard across the EU. It is therefore recommended to let the question what particular certifying body should be responsible to be a national issue. Secondly, Irish law requires the blasting machine to be of the same manufacturer as the cables, whereas Finnish and Swedish law require the use of the same manufacture detonators and ignition systems. It is therefore assumed that the entire initiation and ignition system, from blasting machine to detonation, should be of the same manufacturer, unless it can be ascertained that they are designed as compatible systems.

6.4.3.2. Clarity on explosive materials used

It is possible to combine these requirements; the Irish regulator has apparently (again) wished to emphasize the exclusive duty of the employer to provide the materials used. It seems reasonable to assume that the Nordic regulators think this can be reasonably expected. It can also be assumed to be part of the duty of care under Irish law that, when the operator of a mine decides to use certain explosive materials, he will also make sure he obtains all the necessary material from the manufacturer as well. For the sake of being complete, both requirements have been added.

6.4.3.3. Requirements on Explosives to be used

These specific requirements appear to be not necessary to include in the list of applicable regulations given. Since Boliden's mining operations do not take place in urban areas, the Finnish requirement does not apply. Also, the Irish requirements reiterate the need of materials to comply with legal requirements, which has already been discussed before.

6.4.4. Storage

The legal requirements on storage are rather extensive, as can be seen in the previous chapter. The vast majority of these requirements are related to the construction of and requirements on new storages, together with permitting procedures. Given that these vary between the different countries, and the construction of new storages do not form part of the regular activities at a mine site, it is not deemed useful to develop a standardised set of requirements for this topic. The rules that have been listed for this topic are therefore always related to the way in which explosives materials should be left in a storage, necessary signs and on access to the site. One remarkable difference is discussed below.

6.4.5. Transportation

Extensive regulations on road transportation have not been included, although its key issues such as compliance with ADR-requirements, and the need to request permits have been mentioned. Again, permitting procedures differ per country, and apart from that will in general be the responsibility of the supplier and not of the mine. As for the transport within the mine several specific requirements exist, and these requirements overlap for a large part and in any case, do not contradict. One major difference in approach is the concept of the "Scheme of Transit" in Ireland.

6.4.5.1. Scheme of Transit

Apart from the distinction between magazines and reserve stations, Irish law has another characteristic distinct from Nordic requirements, namely the requirement of developing a detailed plan, the scheme of transit, on the shipping of explosive materials within the mine, following §18 of the Mines (Explosives) Regulations 1972. This scheme connects with the concept of the distinction of moving explosive materials from the magazine to the reserve station, and subsequently from the reserve station to the blast site. It does however also deal with the return of explosive materials to their original place, and also contains requirements on the locations of storages, also for low-sensitive emulsions. It connects closely not only with storage standards, but also implements other standards, such as the track&trace system. Since this therefore forms an integral plan on all aspects of handling of explosive materials in the mine (until the charging/blasting phase), it seems to be a good approach to deal with explosive materials in a mine, and therefore have been included in the comprehensive legal requirements.

6.4.6. Charging

Although charging regulations form a large part of all the identified requirements and all three jurisdictions have laid down rather extensive regulations, only two issues have been identified as more problematic. These issues are discussed below. Apart from this, no apparent difficulties have been identified, except for certifying requirements that may vary from jurisdiction to jurisdiction. There are five main issues in regard of charging, namely the development of the blasting plan prior to charging, then the preparation of the materials needed, the working environment during charging, regulations on the equipment used, drilling and finally the charging activities themselves. All these tasks may in practice be the responsibility of different people/crews, and will therefore require some more elaboration in the final chapters.

6.4.6.1. Number of Detonators per Blasthole

The only requirement that was found that appears to contradict another requirement is the different rule on the number of detonators to be used per blasthole; Swedish law explicitly recommends two detonators per blasthole in order to minimise the risk for non-detonation, whereas Irish law assumes that at a maximum one detonator per blasthole should be used; the background of this different approach may be that the Irish regulation was specifically developed for underground mines, which generally will have smaller blastholes, and the Swedish regulation also applies to surface mines, where it is more common to use two detonators in very large blastholes (as was mentioned in subchapter 3.2). It is not the case that these requirements cannot be combined; The applicable Swedish regulation literally states that:

"*Charging activities shall be executed in such a way that the risk for misfires is minimised. If it would be necessary two or more detonators shall be primed in the same drillhole*" (§18, AFS 2007:1)

It therefore is appropriate to assume that the regulator has introduced this requirement explicitly in the context of minimising risk of misfires. Importantly, it is *obligatory* to use two or more detonators, if risk assessment would indicate that not using two or more detonators would significantly increase the risk of misfires, following the wordings "shall be" (*skall* in Swedish).

The Irish regulation literally reads as follows:

"*A person shall not insert more than one detonator in a shot-hole in a mine, except in accordance with Part IX of these regulations or except where the method of shot-firing being used determines otherwise.*" (§29(1) Mines (Explosives) Regulations 1972)

Part IX is the part of this regulation that is dedicated to misfires. In any case the regulator has made it obligatory to not use more than one detonator per blasthole, with two possible exceptions. Part IX does in fact not contain specific regulations on the number of detonators to be used; Regulations in this part all deal with the procedure to follow if a misfire has occurred, not on the measures to be taken to avoid misfires. It can therefore be assumed that additional detonators are allowed in a drillhole when attempting to blast a misfire. The only exception to rely on to allow more detonators would therefore be the blasting method exception. It should therefore be assumed that when it can be proven that the use of multiple detonators per blasthole is essential to the success of a given blasting method this will be allowed. It should be noted that the Health and Welfare at Work (Quarries) Regulations 2008 do not specify a maximum number of detonators per blasthole, not even in the accompanying guidelines. It seems therefore best to assume that the limit on the maximum number of detonators to be used is typical for underground mining, where smaller drillholes are common. When drawing up the combined safety rules, a distinction is therefore made between underground and surface mining in this regard.

6.4.6.2. Preparation of Blasting Materials

Irish law prohibits the preparation of blasting agents underground, only with the literal text being:

"*The preparation of a blasting agent shall not be carried out below ground in a mine.*"
(§11(3) Mines (Explosives) Regulations 1972)

Given the formulation of "a blasting agent" this is assumed to refer to the manufacture of a single agent, and it is therefore assumed not to refer to the mixing of gaseous nitrates and oxidisers as part of emulsions just prior to loading. In any case permission is required of the Mine Inspector, following §11(4). The Swedish requirement emphasises the need of "sufficient distance" and protected objects. Since Boliden mines are located remotely, and does not produce its own explosives, this is judged to be inapplicable. In general, the requirements identified are all rather general or seem to deal with materials not regularly used. However, a short list of the main requirements in this field has been assembled.

6.4.7. Blasting

Arguably the most critical phase in the blasting process is the blast itself, but when all preparational activities have been carried out well it should not be a major workplace hazard anymore, given that all people have to be evacuated according to all three jurisdictions. The number regulations are therefore limited and primarily focus on the evacuation procedures, where no major differences can be distinguished. In practice, the difference between underground and surface operations can be large, but that will be discussed in the next chapter. Two issues on blasting materials are discussed below, in general all matters giving some complications are related to less used technologies.

6.4.7.1. Fuses and Special Blasting

Fuses are not used for regular blasting in Boliden mines anymore, and therefore only relate to special blasting instances. The requirements stipulated have been implemented however. Swedish law discusses tools that substitute smaller explosive charges for scaling or the removal of boulders. To be complete it has been included in the regulations, but will not be discussed further since it lies outside the scope of this research. The Irish regulations are related to shafts and winzes, and therefore will usually not be applicable.

6.4.8. Post-Blasting

No major difficulties have been encountered on issues in the post-blasting phase. Inspections on the quality of the blast and dealing with misfires form the main topic of regulations in this field. It should be noted that issues related to misfires are also relevant for drilling and loading/hauling operations, this will be dealt with in subsequent chapters.

6.4.8.1. Handling Misfires

The Irish regulations, following §50 of the Mines (Explosives) Regulations 1972, appear to be specifically related to techniques not in regular use anymore, namely either fuse-blasting or electric detonation (whereas all Boliden mines now use NONEL and incidentally electronic detonators). It is however judged to be worth a look when setting up guidelines on the treatment of misfires.

6.5. Resulting Combined Requirements

When drawing up the aggregated legal requirements, it is important to remember some fundamental legal principles. One of the fundamental principles in democratic states under the rule of law that statutes approved by parliament, i.e. law that has a definite democratic legitimacy, prevails over regulations and decrees issued by not directly democratically elected ministers and government agencies, in case there would be a conflicting requirement. A second important principle is that more specific requirements prevail over generic ones. Thirdly, if national requirements would be conflicting with international treaties or European law, since the European Commission can enforce member state's compliance with European law in case it is uncompliant, and international treaties prevail over national law.

By adding up the straightforward specific legal requirements from the different jurisdictions that do not appear to give a problem, and by implementing the elaborations made in the previous subchapter, it has now been possible to define a comprehensive set of rules that complies with all three jurisdictions and provides the highest standard of safety requirements. These combined regulations that have been assembled can be found in Appendix IX, and serve as the comprehensive legal requirements for the rest of this research.

6.6. Concluding Remarks

This chapter has found that there are rather detailed regulations regarding explosives safety in mining for practically any stage in the explosives handling and blasting process. It should however be noted that each country seems to have prioritised different issues, and maintains different levels of detail regarding different issues. It is not the case that there are many cases where aggregation of these regulations will be impossible; assessing how this combination of various legal requirements can be done to develop a multinational high-level safety policy will be done in the next chapter.

The structure of the different regulations and other legal requirements in the three countries appear to be fairly similar, and it therefore seems reasonable to undertake a closer comparison. In general, as was already found that all three jurisdictions explicitly require mine operators to assume a duty of care for their workers, and to develop risk assessments and working procedures to ensure working safety. Taking this as a shared common approach, exchanging practices would therefore be compliant with the law.

A distinct difference in regards of the main document on blasting safety between the Nordic and Irish regulations is that the Nordic regulations are relatively new, whereas the Irish regulation was drafted in 1972. This sometimes appears to make some issues less relevant, given the development of mining and new technologies that has occurred in the meantime. This does not mean that this makes the legal requirements less valid however. There are various differences on a detailed level, especially since some regulators have left certain legal requirements completely open and others not. It is generally fairly easy to work this out, by simply adding up the various specific requirements. However, there appear to be three main differences between the Nordic and Irish requirements:

- Relatively detailed legal requirements in Ireland
- The distinction between “magazines” and “reserve stations” in Ireland
- The explicit legal requirement for a comprehensive “scheme of transit” in Ireland

The approach taken to these three main differences has been to implement the more detailed requirements, since they offer a clear and distinct benchmark. The distinction between the different types of storage does not seem logical to implement in Nordic requirements, since it would require a thorough overhaul of existing mining operations in these countries. Although each jurisdiction has obligations on planning and risk assessment requirements for explosives handling, the comprehensive and more specifically regulated approach taken in Ireland seems to be worth comparing in detail for its actual practice.

7. Recommended Safety Technologies & Practices

In the previous chapter detailed legal provisions were outlined that follow from the identified applicable legal sources. These provisions still contain many open ends, and just following these requirements may not be enough to fulfil the duty of care an employer has under Swedish, Finnish and Irish law. Furthermore, some requirements may not be applicable to current Boliden mining operations, given that some rules may be primarily intended for e.g. coal mining, or civil engineering situations, and other safety requirements may therefore apply. This chapter will address some explosives risk management techniques, methods and strategies that are suggested by work safety authorities, scientific literature and other authorities in the field of blasting and explosives engineering. The goal of this chapter is to identify matters that require further consideration, and the suggestion of methods that can be used to identify the importance of various different explosives safety hazards, either by chosing different technologies or working methods, that ensure safe working practices.

7.1. Approach

The purpose of workplace safety regulation is to set safety standards, or, to put it differently, to set acceptable levels of risk (Fuller & Vassie, 2004). These regulations cannot be seen in isolation however; there may also be various non-governmental actors, or the employer itself, that has views on acceptable levels of risk. In addition, the sometimes rather general, and more duty-of care type of regulations require the consideration of more factors than just workplace legislation. Views by stakeholders in the right side of the picture will not be studied, since it can be assumed that they generally simply want something close to a guarantee that nothing harmful will happen to employees; governmental, regulator and other organisational standards have been discussed before; this chapter will essentially discuss how these standards should be interpreted and translated into a working practice. The main sources to undertake this task will be scientific literature, but also recommendations on how to meet safety standards and guidelines issued by governmental authorities, explosives manufacturers and other professional organisations. Risk management approaches are part of this chapter, but more detailed discussion on concrete incidents are part of Chapter 9.

7.2. Risk Management

Central to any systematic safety management, and a legal requirement, is the undertaking of risk assessments. Therefore, a risk assessment will be made in order to establish what topics deserve extra attention, on top of the fixed requirements. This subchapter will discuss ways to approach risk assessments.

7.2.1. Types of Risks

The first step is to decide what the risk scope will be. In the field of blasting, three types of risks can be distinguished (Seccatore, et al., 2013):

- Health & Safety Risks
- Economic Risks
- Environmental Risks

The latter two are not the topic of this research. Nevertheless, insofar relevant to this topic, they will be considered in conjunction with an assessment of health & safety risks. The ultimate goal of this risk management approach will be to remove, mitigate or at least minimize these risks. In order to do this, it needs to be clear what the hazards intrinsic to blasting activities are, which will be discussed in the following paragraphs. Techniques to analyse the importance of different elements of entire blasting operations and ways to analyse the available data will be discussed subsequently.

7.2.2. Explosives Utilisation Hazard Identification & Mitigation

Below follows a list of the main concerns that are associated with the utilisation of explosives, together with some of the typically associated mitigation measures. This list is based on an analysis by (Maier, 2000).

1. Incorrect timing of the detonation

Perhaps the main risk is explosives detonating before they are supposed to. Countermeasures focus on explosives standards and the storage, handling and transport of explosives. Also, for charging operations, the avoidance of time pressure in blasting operations to ensure safe handling is important, together with the need to only start charging when drilling has been finished.

2. Incomplete detonation

Explosives partially or completely detonating (misfires) form a hazard since they may explode at a later stage, apart from the fact that they harm mine productivity. Countermeasures need to focus both on misfires occurring in the first place as well as on how to deal with cases where they have happened anyway. Useful countermeasures include the avoidance of re-boring bore hole sockets, the monitoring of the blasting process and checking the debris for misfires after the blast.

3. Absorbing nitroglycol or nitroglycol through the skin or the respiratory tract

Proper explosives selection can play an important role in avoiding the most hazardous/unhealthy substances. Nevertheless, when dealing with hazardous materials, the use of necessary PPE and maintaining hygiene standards are important.

4. Explosives shocks and/or sound pressure waves

In order to deal with this (both health and safety) hazard, it is most important that people keep sufficient distance to the point of explosion, and that detonating fuses do not protrude from boreholes since they cause extreme waves.

5. Flying stone and/or the centrifugal effect

Getting hit by flyrock is a major risk, both when it hits people, but also when it hits equipment. Determination of the danger zone, and keeping people and equipment out of here is key to effectively mitigate this hazard.

6. Blasting vibrations

Normally primarily an environmental concern, large vibration may also cause mine damage and thereby possibly hazardous situations. The quantity of explosives used and the precision of blast timings are central to ensure that vibration levels are limited. Assessment of damage after the blast is also central.

7. Noxious components in released blast fumes

Toxic fumes will be released at any blast, given the nature of chemicals used in explosives. Nevertheless, the type of explosives used can influence the severity of this hazard, and good ventilation, sometimes even in surface mines, is therefore a key consideration.

8. Hazards as a result of incompatibility of the explosives, igniters, the equipment and the auxiliary articles envisaged for the blasting operation

It can be a considerable hazard when incompatible explosive materials are used, both in terms of decreased blasting precision, and in terms of early or failing detonation. In this research, it will therefore be considered to be a factor contributing to the previously discussed hazards.

9. Hazards from the environment

Hazards from the environment are primarily related to rock falling down, or getting hit by flyrock during the blast. The first subtype is considered to be outside the scope of this research, since it is a general mine safety hazard. The second subtype is effectively mitigated by keeping people out of the blasting area, and will be de discussed under issue 5.

10. Burdens suffered by the working staff

Hazards relevant from this category are primarily related to noise and dust, or the lifting of heavy loads. Since these are more general mining health (and to a lesser extent safety) hazards they will not be discussed in further detail, except in the context of the previously discussed hazards. Apart from these hazards, another major risk is theft or other ways in which explosive materials may end in the wrong hands. Since this is a security risk, and not a health & safety risk they will not be discussed in further detail however.

It can be seen that there are essentially three main type of safety hazards and one smaller health hazard; first the hazard of unwanted (or untimely) detonation (hazard 1), secondly the hazard of incomplete or failing detonation (misfires), hazard 2, and thirdly hazards related to the impact of blasting (hazards 4-7) and fourthly due to the handling of the explosive materials themselves (hazard 3). All safety rule recommendations, both these prescribed by governmental authorities, recommendations by other bodies and own findings will be seen in the light of how they contribute to the mitigation of these hazards in Chapter 10.

7.2.3. Fault Tree Analysis

Before looking at the actual statistics it seems appropriate to first establish on a theoretical level what events can lead to a dangerous situation, and perhaps most importantly, how important the failure of one element of an entire operation is in terms of its impact on the overall safety of the system. A suitable way to make

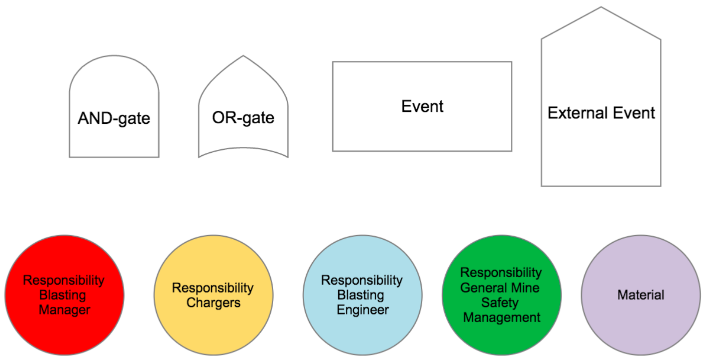


FIGURE 9: LEGEND FAULT TREES

such an assessment is by using fault trees. Fault trees were developed in 1962 to analyse system failures for the US Air Force and offer a good way to analyse the importance of elements to the overall safety performance of a system (Zhou, et al., 2005). See Figure 9 for a legend of the symbols used. For this research, it will immediately be assigned whose responsibility a certain activity is, in order to quickly see where certain rules should be directed to, or what materials should be used.

One of the useful aspects of fault trees is that it can be established what the importance of specific elements of an entire operation to overall safety performance. This can be done by describing all the minimal cuts that can lead to failure; a minimal cut is essentially the series of activities that need to fail in order for a (possible) accident to occur. Minimal cuts in this tree are $\{X_1\ X_4\}$, $\{X_1\ X_2\ X_3\}$. This immediately makes clear that by simply eliminating the possibility of failure of X_1 would already create a safe system. An alternative would be to eliminate X_3 and X_4, assuming that external event X_2 cannot be changed. Assuming that all elements are equally improvable the preferred option would thus be to ensure safe function of X_1, since then only one element needs to be improved. It is therefore a very effective way to see what procedures or materials should be prioritised to ensure a safe operation.

In more complicated systems, the importance of respective elements can be established with the so-called Birnbaum's factor of importance (Limnios, 2013).

$$I_{\varphi}(i) = \frac{\delta r}{\delta p_i}\left(\frac{1}{2}\right) = \frac{1}{2^{n-1}} * n_{\emptyset}(i)$$

With $I_{\varphi}(i)$ being the importance of a basic event for the safe functioning of the system, n being the number of components in the minimum cut that need to fail and $n_{\emptyset}(i)$ the number of minimum cuts that will lead to the occurrence of the top event.

The following elements have been identified as having a (theoretical) impact on blasting operations, and included is what person(s) would legally, or otherwise practically, be responsible for this task. All fault trees are built from (some of the) components of the blasting system. In Appendix IX.Q, fault trees are worked out for types of hazards that have recently led to accidents composed of these events, and resulting minimum cuts outlined. Apart from the below mentioned controllable events, events that are assumed to be beyond reasonable controlled are detonated by "N".

7.2.4. Risk Assessment per Operational Activity

Just knowing what the hazards are is not enough; the question is how likely it is that a certain hazard will indeed cause actual damage or injury, and what this damage or injury will turn out to be, in other words what the risk is. It can be rather hard to make good estimates of what the risks actually are, especially when adverse events do not happen frequently but can theoretically have enormous impacts, as is the case with explosives handling and blasting. Nevertheless, an attempt will be made to quantify the different risks.

In order to decide on the importance and need of safety measures and standards, this research will undertake a comprehensive risk analysis for the different stages discussed. The result of this will be a risk matrix (see for an example Figure 10), from which it can be judged what measures deserve the highest priority. Risk matrices are fundamentally based on the definition of risk, being:

$$R = P * D$$

With R being the risk, P being the probability that a certain type of adverse event will happen and D being the damage that can be expected from the occurrence of such an event.

In this research, two types of probabilities of risk will be distinguished, based on the available data; consequence risks (i.e. the risk of certain accidents occurring) and causal risks (i.e. the probability that certain components of the system will fail that might possibly lead to an accident). This distinction has been made given the availability of data; on one hand data of minor incidents in Boliden sites that did not lead to actual harm and on the other hand data from health authorities just stating the type of accident but not its cause. The first type shows what types of accidents occur frequently, either because of the major damage associated with it or the high likelihood that this type of damage occurs. Types of accidents can be linked to a specific type of failure in the blasting process. The second type shows what components in particular deserve most attention, either because it is likely that their failure will lead to failure, or that when they fail the associated possible damage will be big. This report will continue to make this distinction between issues related to the *cause* and those related to the *consequences* in the types of hazards, risks and measures discussed.

In order to assess the level of risk per activity, risk matrices will be used. Risk matrices offer a good way to judge different risks, and are thereby a helpful tool for effective risk management. Although criticized for the way in which statistical uncertainties are dealt with, they offer an easily understandable method to assess risks associated with a given project or operation, which is helpful in the allocation of priorities and resources for specific tasks (Cox, 2009, p. 102).

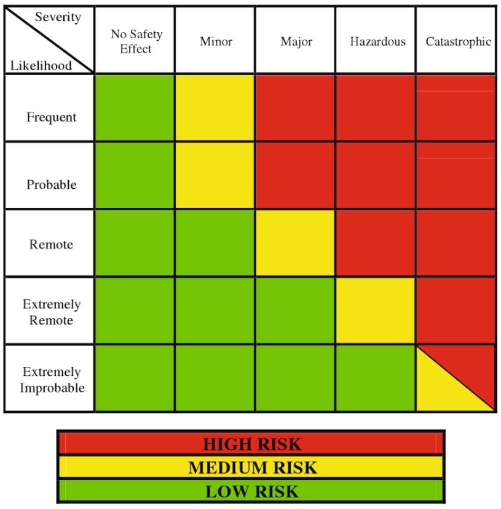


FIGURE 10: EXAMPLE RISK MATRIX (FEDERAL AVIATION ADMINISTRATION, 2007)

7.2.5. Assigning Probabilities and Expected Damages

Assigning probabilities for certain failures in the blasting process may be the most difficult step, since these may be dependent on many different factors, and especially for less frequently occurring failures making reliable estimates may be difficult. In this report, available data on incidents of certain process steps will be used to make an estimate of the probability of failure of certain components of the blasting process, and subsequently failure (e.g. accidents leading to material or personal injury) of the blasting process itself, in a method that is usually used for the estimation of failure of mechanical, chemical and other physical systems. A method to translate the occurrence of incidents into a reasonable probability estimate is to define the so-called point estimator of failure rate λ (Gheorge & Mock, 1999, p. 34):

$$\lambda = \frac{n}{t_{acc}} = \frac{n}{\sum_{i=1}^{N} t_{i,op} * N}$$

With n being the number of failures of a specific failure mode, t_{acc} the accumulated time of service of the items or operations involved, $t_{i,op}$ the accumulated time in service of the relevant items or operations and N the total number of considered items or operation. It is important to realise that this λ does not equal an actual probability; certain incidents may fail more than once for the given time period of a year, but this does not mean that the probability of failure during a year is more than one. It is therefore necessary to assign a so-called probability density function. To do this it is necessary to assign a certain expected type of failure probability density; some types of activities or mechanical parts are more likely to fail at the beginning of their life, others once they get older for example. In the case of a continuously ongoing human process, with continuous replacements at various sites, it seems most reasonable to assume that the "hazard rate", the probability that some activity fails at a certain point in time is constant, e.g. that how long the activity goes on (in this case how many times a certain charging process is repeated) is irrelevant. The appropriate formula for this type of function is the exponential density function, given by (Dekking, et al., 2005, p. 62):

$$f(t;\lambda) = \begin{cases} \lambda e^{-\lambda t} & t \geq 0, \\ 0 & t < 0. \end{cases}$$

To have a proper computation with statistical relevance of λ, it is important to have at least five item/operation failures that can be judged to be (moreorless) similar (Gheorge & Mock, 1999). Expected damage will be based on the maximum damage or injury that occurred following accidents of a certain type.

It is possible to also establish a confidence interval for all of these probabilities, since having more failure data will increase the confidence that the given probabilities indeed reflect reality. It will be assumed that we always need to be on the safe side, and an upper probability limit will therefore be introduced, with:

$$F_{upper}(t) = F(t) + \frac{0{,}03}{n+1}$$

With n being the number of reported failures. The margin that is added for the, statistical relevant number of five operating failures will then be 5 per mil, and the minimum assumed probability of component failure per shift is therefore 3 percent. See Appendix IX.C for a further elaboration on this topic.

7.2.6. Process Improvement

The previous analysis focused only on hazardous events that have actually occurred; To make a more detailed analysis of actual problems that occur for the most severe hazards with the execution of elements of the entire system for underground mines, another approach is suggested based on the bow-tie method integrated with statistical data. The bow-tie method is frequently used in order to map possible causes and prevention and mitigation measures for a given hazard. Causes and associated possible prevention methods are outlined on the left side of a certain hazard, and possible mitigation measures and consequences if all measures have failed are displayed to the right (Rausand, 2011). See Figure 11.

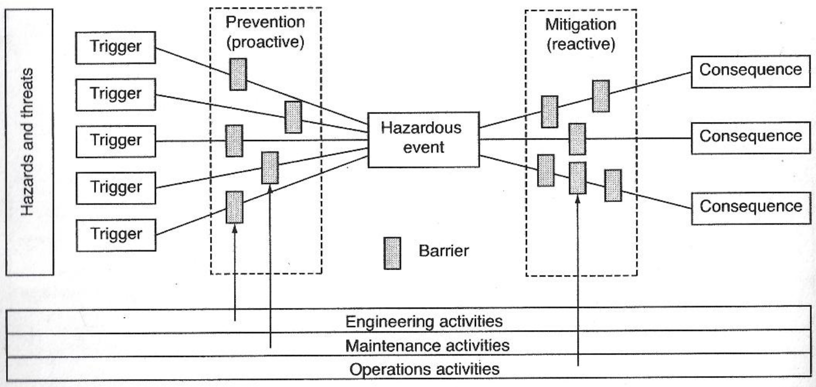


FIGURE 11: SET-UP BOW-TIE DIAGRAM (RAUSAND, 2011, P. 120)

Following this bow-tie method, the conception of risk discussed before is indeed rather simplified; first of all, it is important to consider both sides of the adverse event, namely the failures (e.g. breaches of certain safety protocols) on the side leading up to the adverse event, and on the other hand the failures that aim to limit the impact of an adverse event (e.g. not wearing PPE).

For this analysis, an adaption to the bow-tie method will be made, since it is interesting to implement statistical data and to use this quantification to establish the likelihood of certain consequences given the occurrence of a certain hazard. What we want to know is how likely it is that a certain hazardous event will lead to a certain consequence, and on the left side what the most vulnerable path is leading up to the hazardous event. Following breaches of procedures or material failures reported in underground Swedish mines, a likelihood is assigned to each element on both sides that they will fail. With this knowledge, an assessment can then be made to judge what would be the most effective way to improve safety performance.

The model developed will essentially implement Reliability Block Diagram (RBD) into the bow-tie method. The RBD is a tool similar to fault tree analysis that can be used to judge on the reliability of a system based on the reliability of individual components (Gheorge & Mock, 1999, p. 72).In this application, the cause-side is rather small, since it will be assumed that causes must be beyond reasonable control of staff involved, since it would otherwise be a failure of a certain measure. The goal is to establish how likely it would be that these uncontrollable events would lead to the occurrence of a dangerous event, if they were to occur. Data on reported possible causes are used; when certain prevention measures appear to fail frequently this makes it more likely that the cause that is connected with this prevention measure is by definition riskier, if it were to occur; after all, when it would occur, it would be more likely to progress to become an actual hazardous event. In order to make these calculations, is important to distinguish between events or parts that can lead to failure of the entire system that are in series or parallel (similarly to the AND or OR-gates in fault tree analysis); if only the failure of several activities or parts at the same time leads to failure of an entire system it is considered to be in series; when the failure of only one part out of many can lead to failure of the entire system the system is considered to be parallel (Fuller & Vassie, 2004, p. 262). See Figure 12 on how to calculate the probability that an entire system would fail based on the probability of failure of individual components. It is assumed in the model that each failure in the failure-path has to occur in the same shift to turn into a system failure.

For the consequence side, it will be calculated what the likelihood is that certain consequences will occur, following the likelihood of failure of certain safety measures and assuming that the dangerous event has occurred. Furthermore, it is interesting to assign a risk for a certain element in a chain. Since the criticality of some components is less, as can be concluded from the fault tree analysis, the probabilities will be translated into risks per criticality level. Accordingly, the riskiness of each element on this side is given by:

$$R_{element} = I_{\varphi}(i)_{element} * P_{element}$$

finally, in order to also have a risk estimation based on this model, the possible damaging events at the end can be calculated by the following formula:

$$R_{consequence} = P_{consequence} * D_{expected}$$

In order to distinguish between different types of components of the explosives handling and blasting process, the bow-tie model will assume five different types of failure; failure of the rules/procedures themselves, failure of the materials used, failure of the practical execution of certain tasks, failure of typical inspections to note such failures and finally failures in engineering aspects such as blast design. Each component can be marked with a certain probability of failure based on the incident reporting. See Figure 13 for a legend of the markings used.

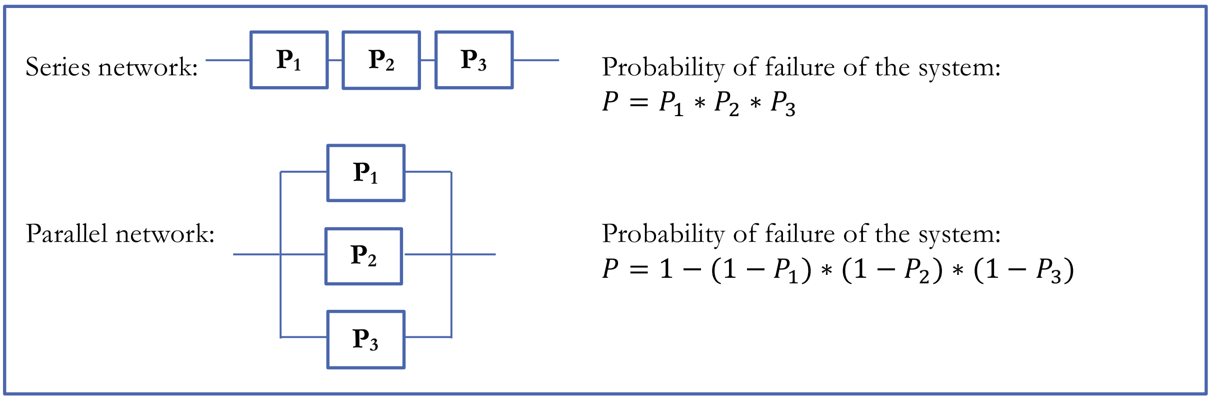


FIGURE 12: SYSTEM FAILURE PROBABILITY

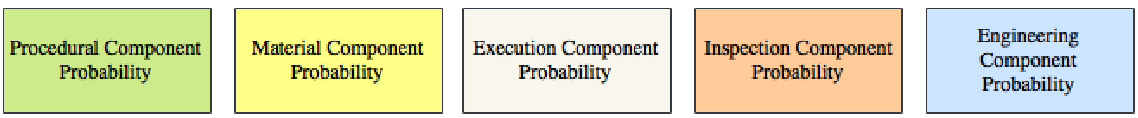


FIGURE 13: LEGEND ADAPTED BOW-TIE MODEL

7.3. Causes of Failure

When all legislative requirements been implemented correctly, the right technologies have been selected and best practices have been developed, the phase of implementation may still lead to problems. This can be caused by either because implementation issues, or because people deliberately violate rules or simply make mistakes. Even when drawing up of working methods, procedures and the selection of technologies mistakes can be made. In order to improve overall safety performance, it therefore is important to consider the possible reasons why things go wrong.

7.3.1. Errors and other types of Incidents

In order to assess what the root cause of possible incidents and accidents can be, it is important to distinguish a few types of different failure causes. Although the word "incident" can have several meanings, for the purpose of this research, it is defined as the occurrence of (possibly) dangerous situations that are unintended (Brown, 1993). It is assumed that these situations will have three possible type of backgrounds:

- Human error
- Material failure
- External causes (e.g. unexpected difficult geology, climate, uncontrollable people from outside the organisation)

The last category is the most difficult one to deal with, since its causes lie outside the organisation itself; possible measures are therefore related to monitoring and general mitigation measures. The topic of human error will be discussed in more detail below. Possible material improvements will be discussed in this chapter under the subchapter on available technologies.

7.3.2. Type of Errors

People make mistakes, and this in many takes the form of a conscious violations to subconscious slips. It is important to recognise the differences in types of errors, in order to find a way that minimises risks of errors and has opportunities in place to correct them. A first distinction is between active and latent errors. Also, a distinction can be made between various types of human safety errors (Simpson, et al., 2009, p. 7):

a) Violations

Arguably the most important type of safety error, since they are intentional, and are therefore always related to the deliberate non-compliance with a certain safety standard. This type of violation may seem "malicious", but there can be many different reasons for non-compliance, and it is important to be aware of these reasons to effectively mitigate them. The following subtypes can be distinguished (Reason, 1987):

- Routine violations: Follow habitual behaviour which is considered to be normal within the given environment (common excuse: "everyone does it like this").
- Situational violations: Happen when factors in the workplace make it difficult to comply with certain rules, and people may deem the rule to be ineffective or even contra-productive in the given environment (for example, when wearing safety glasses in a dusty environment view may become bad, for this reason many people may choose to take them off).
- Exceptional violations: Occur in uncommon situations, when people have to find new solutions and feel that violating existing rules in this new situation is unavoidable. This type of violation is especially dangerous, since the consequences are unknown.
- Optimising violations: People trying to make their work more "interesting" or "efficient" by ignoring certain rules.

Assuming that staff generally is not of bad intent, it can be concluded that it is to be recommended to make people see the logic of safety rules, and not to "over-regulate", since this could lead to an inflation of how serious important rules are taken. Preparedness, and a culture of regular communication on more unknown issues, seems especially important to avoid situational and exceptional violations.

b) Mistakes

Mistakes are defined as cases where you do the wrong thing, even though you believed it to be the right thing to do (Simpson, et al., 2009, p. 8). This type of error is therefore always related to some kind of unawareness. The following sub-types of mistakes can be distinguished (Reason, 1987):

- Rule-based mistakes: Occurs when a certain procedure has been interpreted in the wrong way.
- Knowledge-based mistakes: Occur when a situation goes beyond someone's training and expertise.

c) Slips/Lapses

Slips/lapses are cases where people start of doing the right thing, but end up in doing it the wrong way. This type is therefore usually related to distractions causing inadequate execution of a certain task. The following sub-types of mistakes can be distinguished (Reason, 1987):

- Skill-based slips: Occur when people work in 'auto-pilot', and start relying too much on routine.
- Rule-based slips: Occur when rules have been interpreted correctly but accidentally executed in the wrong way.

Mistakes are therefore common with tasks that are too complicated or require a lot of training, whereas slips tend to be associated with tasks that are (considered as) easier (and therefore boring).

Concluding, it can be stated in general given the backgrounds of possible errors discussed that it seems logical to provide a guideline on the most important lesson that can be learned to avoid Rules and working methods that are in place should therefore:

a) Not give active reasons to ignore/violate them;
b) Be straight-forward, easy to understand and leave no room for confusion;
c) Ensure that they are not too boring to execute and comply with.

Effective ways to ensure that these procedures are indeed followed are the following (Simpson, et al., 2009):

a) Oversight and active enforcement of safety standards, together with feedback that can assure that it indeed is doable to comply with all rules;
b) Involvement of different people to critically assess the way jobs are done;
c) Post-execution of work checks.

These concepts of errors, and the recommendations on how to ensure compliance with working procedures, will be used to make suggestions on how to avoid the types of breaches discussed before. It should be noted that human errors should not be solely blamed on the individual making the concrete error; it is likely the result of a set of factors; the way in which an organization is set up, how it motivates individuals to work (e.g. is there a perceived notion that for example higher production rates comes first) and in what way staff, both at the same and at different levels, communicate (Reason, 1987, p. 13). Violations may be the result of the wrong incentives, mistakes may for example be the result of inadequate training and slips perhaps with bad working conditions, either because they are too boring or actually with too much haste. When assessing incident reporting, these factors should therefore also be taken into account, when the aim is to make compliance with workplace safety requirements more effective.

7.3.3. Personal Failure vs Systemic Failure

In order to successfully deal with human errors, it is important to look beyond the sharp end of failure, i.e. blame all mistakes made by operators (only) on operators. In his paper, (Reason, 1990), dealt with this issue and suggested the so-called "Swiss-Cheese model". This theory relies on the assumption that there are three elements to any accident, namely hazards, defences and losses. Hazards can form an intrinsic part of an operation, and have been listed before. Defences are the technologies, rules and checks available to mitigate these hazards. An accident is assumed to only occur when a hazardous event occurs and is subsequently not stopped by any of the defences that could be in place, leading to forms of losses. This theory has been elaborated further for different sectors (Reason, 2000), and applied and adapted into different industries, e.g. (Eurocontrol, 2006). The main goal of this model is to identify factors that can reduce, or actually

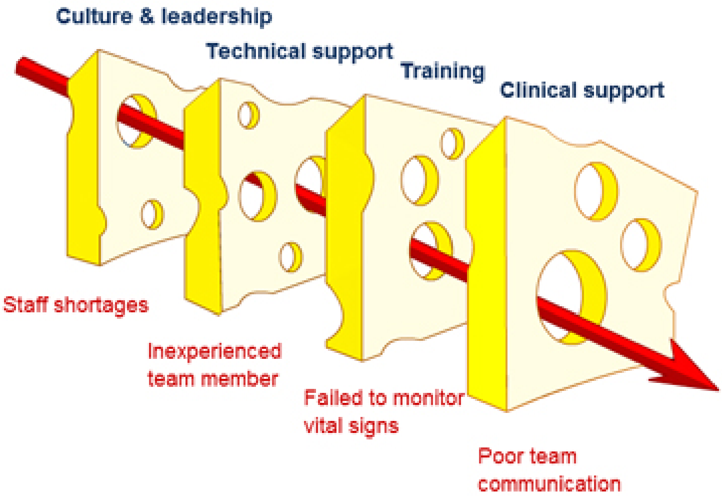


FIGURE 14: EXAMPLE SWISS-CHEESE MODEL (STRATOG, 2017)

increase, actual risks, taking into account issues such as for example insufficient funds, time pressure on employees, failing maintenance and inadequate checks. See Figure 14 for an example of a Swiss-Cheese model, with examples of human errors and how they are influenced by decisions at the management level. Since it is the latent failures in the organisation of organising such matters properly, rather than individual mistakes, are the focus of this report, these notions are taken into account in the recommendations made by this report. This is expressed foremost in the Bow-Tie-Reliability models used to identify what activities are most problematic, including factors such as the quality of materials used, effectiveness of procedures in place or checks executed by more senior staff. The theoretical background of this has been discussed in paragraph 7.2.6, and is worked out in Chapter 10. Furthermore, to go deeper into (possible) root causes of failures, the Five Whys Technique will be used for the most problematic issues.

7.3.4. Five Whys Technique

In an attempt to ensure a more reliable production of cars in Toyota plants and avoid breakdowns, Taiichi Ohno developed a technique called the "Five-Whys Technique" (Ohno, 1988). The technique relies on the notion that, in order to really deal with a problem, it is necessary to keep asking five times why a certain incident occurred, in order to find the root cause of a problem (e.g., why did the blast cause so much flyrock? –because too much emulsion was used. Why? – wrong settings on equipment. Why?… etc.). It is therefore an effective way to go deeper into the actual causes of problems, rather than to stay on a shallow level. Still, it has also been criticized for delivering different results when used by different people, since problems can have many different causes and different people may interpret problems differently, and therefore sometimes hard to verify (Serrat, 2009). In the context of this report it is deemed to be a useful tool to point into the direction of solutions to deal with bigger problems, based on the available internal documents, interviews and incident reporting. When the recommendations following this report would be worked out in greater detail it is recommended to use the technique also for less problematic issues, and in close collaboration with people involved in these problems.

7.4. Recommendations by Regulators and Industry Best Practices

Apart from the analysis made in this report it is valuable to also take other recommendations into account. In addition to the actual legal requirements, more specific guidelines have been issued as annexes to AFS 2007:1 and in the Guidelines to the Safety, Health and Welfare at Work (Quarries) Regulations 2008 (specifically for surface mining and smaller quarrying, some of these recommendations might therefore be less relevant). It is not deemed useful to simply list long standards following these documents, since they can simply be looked up, but an example is given for both documents. When working out specific safety practices it is recommended to take note of these documents, since they have been issued by the regulator. Complying with these soft semi-legal standards will therefore certainly help to meet legal requirements.

Industrial organisations also set up best practices to work with explosives. These practices are either issued by mining industries, but in many cases also by explosives manufacturers or professional organisations. Similar to the previous subchapter, another example will be discussed here. The Australian Explosives Industry and Safety Group (AEISG) posts its best practices online. The current practices that have been posted online relate to the following topics (AEISG, 2016):

- Storage and Handling of UN3375 (Edition 4, May 2017)
- Mobile Processing Units (Edition 3 June 2014)
- Blast Guarding in an Open Cut Mining Environment (Edition 1 March 2011)
- Elevated Temperature and Reactive Ground (Edition 4 March 2017)
- Prevention and Management of Blast Generated NOx Gases in Surface Blasting (Edition 2 August 2011)
- Segregation Barriers for Transporting Mixed Loads of Detonators and High Explosives (Edition 2 March 2014)
- On-Bench Practices for open cut Mines and Quarries (Edition 1 November 2015)

See Appendix IX.D for an example of such best practices and recommendations.

7.5. Technology: Explosives Handling

Explosives handling is a topic where technology may play a smaller role than in the section on blasting. There are still some physical/technological issues that do affect explosives safety and are also referred to in the studied legal requirements. These issues and their mitigation measures will be discussed below.

7.5.1. Vehicles Used

Vehicles used to transport explosive materials can be a potential safety hazards, due to the shocks they can cause to explosives in case of collisions, and due to burning exhausts, or even fire or explosions of fuel in the case of more sever incidents. For these reasons, the right exhausts are legally required, and each vehicle has to be equipped with a fire extinguisher. Slow and safe driving is essential as well. In the longer term, electrical vehicles would be helpful as well, given their lack of exhaust sparks and use of explosive fuels.

7.5.2. Storage Conditions

Bad climate conditions can affect the performance of explosive materials when they are stored for a longer time. Having unreliable explosives can pose a risk in terms of an increased chance of misfires. Emulsion storages are therefore maintained and monitored directly by the emulsion supplier. Other explosive materials are however not monitored as closely, and this is not a problem as long as the climate in storages is as it should be. To ensure that the climate is indeed as it should be, real-time monitoring of the climate in storages is therefore recommended. Whereas the surrounding climate in underground mines tends to be relatively stable, this can pose a bigger problem in surface storages in land climates.

7.5.3. Traceability of Explosive Materials

Following the legal requirement of the implementation of track&trace systems in mining operations, mines have increasingly switched to digital track&trace systems, where both packaged, and single units of, explosives are scanned in and out from each different phase in the explosives handling process, until it is ascertained they have been used at the blast site. The advantage of a digital online system is that it is much easier to be verified from for example an office than paper records recorded in the storage, and that updates occur real time. Still, reports from Tara is that these systems, and their interoperability with Maximo-ordering systems still cause problems, with scanning difficulties and incidentally lagging data processing. The development of a reliable explosives management system therefore seems essential to one hand ascertain knowledge of the whereabouts of any type of explosive material at any time and at the other further simplify the explosives handling and easier to be checked. Also, if one wants to assess the performance of certain specific explosive materials, especially in the context of misfires, it is important to have a system that can effectively automatically trace back a specific misfire to a batch of delivered explosive materials.

7.6. Technology: Blasting

In the field of blasting technologies used determine the success of blasting for the largest extent. Both the need to reduce risks for misfires, and the risk for unwanted detonation, as well as limiting damage following blasting can be met by selecting the right explosive materials for the task.

The explosive performance or the "brisance", the ability to fragment solid objects. The brisance value B_v is given by a simple formula from the 1920's:

$$B_v = f * \rho_0 * D$$

Here, f is defined as the specific pressure by the gas, ρ_0 is the loading density and D is the detonation velocity. Although not judged to be a reliable measure of bench blasting performance anymore (Persson, et al., 1994, p. 122), it gives a good indication of the factors that effectivity of an explosive, namely the pressure generated by the gas, the speed and the density of the exploding component of the explosive material. All these factors are intrinsic to the explosive material, but may be affected by the environment in which it is charged. It could therefore be a consideration in explosive selection in a safety context, it would be unnecessarily hazardous to have an explosive that might be more destructive outside a (for example wet) blasthole, such as the difficulties of ANFO in functioning properly in difficult mining environments. On the other hand, an explosive is selected exactly because it is as destructive as possible per weight, so it seems impossible to completely remove the brisance hazard. To sum up, there are a few considerations when selecting explosives purely from the safety standpoint:

- Low sensitivity required; a disadvantage of lower sensitivity can however be an increased risk for misfires (Persson, et al., 1994); initiation systems should therefore be reliable enough to guarantee detonation.
- Reliability in difficult environments; again, risks for misfires increase when the explosive does not detonate when required.
- Explosive material becomes sensitive to smaller explosions or other impulses as late as possible.

For this reason, the use of emulsions is also well defendable from a safety perspective (Tamrock, 1999). Because of this, emulsions, with their low sensitivity, and complete insensitivity before the blast, and suitability in difficult environments, have taken away many of the traditional concerns of explosive materials. Chapter 9 also shows that nowadays accidents with high explosives detonating by themselves do not occur anymore, and this is therefore deemed to be not a safety hazard anymore. Another important topic in this regard is the selection of different detonation systems. A more detailed outline of the background and characteristics of different initiation systems can be found in Appendix IX.F. Generally, it can be assumed that electronic detonation systems have considerable advantages, given the fact that they will not detonate except for when a coded detonation pulse is given, and their very limited scatter in delay time will make it possible to use less explosives for high fragmentation, leading to less fumes, flyrock and vibrations. Also, it is possible to spot misfires prior to a blast by checking the set-up in advance.

7.7. Conclusion

This chapter set out to outline some of the basic aspects of explosives safety, and the reason why certain measures are necessary or certain explosive materials are to be preferred over the other from a safety perspective. Also, additional resources for the formulation of safety procedures have been suggested, beyond the requirements of "hard law". These resources are best practices and guidelines issued either by governmental authorities, usually as annexes to applicable regulations, or industrial best practices commonly issued by the explosives industry. Examples were given of factors that should be considered in the minimisation of hazards. Technological opportunities, in terms of explosive performance and detonation systems were discussed, to see what techniques could be helpful in mitigating safety hazards. Electronic detonation systems have been identified as being helpful in improving safety.

8. Application of Explosives Safety Requirements

The aim of this chapter is, now that we are aware of the legal requirements that have been put on mining companies and the actual safety hazards and technological and methodological safety measures that can be applied to meet these safety and legal requirements, to see how this actually is carried out by Boliden Mines. Explosives safety rules and guidelines are formed in Boliden by several parts of the organisation. These rules and guidelines can have various backgrounds, such as legal requirements or practical experience, and have been developed both at Boliden Mines central office in Sweden or at the different mine sites. This chapter gives an overview of how and why these rules, guidelines and practices are developed, the most essential practices and give notable examples of different approaches. It is assessed what the relation of these rules, guidelines and practices with legal requirements is made, based on the integral legal requirement that follows the findings of chapter 0.

8.1. Working Method

This chapter is relying on sources that are neither legal sources nor are scientific works, like the previous chapters. Instead, information has been obtained from the internal Boliden management systems, contacts with staff and actual mine visits. The following sources have been used to obtain the necessary information:

- Notes from talks and observations of mine visits
- Internal Boliden guidelines and other management documents
- SOP's (Standard Operating Procedures) issued to be used on the job
- Input delivered via email or phone from people working with either health & safety, management or blasting activities
- Pictures and videos from actual operations

Notes and interview results made can be found in Appendix IX.H. Excerpts or drawings from important documents have been listed in appendices as well. Mines from all three studied countries have been visited, in order to obtain input from a different set of mining cultures. All the notes made have been shared with the mines visited, to ensure that the notes made do not misrepresent the actual situation. The following four mines have been visited:

- Kankberg underground gold mine in the Boliden area, Sweden
- Aitik surface copper mine in Sweden
- Kevitsa surface copper mine in Finland
- Tara underground mine in Ireland

Kristineberg, Renström and Maurliden (Boliden area, Sweden), Garpenberg (Sweden) and Kylylahti (Finland) have not been been visited. Basic information on these mines has been obtained as well, in order to see if there are interesting outliers or different practices, but in general the focus of this research has been on the mines that have been visited. These mines account for around 1760 out of 2780 (or 63%) employees working for all Boliden Mines (New Boliden, 2017), or more than 90% of Boliden's ore production in Sweden, 85% of Boliden's ore production in Finland and 100% of Boliden's ore production in Ireland (New Boliden, 2017). For this reason, they have been judged to be the best mines to visit, giving a good representation of the company's workings with explosives and safety practices, and different legal and safety cultures.

Since there is a vast quantity of detailed rules on all stages of the process, it would be a very uninteresting and not so useful approach to just list all the actual practices next to the discussed requirements. Instead, the topic is approached from two angles. First of all, it is considered what the actual way of translating legal requirements or safety concerns into actual working applications. Secondly, from stage to stage, the most important aspects are mentioned, by means of examples from different operations. These more specific examples will always come from the mines that have been visited. Especially when an approach differs significantly, this will be discussed, and if possible explained.

8.2. Relation between Legal Requirements and Practical Application

As was established in chapter 5, it is an obligation on the employer in all three countries to prevent any harm to employees, regardless of its source. In order to meet this goal, it is therefore required in all three jurisdictions to develop safety policies in working areas where hazards have been identified. It is also important to realise that there may not be legislation tailored to specific situations, or that in certain fields specific legislation may not even be present. This does not mean that it then is not legally required to have internal standards anymore; the duty of care of the employer obliges him to develop internal rules for these fields as well. It is therefore best to regard the findings and specific requirements in the previous chapter as minimum standards, in some cases requiring additional rules.

On the other hand, it is sometimes possible that specific mines are exempted from certain requirements, when they are very impractical or simply not applicable to the given environment. This is however not to be assumed easily, and it will be necessary to verify if such exemptions indeed have been explicitly allowed by the relevant authorities. In any case, it is important to remember the main objective of zero LTI's in any of Boliden's operations in 2018 (New Boliden, 2017, p. 8), and when existing legal requirements are insufficient to achieve this aim it will be necessary to take further measures. The following paragraphs will all be based on existing practices, not on policies that would follow from the law or general safety and blasting theory. It will however be judged whether each policy matches with legal requirements.

A quick overview of compliance with the Comprehensive Legal Requirements is made, by comparing legislation requirements with the internal rules and practices at all four visited mine sites per section of set of rules. The multinational set of legal requirements that can be found in Appendix IX has been used as the basis for this comparison. It will be indicated when there is something special to note on the compliance with these requirements. See Table 10 for an explanation of the colours used to compare these findings. If there are cases of non-compliance these will be discussed in that particular subchapter. If something is labelled as "Strict Compliance" this usually relates to national requirements or cultures that put much higher requirements on certain operations.

TABLE 10: LEGEND FOR TABLES COMPARING BOLIDEN POLICY AND LEGISLATION

In accordance with legislation	Strict Compliance	Irrelevant	Contradicting with legal requirements	Improvement might be Necessary	Unknown
(blue)	(green)	(yellow)	(red)	(orange)	(purple)

8.3. Approach to Develop Safety Policies

The translation of legal requirements and safety and risk assessments into working procedures occurs for each aspect of the operations in Boliden Mines. Before switching to the content of these procedures an overview will be given of these tools, and the way in which they are developed.

8.3.1. HSE-Rules & General Statements

Currently, Boliden already has several centrally issued HSE-rules in the field of explosives safety applying to several mines. These rules follow, insofar they were based on legal requirements, the requirements of Swedish legislation and therefore currently only apply to Swedish mines. These requirements have been translated and put in the same structure as used in the legal analysis. It is noteworthy that a large part of these internal requirements closely follows legal requirements that have been listed before quite closely. The following internal HSE-rules have been studied for this overview:

- AOG HMS-regel: Explosiva varor, förvaring, transport och hantering (HSE-rules Explosive goods, storage, transport and usage), Reg. nr. C00360.
- AOG HMS-regel Laddning av borrhål (HSE-rules Charging of drillholes), Reg. nr. C00371.
- HMS-regel Ansvarig Mobil tillverkning/Sprängning (HSE-rules: Responsible mobile production/blasting), Reg. nr. C00406.
- AOG HMS-regel Bergborrning- åtgärder mot påborrning av sprängämne (HSE-rules drilling-measures against drilling of blasting materials), Reg. nr. C00411.

- AOG HMS-regel för hantering av emulsionssprängämnen/BAM HMS rule for handling of emulsion explosives, Reg. nr. C21286.
- AOG- HMS REGEL. Rutin för repartion och service på laddfordon (HSE-rules. Routines for reparation and service of charging vehicles), Reg. nr. C6898.

In Finland, the safety department is responsible for drawing up the main guidelines, in collaboration with people in the field. It is important to remember that in this case Orica is responsible for the blasting works; since Orica has their own safety standards based on worldwide operations, these are the main working documents for charging activities in Kevitsa. Orica does not have its own safety officer on site, but Hartikainen, another contractor with much more staff on site actually has its own safety officer. Problematically for this report, these documents are usually developed in Finnish. At Tara mine, "Statements" serve as more general guidelines. They are drafted by a safety officer, reviewed by the safety manager, and then signed by the general manager. The development of such statements is a legal requirement under the Mines and Quarries Act 1965.

8.3.2. Operational Management System & Standard Operating Procedures

An online Centuri-system is used to manage all documents and data on rules, procedures, risk assessments and other safety issues by all mines. In the case of Sweden this is a centralised system, Finland and Ireland have separate systems. In a vast majority, these documents are written in the native language of the country where the mine is operated, since most documents are directed to people in the field as well. Nevertheless, documents are increasingly translated into English as well, but are still kept separate, which makes it necessary to always develop new procedures for each mine, especially these located outside of Sweden, even when this might not be necessary. The Centuri-system is accessible to all staff.

More detailed operating procedures in Finland, follow from Orica's practices as well. It is common here as well to include people with different viewpoints (e.g. safety officers, operators, engineers) in the drafting of these procedures. Blasting plans are however continuously developed, and in case of problems (for example misfires) Boliden engineers together with Orica chargers try to improve the operations. In Tara, more detailed SOP's and safety guidelines are being used. These always include a scope, purpose and definition included in the document. These documents are to be usable in the field by miners. Sometimes particular practices and requirements are imported from Sweden.

8.3.3. Incident Reporting

An important part of safety management is the reporting of deviations of procedure and investigations into incidents, being understood as accidents leading to some form of material damage or personal injury, or near-misses of such accidents. Mine safety requirements also explicitly require the reporting of incidents leading to LTI's and lethal injuries, and incident reporting systems should therefore be implemented. The way this is done differs significantly between Sweden and the other two countries; in Sweden incident reports are gathered centrally to Boliden's office, whereas in Ireland and Finland these systems are separate. Although serious incidents are always reported, company-wide practices in which minor deviations are reported are also very different. This makes it hard to compare safety statistics, although an attempt has been made in Chapter 9.

8.3.4. Improvement/Checks on Practices and Operations

Central Boliden safety policies are sometimes audited by external parties, and the proximity of Kankberg to Boliden also makes it relatively easy to stay in close touch. In general, the Swedish mines appear to exchange a lot of information and practices. Internally, checks are carried out by shift bosses and superintendents. In Kevitsa, Orica has a great level of independence, and there are no structural checks of operations by Boliden staff; still, Orica is for example included in the same safety reporting standards, and also discusses operational issues regularly with Boliden staff. Tara does not externally review their policies, and all development is done separately from Sweden. This does not mean that knowledge and experience from Sweden are not used. Shift bosses visit at least once per shift to see if everything is going well. In some cases, the heads of section, who stand above shift bosses in the hierarchy may go down as well for inspections.

8.4. Responsible Persons

The first issue that is interesting to discuss is how responsibilities, that should be assigned for specific tasks according to the various legislative requirements, have been assigned in practice. Given the large differences in scale between the various mines, this may be a field that is hard to compare. The objective is to find out if it is possible to distinguish some pattern in the assignment of responsibilities, and whether there are certain advantages or disadvantages to for example the use of contractors, or whether different responsibilities should be distributed among different people or assigned to one person only. Table 26 shows that no breaches of legal requirements have been found in relation to this topic.

TABLE 11: COMPLIANCE RESPONSIBLE PERSONS

Part	Kankberg	Aitik	Tara	Kevitsa
1A				
1B				

8.4.1. Training & Licensing

In Sweden, there appears to be a big difference between Kankberg and Aitik, presumably based on their size. For example, chargers in Kankberg also do some other tasks in the mine, and do not have a blasting license. In Aitik however, there is a standard crew of three people per shift just carrying out charging works, and all of these three have a blasting license.

In Kevitsa, the responsibility for obtaining licenses lies completely with Orica. Boliden does not check background requirements and similar issues for the chargers of Orica. During the visit, two summer workers were trained; during the summer, the crew will not consist of all-qualified staff, but these summer workers will never work independently. The mine superintendent does however have a blasting license as well.

In Tara, the chargers do not need to have a license themselves; it is the shift bosses that regularly check the works and have the necessary blasting license. Importantly, both contractors (doing part of the development works) and the internal shift bosses have their own Blasting Foremans and are responsible for their own works.

8.4.2. Responsibilities for Different Tasks

The biggest differences between the practices at the different mines are arguably the division of responsibilities; as can be seen in Table 12, there is no mine the same when it comes to who does what. However, it turns out that there is some noteworthy overlap, primarily based on the distinction between surface mines (Aitik and Kevitsa) and underground mines (Kankberg and Tara), and on the size of the mines. Some interesting features:

- The Blasting Foremans are shiftbosses underground, in Kevitsa this is the Mine Superintendent and in Aitik this is one of the chargers. This could be because charging activities in Kevitsa are carried out by a contractor, there is therefore no "lower" staff of Boliden working with charging.
- Planning is carried out primarily outside the mine site in Kankberg; this presumably has to do with the small size of this mine.
- In Sweden, the bulk of safety procedures is managed centrally; outside Sweden this is done by the mines themselves.
- The supply and storage of emulsion is always the responsibility of the contractor; in Sweden this is Forcit, outside Sweden this is Orica. However, in the underground mines this responsibility stops at the end of storage, whereas in surface mines the supplier also loads the hole. It is suggested that this has to do with the practicality of just driving a truck into the surface mine from the storage of manufacturing next to the site, whereas with underground mines there has to be a transfer of vehicles anyway.
- Storage is always carried out by Boliden staff themselves, unless the charging is carried out by a contractor (Kevitsa).

- Importantly, training on how to use emulsion trucks is always carried out by the supplier. This is in fact a legal requirement.

8.4.3. Contractors

The role of contractors varies significantly; in Kankberg their role is limited to supply and the necessary trainings that follow this, whereas in Kevitsa all explosives handling and blasting works are carried out by a contractor. It does not seem the case that actual safety practices differ significantly based on whether a contractor is responsible or not. The most important notion to take away, is that in all cases where contractors carry out more than just emulsion loading they have their own Blasting Foreman.

Table 12: Responsibility Assignment Visited Mines

Task	Aitik	Kankberg	Kevitsa	Tara
Blasting Foreman	Chargers	Shift Boss	Mine Superintendent	Shiftboss
Development Drilling plan	Mine planning department on site	Drill & blast engineer Bolidenområdet	Mine Planning/Blasting Engineer	Mine Planning
Development blasting plan	Blasting engineer on site	Drill&blast Bolidenområdet	Blasting Engineer	Blast Engineer
Development Safety Procedures	Boliden Central Office & Indenpendently	Boliden Central Office	Health & Safety, Operational	Health & Safety Officers
Storage Emulsion	Contractor (Forcit)	Contractor (Forcit)	Contractor (Orica)	Contractor (Orica)
Storage, explosive materials	Boliden	Boliden	Contractors (also for special blasting)	Boliden
Priming-Development	Chargers	Charger	Contractor (Orica)	Boliden & Contractor
Charging-Development	Contractor	Charger	Contractor (Orica)	Boliden & Contractor
Priming-Production	Chargers	Charger	Contractor (Orica)	Boliden
Charging-Production	Contractor	Charger	Contractor (Orica)	Boliden
Training emulsion charging	Contractor	Contractor	-	Contractor (Orica)
Stemming	Contractor	-	Contractor (Orica)	-

8.4.4. Governmental Oversight

In Finland, the Mine inspector comes from Toukes, the national chemicals safety body. He also inspects the storage. The safety department is responsible to prepare these visits. In Tara, oversight from the government is done by the Mines Inspector, following the Mines and Quarries Act 1965. He visits twice a year and does a thorough check, including visits into the actual mine. On top of this, inspection of the explosives handling is carried out by the Department of Justice once a year. This makes the governmental requirements stricter than in Sweden and Finland, specifically in regards of security issues. This seems to fit the picture of generally much stricter legal requirements related to explosives handling and storage, this may have to do with the long history of terrorism on the Irish island. There seems however little sense in comparing this closely, since governmental oversight is the responsibility of the government and not of Boliden.

8.5. Explosive Standards

Explosive standards are for a large part based on EC Directives 2008/43 and 2014/28, and should therefore be relatively easy to compare. Still, it turned out that many practices on tracking & tracing them are different. Also, different mining techniques make that the quantities and types of explosives used differ.

Explosives standards may be the stage in the explosives handling part that could least be checked, since it is the responsibility of manufacturers, and not of mines, to ensure that explosive materials meet the necessary safety requirements. The responsibility of Boliden in this regard is to ensure that there is no reason to doubt whether this is actually the case, but no detailed study has been taken in this regard for the purpose of this report. As far as could be judged on a quick look there are no problems in this regard, but since this has not been assessed closely for all mines compliance is marked as unknown.

In regards of track & trace systems and requirements specifically following mining regulations a closer assessment could be made. Tara, Aitik and Kankberg have implemented digital scanning systems, which allow for explosives to be traced real-time. Kevitsa still maintains bookkeeping by hand, although this will be replaced in the foreseeable future.

TABLE 13: COMPLIANCE RESPONSIBLE PERSONS

Section	Kankberg	Aitik	Tara	Kevitsa
2 §1-5; §11-13				
2- §6-10				
2- §14-22				

The implementation of track & trace systems is a relatively new development; although the law already provided for the need to register stockpiles of explosive materials exactly, it is now expected to have a much more real-time idea of what explosive material, both as total packages as an individual item is where. This means that all items need to be easily scannable. Tara and the Swedish mines have also already implemented systems to scan all separate items.

Tara mine seems to be the most advanced mine in this regard, in the sense that the "Scheme of Transit" has implemented detailed requirements in this regard, from ordering, to delivery at the face. Still, difficulties with the explosives ordering and track & trace system implemented have led to rejection of this system and a return to previously used systems. Even this current system does not seem to work perfectly however, with errors during scanning, presumably due to bad server connections or other issues internal to the program.

As can be seen, Kevitsa has been marked as in need of improvement. It is not the case that violations of legal requirements could be noticed, but Kevitsa is planning a new storage, among other reasons for the purpose of implementing a digital track & trace system. Kevitsa is therefore an interesting mine to keep an eye on in regards of further developments in this regard.

8.5.1. Materials Features

Issues related to specific mining issues, such as the delay times that should be visible on detonators, the requirement to keep explosive materials in their cases as long as possible, and the materials used to open these cases were all followed closely. Even when more people work at the same time on a bench/face, still each product is unpacked box by box.

Selection of explosive materials relies on a combination of economic considerations, their reliability and safety aspects. No clear ranking in these priorities was given when asked.

Performance of explosive materials is monitored; when in Aitik the number of misfires increased significantly during 2016, it was found that this was to blame on the detonators, that apparently did not perform optimally in the conditions in Aitik. As a consequence of this, different detonators are in use nowadays, and this has indeed led to a significant drop in the number of misfires.

8.6. Storage

Storage is presumably the stage on which most regulations exist, still, most of these regulations do not affect daily workings at the mine, since they deal with the selection of the location of the storage and the standards on construction. As can be seen, the fairly straightforward storage rules were deemed to be applied consistently with the law; Ireland has been marked as much stricter, this has to do with the fact that the entire distinction between magazine and reserve station, and specific tasks of the powdermen, makes the practice in Tara relatively complicated, as seen in Table 14.

TABLE 14: COMPLIANCE STORAGE

Part	Kankberg	Aitik	Tara	Kevitsa
3				

When selecting the right location for the storage it is important to minimize possible interference with other activities in the mine; storages tend to be located at more remote locations therefore. Figure 15 displays the location of storages in Tara. As can be seen, the Explosive & Detonator Magazines are located far from the main operations. The Reserve station is in the same area, but closer to the main road. The location of emulsion storages in Tara are located much closer to the main roads, this makes sense since the need to regularly drive in large trucks for refilling and out for charging makes it more convenient to be located closely to the haulage road. This does not pose a hazard, since while stored, the emulsions are still not mixed. In Kankberg, the emulsion storage was closer to the explosives storage. In Aitik, emulsions are brought in directly into the mine from their manufacturing site in the Aitik business area, explosive materials are stored closer to the mine but also far from office buildings. In Kevitsa emulsions are stored near the restrooms of Orica, whereas explosive materials are located on a remote fenced off site.

It was found that the security measures at the Tara magazine are very thorough compared to the other mines visited; only the powdermen have access to the magazine, and are only allowed in with permission from an external security officer located in Dublin, who confirms the identity of the powderman with a password. The entire area is also under constant camera supervision. The reserve station, storing a load of up to two days of explosive materials, seems more comparable with the Nordic storages. To this place not only the powdermen, but also the shotfirers can have access, and no external permission at the time of entrance is required. The general reserve station and the separate explosives and detonator stores all have their own locks. It is allowed everywhere to keep the main entrance open when people are there.

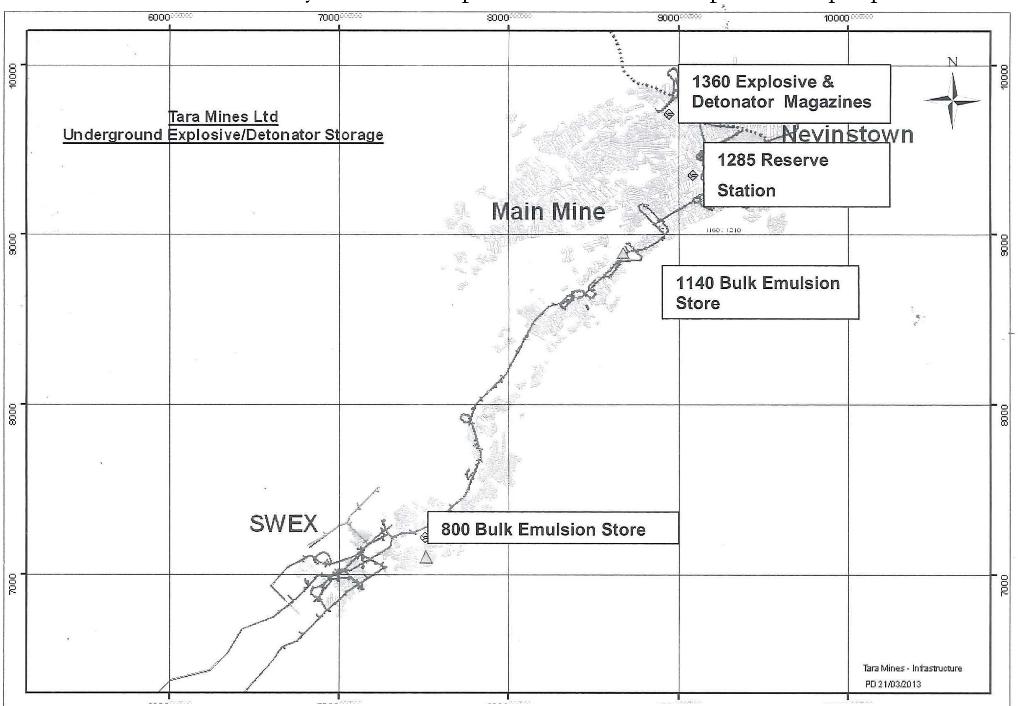


FIGURE 15: OVERVIEW OF STORAGE LOCATIONS IN TARA

Some impressions of storages can be seen below, see Figure 16. The conditions of storage vary between the different mines; the underground mines use unused headings (Tara) or newly excavated spaces (Kankberg), in regular steel containers in a remote area (Kevitsa) or in a specifically constructed storage (Aitik). At the entrance of the storage the appropriate signs should be visible, including the conditions of the permit and a copy of the permit itself, which is standard practice and legal requirement in all countries. In one case, there was an outdated permit still in place.

Stockpiles are checked each month in Kevitsa, on top of the regular bookkeeping, to see if the bookkeeping is still correct. Boliden gets an update on the materials used each two weeks via the invoices issued by Orica, this is the main way in which they are aware of the stockpiles. On the storage site, another small contractor also has their own containers, with separate locks, for the materials needed for the special blasting tasks they are responsible for. At Tara, explosive materials are prepared by the powdermen, and not like in the Nordic mines, gathered by the chargers themselves. For each phase, a separate set of explosives is assembled, based on the blasting plan issued by the blasting engineer. These are then delivered to the blast site. This assembling is carried out in the reserve station. Shotfirers can also sometimes pick up the sets from the reserve station.

In any case, when comparing the different explosives handling and blasting practices it is clear there is no other area where practices differ so much between countries as with the storage of explosives, where Ireland clearly has put much higher requirements on the storage standards.

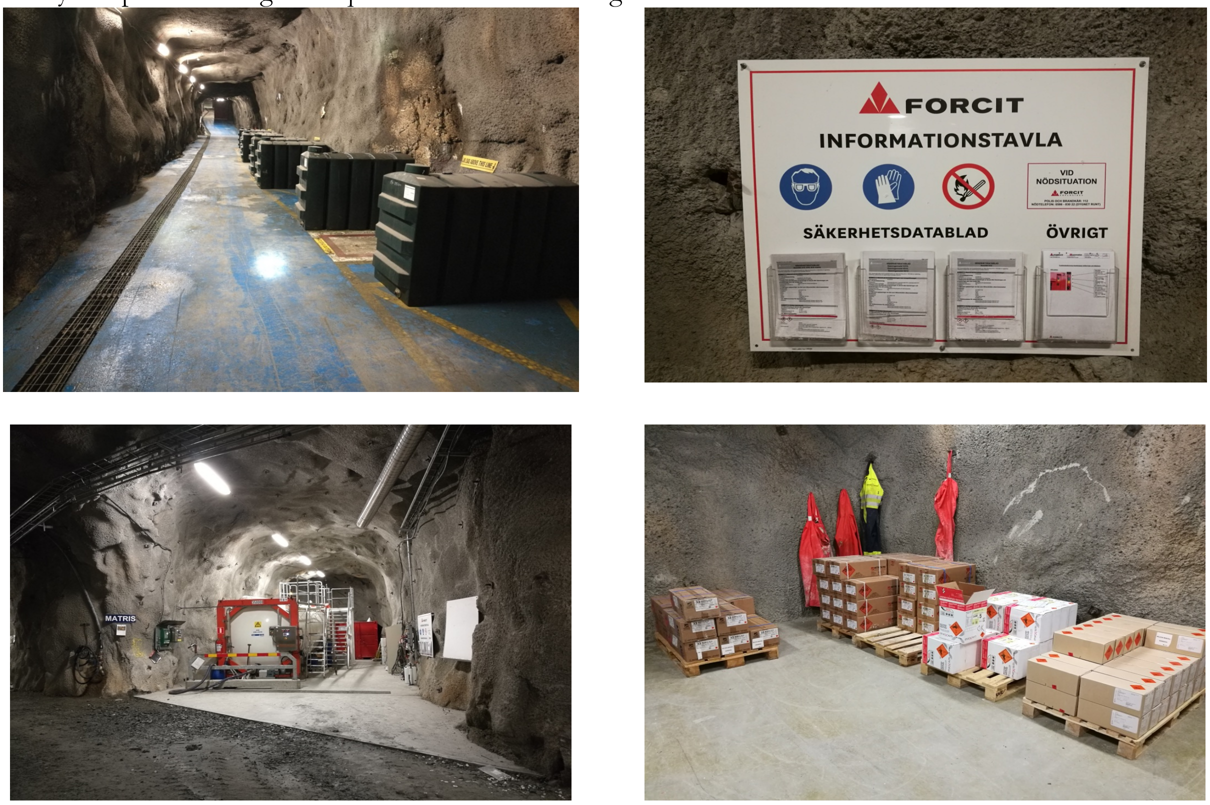


FIGURE 16: IMPRESSIONS FROM, CLOCKWISE FROM TOP LEFT; WATER BUFFERS IN THE MAGAZINE BETWEEN STORAGE SECTIONS IN TARA, PERMITS AND INSTRUCTION MANUALS IN KANKBERG, EMULSION STORAGE IN KANKBERG AND ORDERLY PRIMER STORAGE PRIOR TO CHECKOUT IN KANKBERG

8.7. Transportation

Transportation is a relatively small topic when it comes to explosives handling; legal requirements primarily relate to how vehicles should be equipped, and the need to transport explosive materials separately. It has not been researched to what extent requirements for transport on public roads have been met. Since there is no need for a comprehensive scheme of transit in other operations than these in Ireland, this requirement has been labelled as irrelevant for the other mines. The scheme of transit also regulates other activities in the explosives handling cycle, but it is discussed only here. Table 15 indicates that Tara is again somewhat distinct from the Nordics in its application of the standards following the CLR.

TABLE 15: COMPLIANCE TRANSPORTATION

Part	Kankberg	Aitik	Tara	Kevitsa
4, §1				
4, §2				
4, §4-6				

FIGURE 17: EXPLOSIVES CAR (AITIK) AND CHARGING EQUIPMENT (KEVITSA)

Some of the cars used to transport explosive materials can be seen in Figure 17. Emulsions are brought to the site in special trucks, that also have the equipment to mix the blasting agents right before the loading. In all cases they are equipped with the necessary signs, lights and fire extinguisher. In the case of Kankberg, other explosive materials are also carried on this vehicle; this does not pose a safety risk however, since during the transport the agents are still not mixed and therefore not explosive. Cars used to transport more sensitive explosive materials have separate compartments, as can be seen on the picture the necessary flag in surface mines, and always carry fire extinguishers, signs and lights. No special driver's licenses are necessary, except for the license that all mines issue to people that have proven they can drive safely in the mine.

Distinct from the other mines, explosive materials in Tara are almost always exclusively moved by the powdermen, before they issue them at the blast site to the chargers. When delivered at surface, transports are still guarded by police in Ireland, and they only leave when it is confirmed that the explosive materials have been moved into the mine. All transports from surface into the mine, and transports between magazine and reserve station are also carried out by the powdermen. The "powderman" is a phenomenon not known in the Nordic mines, where all explosives can be obtained and moved from storage by the chargers. This entire practice is regulated in the extensive scheme of transit.

This also means more scanning moments in Ireland compared to operations in other countries, where explosives are "checked in" when delivered to the storage, and "checked out" when ready for transport to the blast site. In Tara, on top of this there is also the move from magazine to reserve station, and the official issue of the explosives to the Blasting Foreman at the blast site.

8.8. Charging

Charging is arguably the topic that involves most detailed procedures for miners in the blasting cycle, since this is the stage that determines the quality of the blast and involves the most people working at the blast site. For this reason, all mines have developed an extensive set of SOP's, based for a large part on legal requirements. Various interesting cases are discussed here. To start with, there are several issues in applying the legal requirements where mining operations seem to have different standard compared to some of the legal requirements that appear to be more connected to civil engineering practices. Table 16 shows that there are some more problematic issues surrounding the multi-country wide implementation of legal requirements.

TABLE 16: COMPLIANCE CHARGING

Part	Kankberg	Aitik	Tara	Kevitsa
5A				
5B				
5C				
5D				
5E				
5F				

Issues related to 5A deal with the development of the blasting plan. This has been singled out since the actual practice in surface mines seems to contradict the legal requirement that the Blasting Foreman has to at least co-develop the blasting plan; in all mines, the blasting plan is developed by blasting engineers or even mine planners, who are not the Blasting Foreman. Then, the Blasting Foreman in the field usually simply applies a standardised practice, and in the case of Kankberg, Kevitsa and Tara the Blasting Foreman is the supervisor or superintendent, in other words someone who does not make the blast design, nor does the charging work himself. This regulation is therefore one that seems more applicable to smaller scale civil engineering operations. In mining operations, most of the blasting work is standardised, and is a repetitive process. This does not mean that the Blasting Foreman is not involved at all in, if necessary, changing the blasting plan; in Aitik it even can happen that the chargers suggest small adaptions when charging in the field. By these opportunities to influence standardised plans it seems that the regulatory requirements are being met.

Part 5C is marked as "irrelevant", not because the regulations on the working environment during charging do not apply, but because there are two issues to note in this regard that make three of the regulations less applicable. The first regulation, to ensure proper lighting, is applicable, and is carried out by lights on equipment in underground mines and by lighting towers in the surface mines. The indication of shelters (§2) appears to be more related to civil engineering, in mining simply the entire pit or underground mine is evacuated for a blast. In regards of §3, electrical detonators are not usually used, only for special blasting. §4 demands that a charged area is kept under constant surveillance; in surface mines, it is common that a field is kept charged for a few days before it is blast, and there is no constant surveillance of these fields. This is not necessary since only authorised people can come into the mining area (the entire mine is fenced off). Still, charged areas are marked, warnings signs placed, and if close to haulage roads even a berm can be used to stop vehicles from driving through the field.

Another legal requirement, mentioned in Part 5E, that does not seem to be met is that no drilling is to take place within close range of charging activities; in these surface mines, it is however common that the drilling jumbo operates right next to each other, in different fields. If during charging it turns out that a hole is not charged well, the drilling jumbo can come in to charge the hole. This however always happens under supervision of the chargers, and can therefore be considered to be safe. Aitik has singled out, since they have obtained an exception from the mining authority to drill close to previously drilled holes from the bench that has just been blasted

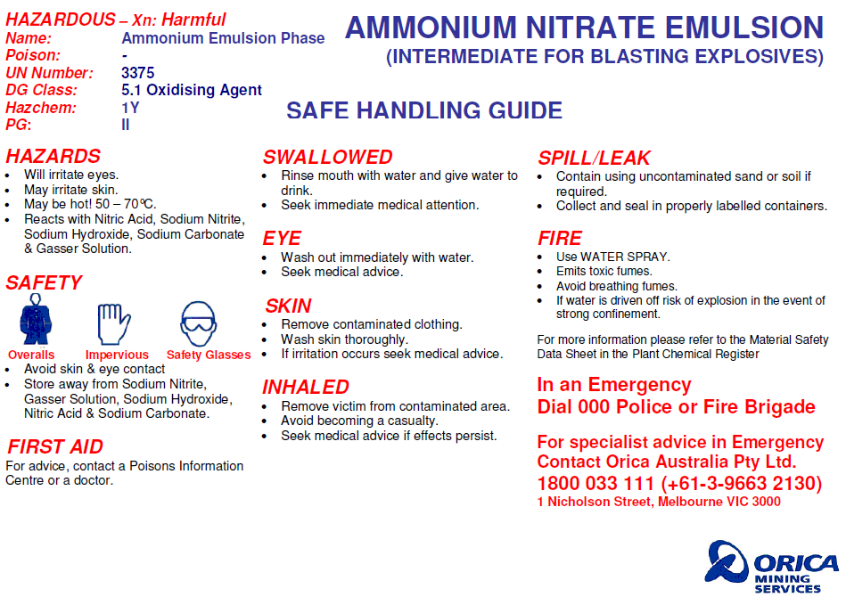
8.8.1. Charging Procedures

Implementation of requirements on charging have been elaborated on in great detail by all three mine sites, in the form of rules and SOP's for chargers. shows a (Swedish) flow-chart for the work flow of a charging process, from the moment of a drillhole being ready for charging until the moment when the round of charged holes is deemed ready for loading and hauling after the blast. In the spreadsheet document where this chart is from, per stage in the chart guidelines were connected, outlining more specific safety regulations per stage. Examples of these guidelines are the AOG-HMS rules that were discussed previously. Several stages are ended with a check, where in case things are not ok contact has to be made with either management or the maintenance shop. SOP's also show drawings of for example how to tie initiation wires, or manuals on how to use certain pieces of equipment. Before such SOP's have been drawn up, risk assessments have been undertaken for the procedure (as legally required), and these documents are continuously updated if necessary.

8.8.2. Charging Equipment

As legally requirement, trainings and documents on the usage of charging equipment is supplied by explosives suppliers in all cases. Some hazards associated with the charging process that are not specified in the various safety regulations are also covered in internal guidelines. The fitting of drillholes with cart board in Kevitsa is an example of this (Figure 22). Chargers in Aitik use colour to mark if there are issues with blastholes, and when they are finished. In underground mines the lowest holes in a face are blocked to prevent inflow of dirt. All of these tasks are related to ensuring clean blastholes, which is legally required to ensure and minimizes the chance of misfires.

As an example of guidelines that do not follow from direct legal requirements nor from internal experience, this example of charging equipment issues is given; although the risks associated do not occur frequently, manufacturers tend to have more experience in this field, since they usually work in many mines around the world. In relation to charging equipment, many safety hazards exist. It is a noteworthy legal requirement that manufacturers provide trainings for these pieces of equipment, examples can be seen in Figure 21 and Figure 18. It turns out that the biggest hazard of ammonium nitrate emulsions is not detonation, but rather health effects. This sheet from a safety training by Orica has therefore been included, as a typical example of such a training. Apart from health issues, there still is a very small risk for explosions, when charging pumps and hoses are not clean; if this happens the system can get blocked, and as a consequence of this a so-called "hot-spot" can develop, which continues heating up the system, with theoretically very dangerous results. Therefore, detailed cleaning and maintenance requirements are being issued, even though they have little underlying requirements in mining explosives legislation.


HAZARDOUS – Xn: Harmful
Name: Ammonium Emulsion Phase
Poison: -
UN Number: 3375
DG Class: 5.1 Oxidising Agent
Hazchem: 1Y
PG: II

AMMONIUM NITRATE EMULSION
(INTERMEDIATE FOR BLASTING EXPLOSIVES)

SAFE HANDLING GUIDE

HAZARDS
- Will irritate eyes.
- May irritate skin.
- May be hot! 50 – 70°C.
- Reacts with Nitric Acid, Sodium Nitrite, Sodium Hydroxide, Sodium Carbonate & Gasser Solution.

SAFETY
Overalls Impervious Safety Glasses
- Avoid skin & eye contact
- Store away from Sodium Nitrite, Gasser Solution, Sodium Hydroxide, Nitric Acid & Sodium Carbonate.

FIRST AID
For advice, contact a Poisons Information Centre or a doctor.

SWALLOWED
- Rinse mouth with water and give water to drink.
- Seek immediate medical attention.

EYE
- Wash out immediately with water.
- Seek medical advice.

SKIN
- Remove contaminated clothing.
- Wash skin thoroughly.
- If irritation occurs seek medical advice.

INHALED
- Remove victim from contaminated area.
- Avoid becoming a casualty.
- Seek medical advice if effects persist.

SPILL/LEAK
- Contain using uncontaminated sand or soil if required.
- Collect and seal in properly labelled containers.

FIRE
- Use WATER SPRAY.
- Emits toxic fumes.
- Avoid breathing fumes.
- If water is driven off risk of explosion in the event of strong confinement.

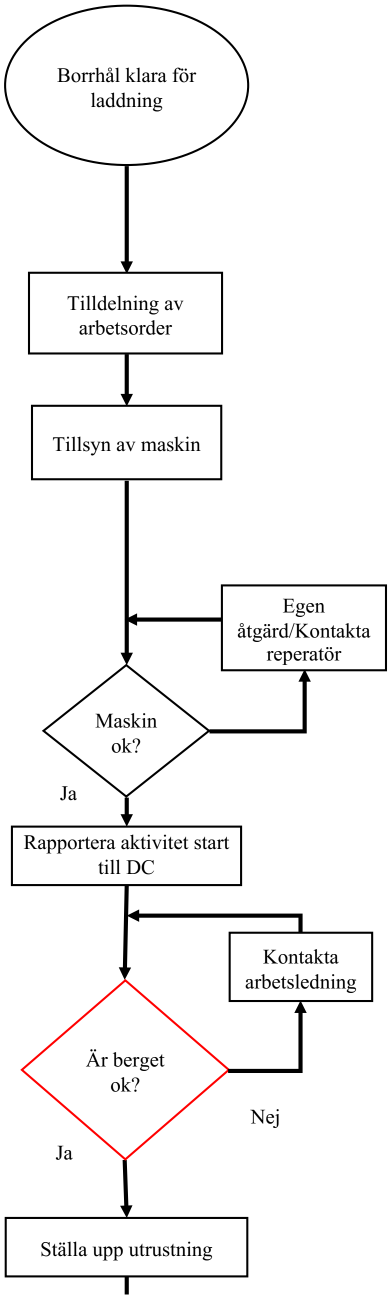
For more information please refer to the Material Safety Data Sheet in the Plant Chemical Register

In an Emergency
Dial 000 Police or Fire Brigade

For specialist advice in Emergency
Contact Orica Australia Pty Ltd.
1800 033 111 (+61-3-9663 2130)
1 Nicholson Street, Melbourne VIC 3000

ORICA MINING SERVICES

FIGURE 18: EXAMPLE FROM ORICA TRAINING FOR CHARGERS



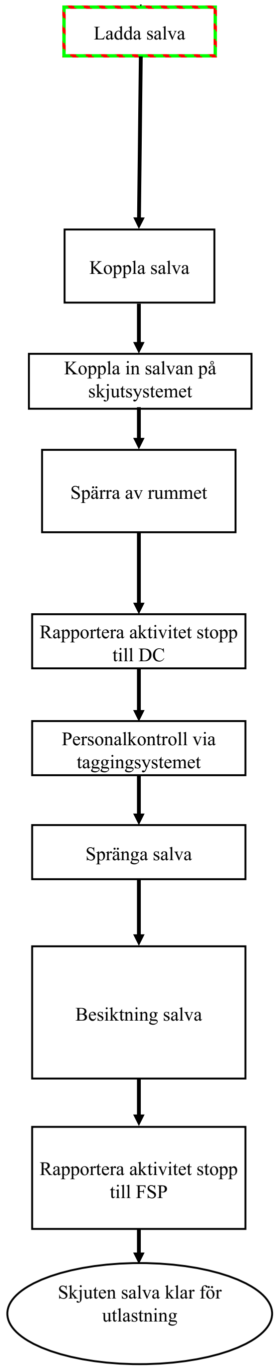


FIGURE 20: SAMPLE BLASTING FLOWCHART

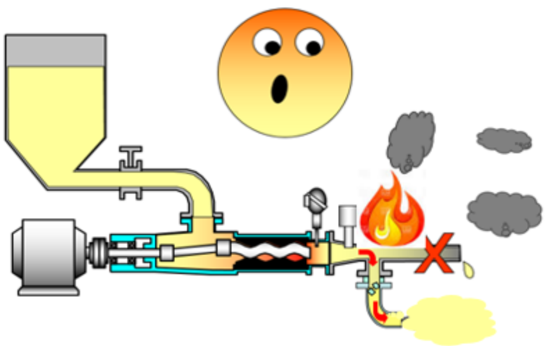


FIGURE 21: BLOCKING OF EMULSION PUMP

FIGURE 22: CARTBOARD PROTECTION OF DRILLHOLES

8.9. Blasting

Blasting procedure is a particularly interesting topic, since it determines the rhythm and shifts at the mine, and thereby influences everyone, not only people who directly work with explosives. A big difference in blasting practices in this regard is that Kankberg blasts daily and Tara twice daily, whereas the surface mines blast around two times per week. This has of course implications for the size of the blast and the time a charged face or bench is not blasted.

In relation to blasting procedure Kevitsa has been singled out in Table 17, since their charging work is carried out by a contractor, but the responsible Blasting Foreman is from Boliden. This makes that the literal requirement that blasting can only be carried out if the holes have been charged by the Blasting Foreman himself or someone under his supervision somewhat difficult, since there is no close supervision of the charging by Orica. Instead Orica does the check of the charged works themselves, and then hand over responsibility to the Blasting Foreman. His responsibilities in this case are thereby limited to ensuring that the entire area is evacuated properly, and if necessary, precautions have been taken. No assessment of special blasting practices has been done.

TABLE 17: COMPLIANCE BLASTING

Part	Kankberg	Aitik	Tara	Kevitsa
6A				
6B				
6C				

8.9.1. Underground Blasting

An interesting aspect of blasting planning is that it has been standardised for regular development operations. Figure 23 shows an example from Kankberg. This plan is included in the SOP, and can thereby be used by chargers when charging holes. The numbers in the plan indicate the delay time, and are therefore crucial to be followed closely to ensure successful blasting. During blasting, only the Blasting Foreman, in Tara accompanied by the shift bosses from both Boliden and contractor, and if necessary someone from Orica to program electronic detonation are present in the mine.

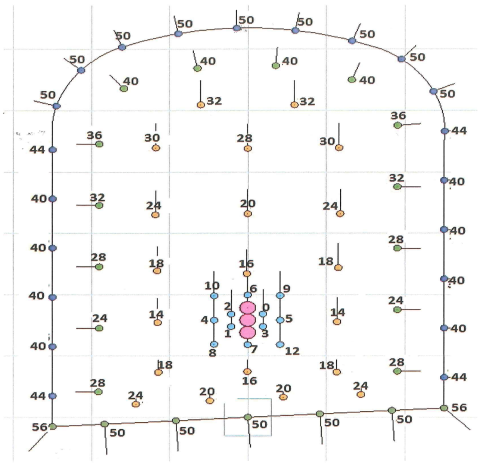


FIGURE 23: BLASTING PLAN FOR KANKBERG RAMPS

8.9.2. Surface Blasting Issues

The most important issue during blasting is the evacuation. For underground mines this means evacuation of the entire mine, for surface mine a distinction is made between three danger zones; one for heavy equipment (300m), one for the other equipment (600m) and one for people (1200m), the distances in Kevitsa and Aitik are similar. An example of an evacuation plan for a blast in Aitik can be seen in Appendix IX.H. The small circles indicate places that need to be guarded. It should further be noted that surface blasts are always planned such that they would not hinder each other, they will therefore usually be located on different sites in the mine. An alternative to removing equipment or infrastructure is by providing cover; it is currently common in Kevitsa to cover power cables close to the mine with contour blasting, and in a rare case an excavator has even been protected by letting two haulage trucks protect it by facing their bucket upwards to shield it from incoming flyrock.

8.10. Post-Blasting

Post-blasting is a relatively straight-forward topic, since the legal requirements in this regard primarily relate to several inspections to ensure the area is safe to re-enter. Other requirements relate to subsequent scaling and the disposal of explosive waste, all of which seem to be aligned with closely in practice. As can be seen in Table 18, there were no practices deemed to need further elaboration. Table 18 shows that no unconformities have been discovered for this topic.

TABLE 18: COMPLIANCE POST-BLASTING

Part	Kankberg	Aitik	Tara	Kevitsa
7A				
7B				
7C				

Verifying that air quality standards are sufficient form the first part of checks after the blast, only after this the other checks are carried out. Misfire checks then follow, and are then completed by an assessment of the quality of the rock, to see if additional scaling by means of special blasting or other means are necessary. All mines have materials available to do both smaller special blasting or use mechanical tools to fracture smaller rocks.

8.10.1. Misfires

Since misfires are arguably the largest hazards in relation to explosives handling and blasting, and each mine therefore has procedures in place regarding misfire checks. An example of a misfire report template is given in Appendix IX.K. Operators of loading and drilling equipment are all trained to spot misfires, at least once every two years. In Kevitsa these trainings are provided by Orica. If misfires are found, they are always brought back to storage, where they can be kept for a short while, after which they are usually destroyed in another blast. Only the Blasting Foreman is allowed to handle misfires; for this reason, if no Blasting Foreman is present works around the site cannot continue. In any case it appears that these technical checks are fairly similar in all mines. Other material used for explosive handling or blasting has to be destroyed when it is not used anymore according to procedure; Figure 24 shows the packaging of explosives being burnt at the end of a shift.

FIGURE 24: BURNING OF EXPLOSIVES PACKAGING IN AITIK

8.11. Conclusion

It can be concluded that there do not appear to be any breaches of the various legal requirements at the researched Boliden mines, except these based on different storage requirements; still, there are some deviations in some cases, when the regulations issued appear to be more concerned about for example populated areas, or other issues that are not relevant to mining operations. When it comes to most working practices they appear to be fairly similar, especially when their background is in the best practices of for example explosives suppliers. Working practices, especially these related to charging and blasting, are always worked out in great detail, and all people that were interviewed were well aware of them and their requirements. The main difference, as could be expected after the previous legal findings, lie in the consequences of the strict Irish regulations on storage and transport of explosive materials. The most concerning issue is probably that Boliden mines outside Sweden are not included in the operational management system, which makes it much harder to exchange relevant experience and standards.

9. Complications and Incidents

In this chapter, a study is made of typical complications and incidents that have occurred in the field of explosives and blasting safety. This is done in order to get a picture of typical workplace hazards associated with the working with explosives. Also, the practice of reporting incidents is an important aspect of effective workplace safety management; following the duty of care that has been imposed on the employer, both in general workplace safety legislation and on more specific issues, it is important to be aware of the fields of work that give cause to concern. If it is known what the fields of concern and its root causes are, steps can be taken to improve the safety performance of the mining performance and thereby the meeting of essential safety requirements.

Sources used for this chapter have three different backgrounds; statistical data provided by Boliden, making it possible to quantify the different types of incidents occurring; input from interviews undertaken at Boliden Mines and it central office on accidents causing concern (notes on these field trips can be found in the appendix); and finally, statistical data and analysis from mining operations in Australia and the United States. The aim is to at the end of this chapter have a good picture of the fields that deserve extra attention and the type of measures that would be necessary to take following suspected causes of failure, with a focus on underground mining operations.

9.1. Approach

Assessing safety risks and trying to draw useful lessons from this is quite a challenge, given that actual accidents leading to physical injuries have not occurred in Boliden Mines during the past 10 years. The approach in this chapter will therefore be to also look outside Boliden operations, in order to have a larger set of available data to see what issues deserve particular attention. After a discussion of general statistical trends in explosives handling and blasting safety, serious incidents that actually have occurred will be discussed, in order to find out what the central blasting hazards appear to be. Since the ultimate purpose of this chapter is to find out what the backgrounds of possible failures are, most attention will be paid to understanding the (suspected) causes of these failures. Fault tree analysis will be used to see what components of the explosives and blasting process are critical, and incident reports will be studied to discussed to see how often certain (possible) incident causes occur in underground mines. Incident causes will be categorised in three categories, namely material, procedural and external causes, in order to see what measures could best be taken to improve safety and meet both specific and general legal requirements.

Data have been assembled regarding incidents related to explosives and blasting safety in all Boliden mines. The total number of incidents per year has been listed below. As can be seen, a distinction is made between "red", "yellow" and "green" incidents, with red incidents being incidents that have caused physical injuries or material damage, or could have caused such harm and/or damage (thereby including near-misses), yellow incidents are incidents that have been judged to be hazardous in general without a direct threat, and green incidents are breaches of procedure that do not pose a direct threat. See Figure 25 for an overview of the development of reported incidents.

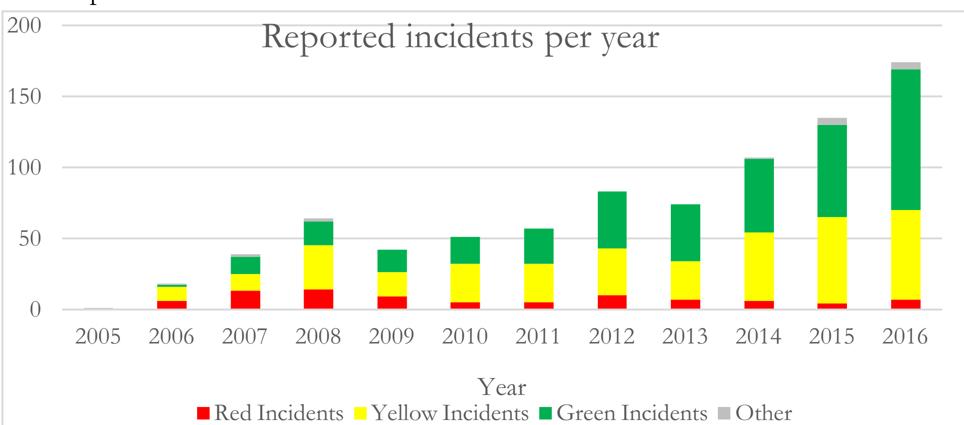


FIGURE 25: DEVELOPMENT OF REPORTED INCIDENTS PER YEAR

9.1.1. Development of Trends Blasting Incidents

As could be seen in Figure 25, it almost seems as if the safety situation related to explosives and blasting safety at Boliden Mines is severely deteriorating; the sharp increase of “green” incidents and to a lesser extent of “yellow” incidents has however been the consequence of a new campaign to make people aware of the need to report any type of incident, even these that pose no direct threat whatsoever or are not even near-misses. The reporting of “yellow” and “green” incidents is not developed in a similar manner outside Sweden. Only the more serious (red incident) data can be compared with cases in Ireland and with external data, since these are all related to actual accidents, and not just to small deviations.

Therefore, the only way to get a credible indicator of the actual safety situation is to compare only “red” incidents. As can be seen in Figure 26: Trend Development Severe Incidents, there is a clear downward trend when it comes to the more severe incidents, with on average more than 3 reported incidents less per year over a period of 4 years, which leads to the current number of serious incidents between 4 and 7 cases per year since 2013. It therefore appears, given that in the meantime production has increased, that the overall explosives handling and blasting safety situation in Swedish Boliden Mines has improved.

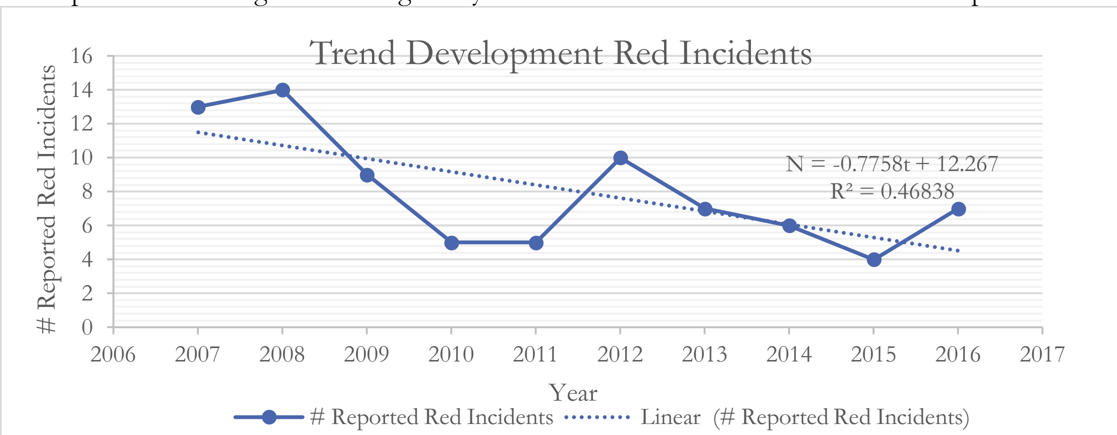


FIGURE 26: TREND DEVELOPMENT SEVERE INCIDENTS

Comparing these data with external data overall the period between 1978 and 2016 in metal mines across the United States shows that a similar trend can be distinguished there (see Figure 27); when looking at the period since 2006, almost no severe incidents have occurred, whereas previously a significant amount of injuries was reported. Also, relative to other types of severe mine incidents, the average number of incidents decreases (as can be seen in the graph, as a percentage of all underground and surface metal and industrial mineral mining incidents). It should be remembered that “red” incidents at Boliden are still much less severe; the data for the US only included incidents that had to be reported to the health authorities, given that they involved severe injuries and, given the nature of blasting operations, casualties.

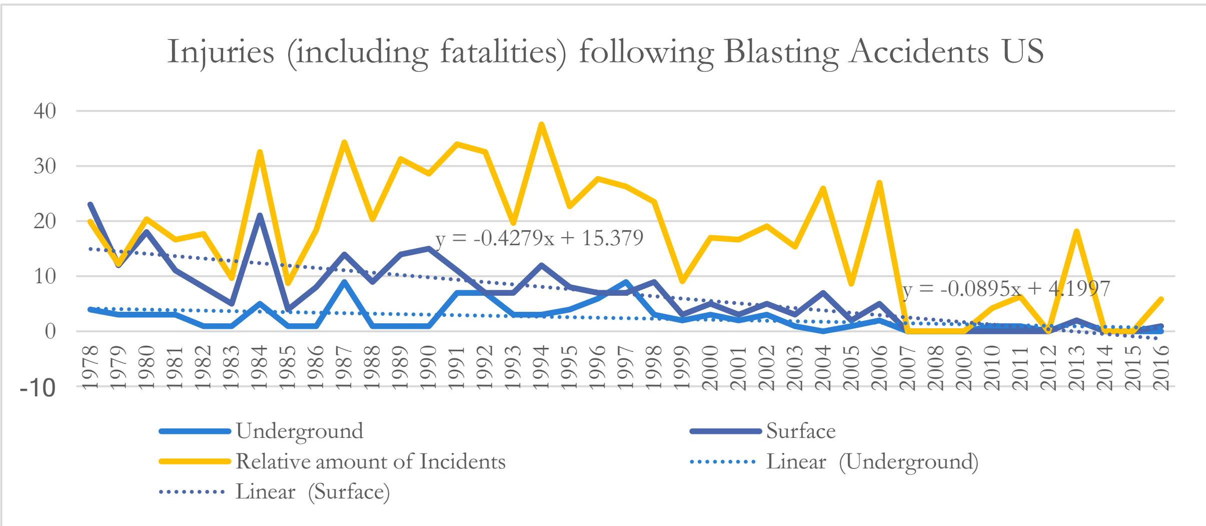


FIGURE 27: REPORTED EXPLOSIVES HANDLING AND BLASTING INJURIES IN THE US

9.2. Severe Incidents

In order to find out what types of accidents should deserve special attention on top of the minimum legal requirements in terms of material selection and procedural development, it would be interesting to know what types of sever incidents have occurred in Boliden Mines and elsewhere.

9.2.1. Sever Incidents at Boliden

Incidents leading to fatalities or injuries requiring medical treatment have not occurred in the pas 7 years as a consequence of blasting activities in Boliden mines (except for minor injuries due to slips, knife-cutting and falls, but these are not part of the scope of this research). However, there have been several more serious accidents and near-misses, the most notable of which are discussed below. Figure 28 shows a breakdown of the relative amount of serious (or red) incidents at all underground Boliden mines.

A. Garpenberg Mine

During a training exercise for blasters in Garpenberg on surface, the reach of flyrock was underestimated. As a consequence of this, debris reached as far as the parking lot. Although no one was injured and no severe material damage occurred the consequences might have been much more severe indeed. Given that this was a non-regular blasting operation it once again highlights the risk of non-regular operations.

B. Tara Mine

Although not a typical health and safety issue, issues with the track & trace system have been a source of concern for Tara Mine. Failing IT-systems make it impossible to deliver explosives to the right sites. Given that improvements failed to deliver, the powdermen even went on strike, leading to a two-day shut-down of the mine. In an accident in Lisheen Mine, a mine similar to Tara in Ireland, a miner's hand was blown of as the consequence of static charging, by a copper wire being rolled off during charging works with one hand, while the detonator was held in the other. Although the accident occurred at a different mine, this has led to the use of different detonators, needing a higher current for detonation in Tara as well.

C. Kevitsa Mine

Given that Kevitsa is a relatively new operation, where a lot of contractors operate, including Orica as blasting contractor, one could expect more severe incident. The most notable incident that occurred, when the mine was still operated by First Quantum Minerals, there was a case of a fuel truck driving out of the pit just before the blast, and after the complete evacuation should already have been complete. The experience in Kevitsa is also that in general contractors appear to have lower injury rates than Boliden's internal staff, and since explosives handling and blasting in Kevitsa is carried out by Orica, overall safety performance related to this topic is relatively good.

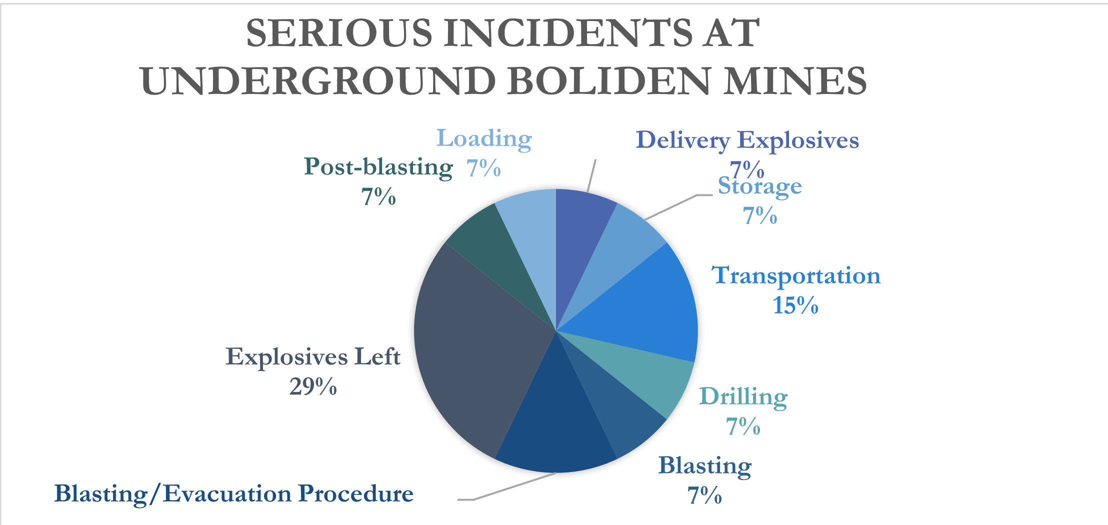


Figure 28: Serious Incidents at Underground Boliden Mines

As can be seen in Figure 28, the largest share of severe incidents deal with explosives left outside the storage; all of these incidents occurred in Sweden, Tara Mine has not reported any incident of this type. The special attention paid to explosives handling, in the form of dedicated powdermen, separate storages inaccessible to all chargers and digitised track&trace systems in Tara can arguably lead to this performance. Otherwise there do not appear to be large distinctions between different mining operations, which makes sense, since apart from their size, there do not seem to be large differences in between the different mines regarding working methods and materials used.

9.2.2. Comparison of Boliden incidents with accidents in the US and Australia

Although it is good to know that actual harmful accidents have not occurred anywhere at Boliden Mines, this does not help in establishing what the main concerns should be; for this reason, broader data from the US and Australia will be used to establish this.

The United States Mine Health & Safety Administration (MHSA) publishes reports of serious accidents and near-misses of serious incidents of all US metal and industrial mineral mines occurring over the past two years; out of 87 incidents reports in between 20 July 2015 and 20 July 2017, only one (1,15%) was related to blasting. In this incident in an open pit quarry, passers-by were hit by flyrock, leading to small injuries (MSHA, 2017). Following data collected by the MHSA between 2010 and July 2016, 7 miners in the United States have died as a consequence of blasting, either by flyrock, toxic fumes or misfires in metal and industrial mineral mines (Mine Health & Safety Administration, 2016).

Similar data are available on mining operations in the state of Queensland, Australia. In between 2005 and 2009 725 serious blasting incidents, both these that led to injuries and these that did not, have been reported to the State government of Queensland; the vast majority of these incidents, 658, were related to misfires; an uncontrolled shockwave was the cause of only one incident, whereas air overpressure and vibration issues were the cause of 2 incidents (Seccatore, et al., 2013).

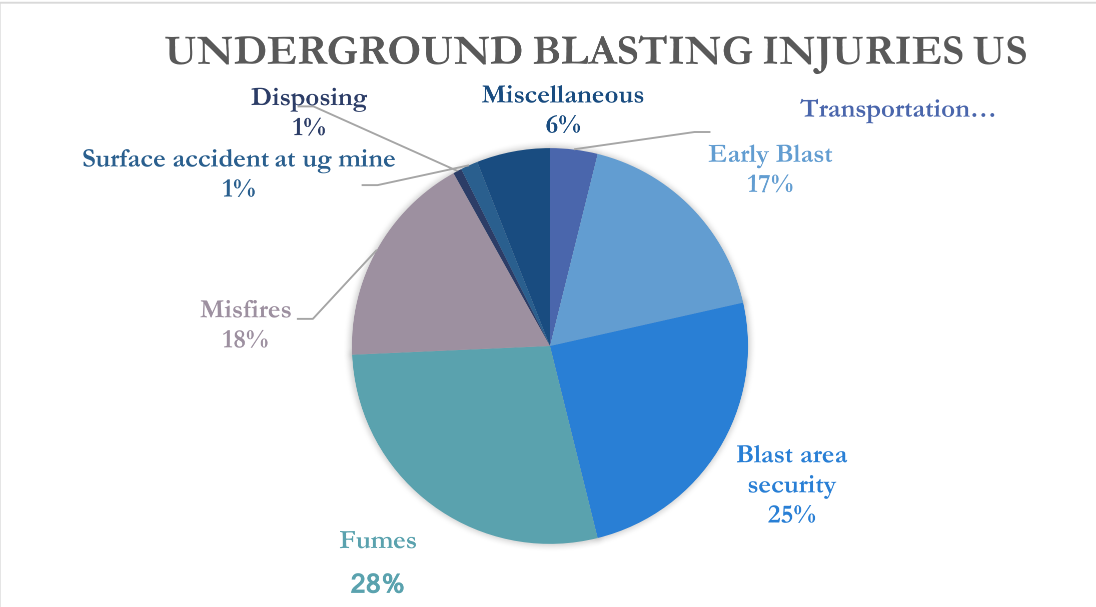


FIGURE 29: UNDERGROUND BLASTING INJURIES US

As for underground mines, both Figure 28 and Figure 29 show a similar picture, if one discounts for the fact that explosives left around are treated as a serious incident but do not cause injury by themselves and therefore cannot be compared with the US statistics. Generally, incident types are fairly evenly spread over different parts of the blasting process, although it is clear that blasting procedure in the US (which will usually mean flyrock hitting people who should not be there) is by far the most common concern when it comes to actual injury.
Figure 30, based also on less severe incidents but just in Swedish Boliden Mines, confirms again that types of incidents are fairly evenly spread for underground mines.

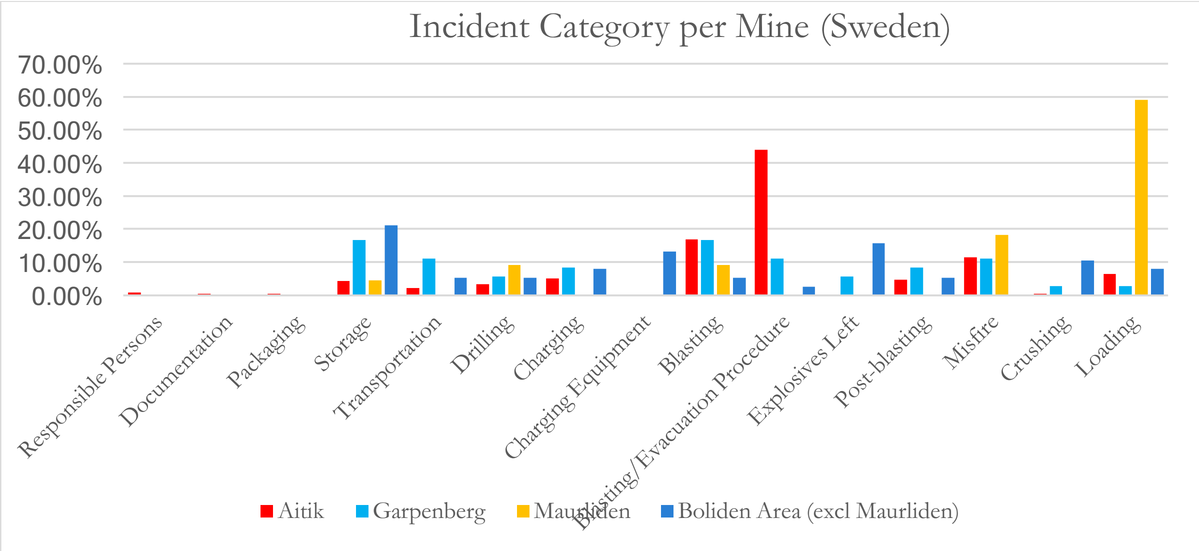


FIGURE 30: DEVIATION TYPES PER MINE

When comparing these injury backgrounds in the US and the difference between underground and surface injuries with reporting on all types of incidents in Swedish mines, some interesting conclusions can be drawn. As for surface mining, it can be seen in
Figure 30 that the two surface mines considered, Aitik and Maurliden, there are two distinct main concerns; in the case of Aitik these are troubles with evacuation of the pit, with Maurliden these are all related to misfires (loading incidents in these cases are all related to finding misfires), and no others. This is the case because Maurliden only reports red incidents, and there seemed to be a product failure with the detonation systems; it can therefore safely be considered to be an outlier. When comparing with Australian incidents for surface mines, a completely different picture arises, see Figure 31. In Australia, it appears that misfires are the most common concern (Seccatore, et al., 2013). It should be noted that this is probably related to the fact that in Queensland misfires need to be reported to the mine safety authority; together with all other serious incidents. This therefore mostly seems to be another confirmation that actually severe incidents happen very rarely, but if they happen half of them are related to flyrock (and thereby also closely connected with the blasting procedure) another large part is connected to toxic fumes and early detonation also still is a source of concern. This picture therefore appears to be fairly consistent with Boliden and US data.

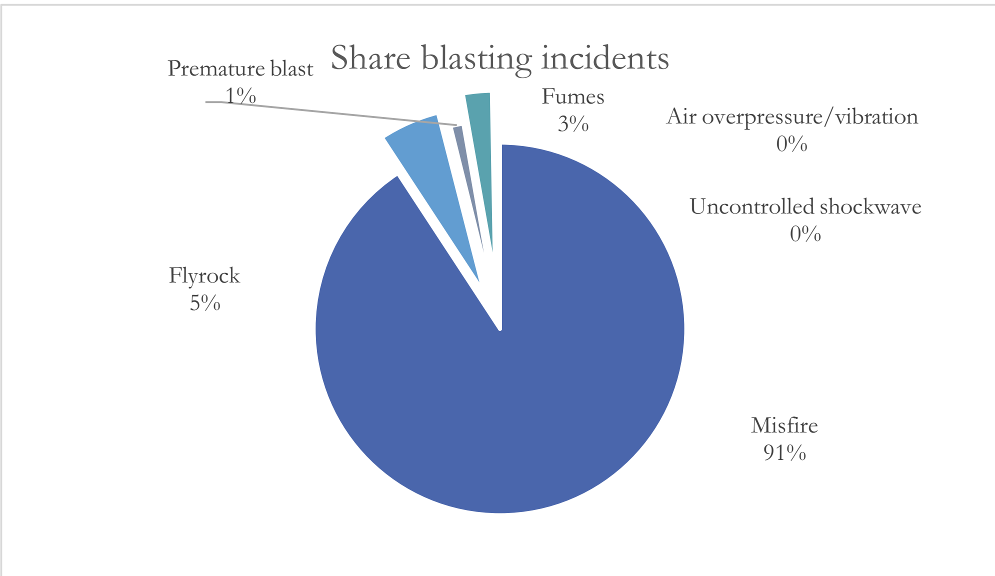


FIGURE 31: BLASTING INCIDENTS IN QUEENSLAND, AUSTRALIA (SECCATORE, ET AL., 2013)

9.3. Results Fault Tree Analysis

In order to assign a structural importance to the respective parts of the explosives handling and blasting process, without having possible biases that would result from the use of just statistical data, fault trees without assigned failure probabilities have been assembled for the four most hazardous events, following the results in the previous subchapter, i.e. misfires, unwanted detonation, toxic fumes and flyrock. The values given are the Birnbaum's factor of importance, as discussed in Chapter 8. These results have been summed up, and the results are given below in Table 19. Since this analysis has been done to understand the structure, not the probability, of pathways leading up to an accident, the values do not have a unit, but are rather useful to compare the relative criticality of the various subcomponents. A full table is provided in Appendix IX.R, below the most important lessons are discussed.

TABLE 19: RESULTS STRUCTURAL ANALYSIS

B4	A4	O1	V1	V2	P3	A5	A3	C3	B5	H1
3	2,875	2,25	2	2	1,5	1,375	1,0625	1,03	1	1

H2	M1	M2	N2	P1	P2	S4	A1	C1	C2	N1
1	0,75	0,75	0,75	0,75	0,75	0,75	0,58	0,58	0,58	0,38

B1	B2	M3	M4	S1	S2	S3	A2	N3	B3	B6
0,3125	0,3125	0,25	0,25	0,25	0,25	0,25	0,15625	0,15625	0,125	0,046875

B4: The part of the process having been assigned the (by far) highest value is the selection of explosive materials; this seems to make sense, given that it affects the safety and reliability of the entire process. As discussed before, explosive materials are nowadays extremely reliable.

A4: Checks of the blasting area are arguably the biggest concern, since they were also deemed to be responsible for a large share of reported accidents in the previous subchapters. It also returns as a component for several risks, since they mitigate for both flyrock and fumes. Connected to this are also P3, the conditions under which return to the blast site is allowed, A5, the systems used to secure the blast site and A3, awareness among staff of blasting evacuation rules, are also related to blast area security.

O1: PPE-usage and protective material on equipment may be an effective help with smaller accidents, and are therefore in general an effective measure. Still, the safety planning should not rely on these tools, given that the value of such protection is limited in case of more serious blasts and flyrock.

V1&V2: Ventilation capacity and the ability to quickly push out noxious gases are central in being able to avoid intoxication, also given that the occurrence of (at least small amounts of) toxic fumes can never be avoided when using chemical explosives. This is also a topic that is regulated precisely, and which can be dealt with in mine ventilation planning.

Using this order to prioritise safety measures, both in terms of working procedures, the necessity to go beyond the minimal legal requirements and the technologies used, can contribute to improving the blasting practice in the most effective way. The next subchapters will discuss to what extent these separate components actually do lead to concerns.

9.4. Causes for Concern based on Interviews

Questioning has led to the conclusion that there are two issues that appear to give the most issues; the implementation of the digital management system for track & trace in Tara has been troublesome, given that the systems stopped working for a few days when it was introduced, and still frequently lags or has other forms of disruption. There are no immediate safety issues in this regard, but since the track & trace system is essential in regards of the safety and security of the explosives handling cycle, it should be noted. Furthermore, difficulties with perfect guarding of open pits is another concern. The main concern mentioned in all three countries and the main office were misfires. Working with contractors or communication with them is generally not regarded to be a safety hazard; although for example in the starting phase of Kevitsa there were many incidents with inexperienced contractors, their safety performance now appears to be better than that of Boliden's internal staff.

9.4.1. Misfires

Although mentioned as a main concern, misfires do not appear to occur very frequently. During 2016 for example, out of 17,800 charged blastholes in Aitik mine, only 14 (0.08%) turned out to become misfires. This will for a large part follow from the fact that in Aitik the standard is to use 2 detonators and primers per blasthole, which greatly contributes to detonation reliability. When comparing this with Kevitsa, in the past years between 1 and 4 misfires were usually reported per month. In total 45 misfires were reported for the past 72,000 charged drillholes, in other words only 0.06% of the charged holes turned into misfires. This shows that the use of two detonators and primers per drillhole is a very effective way of avoiding misfires; still, a lot of misfires are currently found in Kevitsa now the mine is expanding into quarries previously used for mine development and in contouring operations in more difficult situations, leading to a recent uptick to above 4 misfires per month. The next subchapter discusses misfires also based on statistical indicators.

9.5. Elaboration on Specific Issues for Underground Mines

Based on the extensive Swedish data on various forms of procedural deviations, a look has been taken into incidents involving deviations from procedure or situations that were deemed hazardous. Examples of such cases are people not being at the right place at the right time, explosives laying at equipment before maintenance, traffic violations and doors of the storage left open. The most noteworthy conclusions for underground mines are discussed below. The complete classification of (suspected) causes per explosives handling and blasting phase category been outlined in Appendix IX.N for underground mines, and in Appendix IX.P for surface mines. The most important lessons are discussed below, based on a distinction between material failure, forms of human/procedural failure and external causes. Misfires are discussed separately.

9.5.1. Material Failure

Apart from misfire-related issues discussed below, material failure appears to be a relatively minor cause of concern; in a few cases there is insufficient ventilation capacity, and in some cases explosives have slightly different characteristics than expected. The main type of material failure appears to be material failure around the evacuation, with 21% of blasting procedure cases related to either a tag failure or an alarm not being loud enough.

9.5.2. Procedural and Human Failure

Human error appears to be the single cause of explosives handling failure; of storage failures, only 10% of incidents were related to direct errors; of these 10% 1 case related to belated maintenance leading to insufficient door standards, 1 case to a storage not meeting legal standards due to unawareness of the legal standards and 1 case to the lack of fire-fighting equipment. The other 90% of cases all related to small errors, mostly due to either sleaziness or lack of awareness/training of certain procedures. Similar issues appear to be typical for transportation, with cases such as lack of the proper markings or explosives that were left in equipment after a shift. For explosives handling, the various forms of human error are therefore the primary reason of concern. Also for the blasting process various forms of human error cause the bulk of concern, in most cases incidents are related to either a lack of training/experience, or apparent carelessness/easy-going mentalities.

For blasting procedures incidents, trespassing of the danger zone is responsible for a quarter of red incidents; it appears that it is usually people unintendedly or perhaps intentionally ignoring warning signs. Furthermore, failures of warning signals, or missing signs amount to 15% of serious incidents. Insufficient checks and last-minute equipment removals also appear to fit in this category. When it comes to the evacuation procedure, communication failures appear to be a main concern. Examples of this are people not being informed properly on the features of blasting planned, or people not being informed at all. Given that for these cases no material failures have been reported, human error must be assumed. Whether the root cause in this lies in negligence or complete unawareness of actual procedures is unclear. Since none of these cases has led to real hazardous situations or accidents no investigations have been undertaken in this field. Given the involvement with contractors, in one case with people not speaking Swedish or English, or people less involved in blasting operations, it appears that in some cases there is insufficient awareness, lack of training or a generally careless attitude in this regard that causes these incidents. There is no exam testing knowledge of blasting procedures of any type before contractors or people not involved in charging and blasting can work in the mine; it may therefore be recommended to undertake more trainings or tests in this regard.

For the blasting incidents, most of the non-communication related incidents appear to deal with the lack of cover when a lot of flyrock is expected, or damage done by flyrock. This may be the consequence of blast planning and sometimes unexpected heavy blasts. The personal injury issue relates to people falling/tripping, or having ear damage following a blast (lack of PPE). In no cases have people been hit by flyrock directly. The other minor categories appear to be related to negligence of individual operators.

9.5.3. External Events

A notable external event was a case of explosive materials being delivered via regular mail, and available for pick-up at the local supermarket. Climatological/environmental issues do not appear to be an issue in underground mines (in contrast, in Aitik surface mine all cases of unexpected large rockfall were deemed to be related to characteristics of the frozen ground that had not been dealt with in a proper way). The reason that a switch has been made from ANFO to emulsions had a lot to do with groundwater-related issues, but this is therefore no issue anymore. There are no cases of people from outside the mine interfering in one way or another.

9.5.4. Misfires

Being the most common cause of concern among staff, the topic of misfires deserves extra attention. In (Seccatore, et al., 2013) a more detailed study was undertaken on the causes of misfires based on the available data from Queensland, Australia. Although the exact reasons were mostly unclear, Figure 32: Causes of Misfires in Queensland, Australia shows the causes insofar they were possible to be identified. Environmental causes or failure of the emulsion itself seem to be rather minor issues. Procedural/methodological failures together account for 28% of failures. Slumping and column dislocation account for 37% of failures, and could presumably be traced back to design or execution failures. initiation system failure is responsible for almost a third of all incidents, and are thereby the biggest cause of concern.

For Boliden, interestingly enough, misfires seem to be relatively as an important issue for surface- as underground mines; in both cases 17% of all reported incidents is related to misfires; given that around three quarters of all incidents are reported at surface mines however, the absolute number is smaller at surface mines, with in total only 29 cases being reported over the studied five-year term. The causes (insofar known) appear to explain why, with surface mines struggling with issues such as vehicles cutting wires and environmental conditions being an issue. The causes of 48% of misfires were deemed to be unclear; for the cases where the cause could be reasonably well assumed 49,5% was related to connection system set-up failures, 34,3% to material (detonator) failure and 16,2% to flyrock damaging the system. For misfires found at later stages than after post-blasting the cause were always unclear, they have therefore not been included here; it seems however useful to consider if misfire-finding can be improved, since these cases amount for almost a quarter of all found misfires, and misfires that pop up later are dangerous when less experienced staff gets in touch with them.

Given that it was previously established that using electronic detonators would reduce the risk for misfires, this seems a very effective way indeed to reduce the number of misfires, given that almost a third of failures directly have to do with this, and also may reduce other major factors that are sometimes related to unpredictable blast design such as column dislocation and slumping, and also procedural errors could be reduced given the opportunity of pre-blast checks.

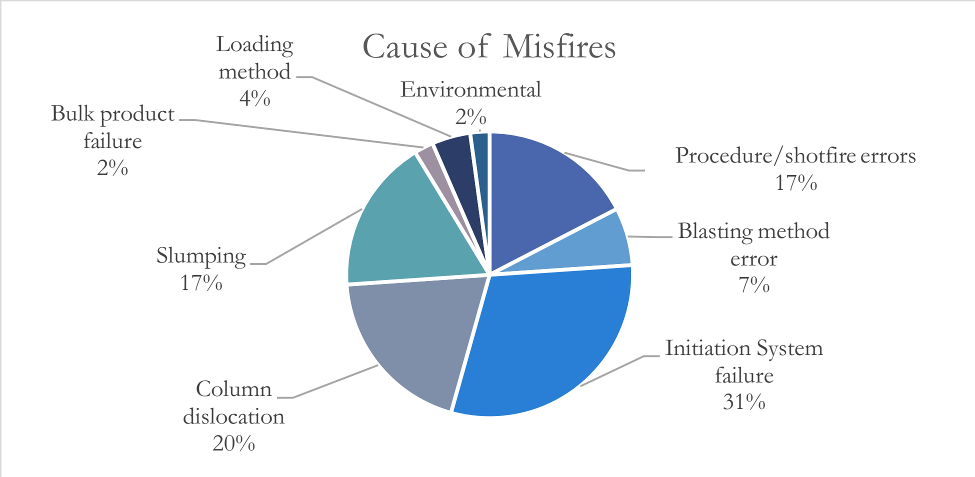


FIGURE 32: CAUSES OF MISFIRES IN QUEENSLAND, AUSTRALIA (SECCATORE, ET AL., 2013)

9.6. Resulting Risk Matrix

In order to classify both the effect risks and cause risks, two different risk matrices will be worked out below based on both Boliden and US statistics. These matrices will not look into suspected causes, as was discussed qualitatively in the previous subchapter and further analysed quantitatively in the next chapter.

It is deemed less useful to compare on the basis of the number of people working with either charging activities or all employees; for the first this seems to be not that important given that many incidents are not related to issues facing the chargers themselves; for the second since it cannot be judged what part of the total number of people working at a mine site could theoretically be affected by blasting incidents. Instead, it seems best to estimate the chance that incidents of a certain type do occur at a mine site per year; given that blasting incidents can affect many different people at the same time and various locations it seems best to treat accidents as a risk for the entire mine.

9.6.1. Set-Up

In order to properly value different types of incidents, the approach of distinguishing the risk of an effect occurring during a mining operation and the risk of possible causes for accidents occurring has been followed. Different categorisations have been applied for these different types of risks and for US accidents vs Boliden incidents. For the effect risks (R_e) two sets of data have been used; internal Boliden data on actual reported safety hazards (e.g. misfires occurring, breaching of air quality standards, excessive flyrock, etc…) and the previously discussed severe incident reporting from the U.S. This is done in order to also be able to assess whether the occurrence of a certain hazardous situation will also likely lead to severe accidents or not (given that barely any serious accidents or even near-misses occurred at Boliden Mines). For cause-risks (R_c), the different components of previously discussed risky pathways have been used to categorise procedural deviation reporting. Also, when causes for effect-risks were known, these have been included, in order to get an idea of the frequency of failure of activities in the explosives handling and blasting process.

TABLE 20: EFFECT LABELS CLASSIFICATION ACCIDENTS

Value	Description	Frequency effect US (/year)	Frequency causes Boliden (/year)	Frequency effect Boliden (/year)
1	Very low	<0.1	<1	<0.1
2	Low	0.1-0.99	1-5.99	0.1-0.99
3	High	1-2	6-12	1-3
4	Very high	>2	>12	>3

TABLE 21: EFFECT CLASSIFICATION LABELS BOLIDEN MINES

Value	Description	Safety (fatalities)	Health/temporary injuries	Damage (potential)	Criticality level
1	Insignificant	0	0	<€10k	<0.5
2	Small	0	1-2	€10k-€100k	0.5-0.99
3	Serious	1-2	3-5	€101k-	1-3
4	Severe	>2	>5	>€1m	>3

9.6.2. Effects

Based on the maximum impact that has occurred for a type of accident, the damage labels have been assigned. Frequencies of accidents occurring over the past 5 years at all Boliden underground mines, and the available data since 1978 for all US metal mines have led to the following frequencies. It should again be remembered that the incidents that have been reported for the US are much more severe. See Table 22 for an overview of all incident types that have led to forms of physical injury.

TABLE 22: RESULTING RISK EFFECT TABLE

Effect Hazards	Damage label:	Frequency (/year/mine)	Label (Boliden)	Frequency (US) (/year/mines)	Label (US)
Misfires (M)	3	2.54	3	1.28	3
Flyrock (R)	3	0,9	2	0.08	1
Toxic Fumes (F)	3	0,604	2	2.05	4
Early Detonation (D)	4	0	1	1.56	3
Vibrations/blast wave (V)	1	0,25	2	-	-
Blast Area Security (A)	4	1,1	3	1.79	3
Absorption explosives (E)	1	-	-	-	-

These data lead to the following risk matrix; most effects score rather high on the damage scale; this is reflecting of the dangerous nature of blasting. The two that do not score high (health injury due to absorption of explosive materials and vibrations and blast waves) do not appear in the U.S. statistics, which is logical, since only severe incidents are reported there; although considered to be a major health hazard by both people in the field and literature, no such have been reported at Boliden either.

TABLE 23: RESULTING EFFECT-RISK MATRIX

Damage Labels

4	**DB**		**DU AU AB**	
3	**RU**	**RB FB**	**MU MB**	**FU**
2				
1		**VB**		
	1	2	3	4

Frequency Labels

What is interesting to see is that misfires and blast area security accidents appear to be of the same importance relative to other types of incidents; toxic fumes appear to be a relatively much more serious issue in the US than at Boliden, similarly to early detonation. This makes sense, given that both issues are closely related to explosives performance; since Boliden data from the period between 2011-2016, and US data for 1978-2016 have been used, it seems thinkable that this difference in performance is related to improved explosive materials and blasting techniques. The difference between flyrock may be a result of classification, given that there is a close relation with blast area security, alternatively it is simple the case that large amounts as flyrock at Boliden have been labelled as a serious incident for this research, whereas only flyrock leading to personal injuries have been reported for the US.

9.6.3. Incidents per Component

Based on all reported incidents over the period in between 2010 and 2016, including all the "green" type of incidents, a frequency of incidents per type of component of the potentially harmful explosives handling and blasting cycles has been established. The number of incidents occurring has been translated into a probability of an incident of any type occurring during a year at a mine site of the size of Garpenberg or Tara. Criticality labels were based on the results of the Fault Tree Analysis, since more critical activities are more likely to lead to harmful incidents, or in the few cases where a certain component failure could lead to direct harm but not to a failure of the overall blasting process, such as injury due to skin contact with hazardous emulsions, a damage label has been assigned. This was done according to Table 20 and Table 21 respectively. See Appendix IX.S for the specific numbers for each activity.

TABLE 24: RESULTING CAUSE-RISK MATRIX

Criticality Labels				
4	B4		E1	
3	C3 H1 O2	A3 A4 A5 B5 C4 C5 H2 H3 O1 P3 V1 V2	B7 H4	U1 S5
2	C1 S4 M1 P1 H6	A1 C2 M2 N2 P2 Y1 Y2		
1	A2 N3 S2	B1 B2 B3 B6 M3 M4 N1 N4 S1 S3	H5	
	1	2	3	4

Frequency Labels

The riskiest components from Table 24 should be mentioned. E1, uncharged explosive materials left outside storage form a big concern according to this classification. As discussed before, it is one of the most common serious incidents occurring at underground mines. In all cases these materials were apparently forgotten at places like charging sites, equipment or even near the lunchroom. S5, access to storage, i.e., doors left open or people walking into places where they should not be, is another big concern related to explosives handling. In both these cases, the "Irish approach" with dedicated powdermen and very restricted access possibilities to the storage, arguably in combination with a real-time bookkeeping system checking making it possible to check were all collected explosive materials have been used, therefore indeed seems to be an effective way to solve this issue. The only type of component related to the blasting process in de red risk category is U1, or "cause misfire unclear". The associated risk of misfires, and since, as discussed before, the causes of misfires that do occur are mostly not clear, put this type of "incident" in a serious risk class. Since the causes are unclear it is also arguably very hard to deal with this; recourse should presumably be taken to the other possible causes of misfires. B7, missing or insufficient cover, and H4, dangerous driving are other more severe risks. The first one seems closely related to the estimation of the danger zone for flyrock, and was therefore treated together with this in the Fault Tree Analysis, but turned out to be a common cause of concern. Dangerous driving is a typical example of a "violation" of rules, probably because people want to be fast, or are careless when putting explosive materials in the car. Some other generally interesting notions are that issues related to the blast design itself do not appear to be very risky, except for the danger zone estimation, which was connected to the flyrock cover. Better ability to predict the reach of flyrock and checks on the presence of flyrock would therefore be the by far most pressing concern in this regard. B4, the selection of certain types of emulsions, score high since they influence the vulnerability to health issues following skin absorption or fumes. It is also interesting to see that most typical blasting process activities (i.e. charging and the blasting/evacuation procedure) fall in the average category. Although N4 (uncertain cause of misfire), other external/untreatable events do not appear to be especially risky, unexpected blast characteristics appear to be of average concern. The next chapter considers how seriously these issues should be taken and what measures could be recommended.

9.7. Conclusion

In this chapter, the main categories of incidents have been identified, using the same categorisation structure as was used previously for the legal assessment. Furthermore, a look has been taken into the (possible) causes of these incidents for the more severe cases. Also, people active in this field have been asked to discuss what they consider to be causes for concern. The main issues that give reason to concern, according to the risk matrices assembled based on both Boliden and international data are blast area security, toxic fumes, flyrock and early detonation. Misfires were however consistently judged to pose the biggest hazard by the people that have given input on this topic, and a similar picture comes from Australian data. Most issues related to blasting incidents and issues related to blasting procedure had to do with lacking or unclear communication or failing communication systems. To add to this, Fault Tree Analysis has been undertaken for the most pressing concerns, in order to see what components of the explosives handling and blasting process are most critical. It follows that blasting procedure components are the most concerning topics.

In general, a clear distinction can be made between surface and underground mines, where underground mines have a more equal number of incidents per incident category, whereas issues with blasting safety and flyrock appear to be of more concern for surface mines. Other issues surrounding explosives handling are explosives that are left somewhere during/after transport, or after charging. In some cases, doors of the storage where open when they should not have been open, which also belongs to the riskiest components according to risk matrices assembled. This is a field where Tara has a better performance than Swedish mines, arguably because of their stricter explosives handling policies.

It can be concluded that, although luckily no significant incidents with harmful consequences have occurred, measures related to evacuation procedures, and then in particular the communication thereof, are worth to be taken more seriously. A problem in this regard however is that in the vast majority of cases individual negligence appears to be the main cause of the incident. This may be hard to solve via regulations or other technologies. Avoiding misfires altogether may be very difficult, assuming that charging has always been carried out correctly, but the use of different methods of technologies may be worth a closer look.

10. Suggestions for a Standardised Explosives Policy

This chapter will try to combine the findings of the previous legal and practical chapters in order to recommend on a consistent and uniform policy for all three jurisdictions. The aim is to develop recommendations that lead to the highest standard of explosives- and blasting safety, both in terms of maintaining the highest legal standards, the safest and most effective technologies and working practices.

10.1. Guiding Principles

To start with, specific legal requirements will have to form the bare minimum of any safety policy. These requirements are generally quite straightforward, and easy to understand. The difficulty lies more in the way of implementation. As required by law, implementation should be straightforward and easy to understand, and to be effective, the right laws need to be known by the right people. A first objective of this chapter is therefore to outline the existing specific requirements to the right process stages.

Apart from this, it should be remembered that the employer has a duty of care under all three jurisdictions. Therefore, risk assessments should be made to assess the need for additional requirements. This also means that in case of doubt, the employer will always need to prioritise worker's safety. It is a general principle of safety, but, as this research has found in Chapter 5 also a legal obligation to apply the hierarchy of controls when developing a work safety approach. See Figure 33. Rules on the side of elimination, rather than on the side of PPE, are therefore preferred.

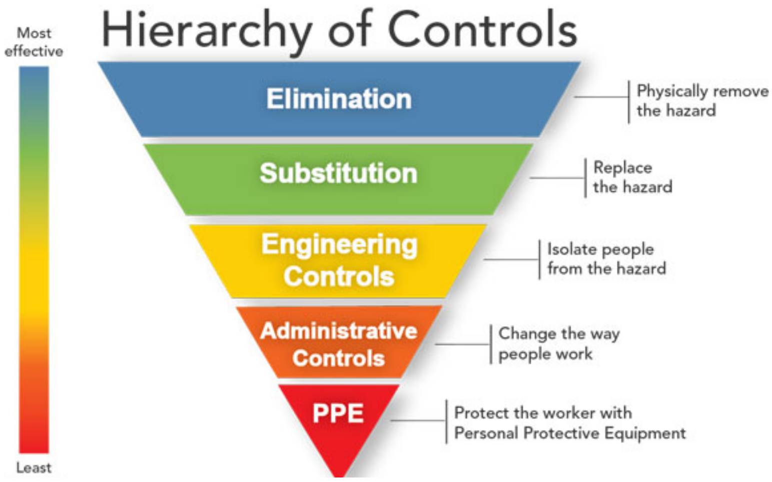


FIGURE 33: HIERARCHY OF CONTROLS (NIOSH, 2016)

10.1.1. Explosives Handling & Blasting

As might have been noticeable throughout the report, there is a clear distinction between explosives handling on one hand, and charging and blasting on the other. The explosives handling stage consists of the acquisition, transportation and storage of explosive materials, whereas charging and blasting activities comprise most of the actual work, but all take place on a single place, namely the blast site. This distinction can also be seen in the studied legal sources, explosives handling has many different sources, ranging from general chemicals regulations to security-related documents, whereas charging and blasting activities themselves are just regulated by the central mine explosives regulations. The distinction is also very clear in Irish law, with the explosives handling part is regulated internally by the Scheme of Transit, and the charging and blasting activities are regulated internally by other documents. Also, the people responsible for the first category are called "powdermen", whereas these for the second part are called "shotfirers". In Sweden and Finland there is no such (legal) distinction. For this reason, it seems an effective way to distinguish essentially different tasks in the mining process, in order to assign clearly delineated responsibilities to different people and to draft working practices for. Separate recommendations will be made for both stages. This does not mean that it is not possible that tasks from both parts cannot be carried out by the same people.

10.2. Bow-Tie Reliability Models

In this subchapter, using both the knowledge of legal requirements and of the reported types of incidents in Swedish underground mines will be used to predict the probability of hazardous events and of damage and injury occurring. Given that it is assumed that prevention always should be most preferred, the bow-tie method is used to distinguish between measures preventing hazardous situations (top-events) from occurring in the first place, and measures that are there to mitigate these top-events once they have occurred. Reliability Block Diagram-analysis will be implemented to calculate these predictions of probability. What measures would be most recommended can then be discussed following these estimates.

10.2.1. Avoid Unintended/Early Detonation

The most "classical" risk associated with the use of explosives is unintended detonation, or any form of explosions or fires in general. It is also the topic were most regulations appear to be focussed on; given that in practice there do not appear to have happened such cases in the studied time period it must be concluded that modern material use indeed has successfully removed this risk, or that the applicable regulations indeed are effective. Assuming the latter, safer, option, strict compliance with the legal requirements is therefore highly recommended.

It is assumed that the emulsions, since they are of GHS-class 1.5 or 1.6 and therefore extremely insensitive, will not detonate unless there is another explosion occurring as well. This is represented by the lowest line in the right-side part of the bow-tie diagram. The most important safety requirement of this entire topic may therefore be the need to keep mixed emulsions separate from any explosive substance as long as possible. This is also expressed in regulatory requirements on separation distances and the need to store emulsions at a different site as the other explosive materials. Other mitigating measures on the right side are all related to minimising the presence of other people and equipment near explosives and charged areas, and the supply of appropriate protective equipment and PPE. Training and taking these measures into consideration with production planning complete the recommended measures on this side. As was discussed in Chapter 8, there is also a very small chance of detonation of the emulsion caused by blocking of the emulsion loading pump. Rules on proper cleaning of this equipment are therefore also necessary, but these guidelines are provided by the emulsion supplier, as is legally required.

The resulting bow-tie reliability model for early detonation, developed for both early detonation during transport and during storage can be found in Appendix IX.T.1. As discussed before, this is barely an issue anymore, but given its potentially very large consequences is still considered. The extremely small probability of this type of accident is also predicted by the bow-tie reliability model, predicting a chance of virtually zero that such events occur. Since this topic is regulated on a very detailed level and practice showed that internal rules closely follow these legal requirements, there is little room for independent rule-drafting. This is therefore not included as a component; it should however be noticed that all components are covered (some rather extensively) by the Combined Legal Requirements.

10.2.2. Failure of Detonation

The main problem associated with a failure of detonation are the subsequent misfires. Factors identified that could lead to misfires are problems with the materials used, the way in which emulsion loading activities have been carried out, and the way in which initiation systems have been set up. Finally, blasting itself can cut off well-installed safety systems. Except for the general risk avoidance requirements, there are no specific legal requirements on the avoidance of misfires, most rules appear to be dedicated to avoiding unintended detonation; this means that this topic in particular requires independent development of safety procedures. The bow-tie reliability model for this issue can be found in Appendix IX.T.2. The part left of the top event in the bow-tie reliability model shows the components that affect the occurrence of misfires. Material characteristics and the execution of tasks is most important in this regard. In case that a misfire has occurred, they should be spotted as soon as possible. See the part right of the top event in the bow-tie reliability model for the components influencing the success of this. Materials do not really play a role in this regard, except for protection on equipment. Rules would primarily be effective in checks after the blast, it is also a specific legal requirement to undertake such checks. Apart from this, training of both Blasting Foreman's and other staff such as loader- and driller operators is important. If such tasks could be carried out from a distance or by self-driving vehicles the risk for personal injury would be removed completely.

10.2.3. Avoid Damage following Blast

There are many different types of damage that can follow an otherwise regular and well-planned blast; flyrock, vibrations and fumes are the main categories in this regard. Given the intrinsically destructive nature of a blast, these effects can never be fully removed without disbandment of the entire mining technique. Effective measures are therefore important to prevent or reduce negative impacts. There are relatively few specific regulations in this regard, except for these related to mine evacuation. Given that Boliden Mines already evacuate much larger areas than legally required legal constraints might not be the most pressing therefore. Maintaining legal requirements in relation to air quality may be the biggest legal compliance challenge, but that is not part of the scope of this research. A difficult issue in this regard here is that preventing the hazards is almost impossible, given that blasts simply cause these effects; in this case the mitigating measures therefore deserve most attention. The bow-tie reliability models for this type of issue can be found in Appendix IX.T.3.

In general, flyrock, if the blast is planned well, should not pose a large problem, given that rock masses can stand some rocks hitting it. Still, effective planning and danger zone assessment is crucial in removing damage. Once again recognising the need to prefer preventive measures over risk-reducing measures, methods that make it impossible for flyrock to come even close to equipment or people are therefore preferred over options to cover sensitive objects. Given the difficulties that were found in the previous chapter with enforcing that people move into or stay in the danger zone this topic deserves extra attention. The rules in place themselves appear to be sufficient; more emphasis should therefore be put on awareness of these topics, especially among contractors or other people that may have less awareness of typical mining hazards. Also, maintaining regular checks on warning systems, signs and communication systems are important to support this objective.

It can be seen that flyrock is to a large extent influenced by the materials used and engineering tasks; blasting engineers therefore have a large responsibility in this regard. As for toxic fumes, most components in the system are related to the proper execution of tasks; the most important topic here seems the successful enforcement of the danger zone evacuation, and reliable measurements and returning decisions. Especially the Blasting Foremen play a large role in these tasks, and the main ways to avoid failure in this regard is ensuring that these jobs are carried out with care.

Vibrations are another concern, when it would lead to rockfall in parts of the mine that are not blasted themselves. As a side-effect, vibrations can also be a concern for people living around the mine. The only way to reduce vibrations is either by limiting the size of the blast or having more efficient blasts. Maintaining appropriate rock support is another additional appropriate measure. A different type of possibly harmful effects of blasting are the fumes released by the blast; these are unavoidable with the explosives available on the market and can therefore never be completely removed, although different chemical compositions could lead to less toxic releases. Still, the amounts can be reduced by blasting efficiency, since smaller amounts of emulsions used will lead to less toxic gases. Apart from that straightforward rules on evacuation, measurements and in the worst case appropriate PPE should tackle this problem.

Again, predictable and efficient blasting is primarily influenced by the characteristics of the explosive materials used, and an effective way in reducing blasting hazards. More than for other topics, proper mine planning, blast planning and operational planning can effectively mitigate possibly damaging consequences. These notions are also phrased in general terms in legal requirements. In all cases, vibrations, flyrock and toxic fumes can all be linked to inefficient blasting or the wrong use of materials.

10.2.4. Overview of Bow-Tie Reliability Model Results

Some of the key lessons from the reliability/bow-tie models are displayed in Table 25; first of all, predictions for the probability of different types of damage or injury occurring as a consequence of explosives handling and blasting in underground mines comparable to Garpenberg and Tara are given; as can be seen the probability of flyrock causing damage is by far the most likely; individuals getting hit by flyrock and unhealthy exposure to toxic fumes are the two other main categories being significant; all other types of damage and injury have an estimated occurrence probability of less than a million. The likelihood of serious incidents occurring at the storage site is extremely small.

Some comments to be made are; as for fumes only health serious injuries are assumed, not very minor cases of feeling not well for a very rare exposure of one minute or less, otherwise the probability should be much higher, given the three cases in underground mines reported on this topic. The storage prediction is based on the fact that all visited storages meet legal requirements (apart from two incidents in the past years, the first relating to not having a fire extinguisher in one case and having an outdated permit hanging in the storage), and on the fact that no malicious or extremely incompetent behaviour has been reported or is expected; if that would be different this probability would presumably increase a lot. The same goes for other forms of early detonation.

TABLE 25: PREDICTED PROBABILITY OF DAMAGE/INJURY TYPES

Rank	Damage Type	Probability (/year/mine)	Human Injury	Most problematic cause
1	Material damage due to flyrock	0.451	No	Missing Cover
2	Individual hit by flyrock	0.33E-04	Yes	Blast design
3	Health issues due to toxic fumes	9.13E-05	Yes	Ventilation Capacity
4	Material damage due to misfire	2.95E-07	No	Material Usage
5	Personal injury due to misfire	1.96E-07	Yes	Material Usage
6	Serious intoxication due to blast fumes	2.29E-08	Yes	Ventilation Capacity
7	Minor injury/damage due to exploding detonator	1.31E-09	Yes	Traffic Violations
8	Multiple people hit by flyrock	4.14E-12	Yes	Blast design
9	Serious injury due to explosive transport	8.10E-14	Yes	Traffic Violations
10	Minor damage due to early storage detonation	0	No	Storage Conditions
11	Major damage due to early storage detonation	0	Yes	Storage Conditions

Strictly speaking, only issues affecting health and safety are the scope of research, therefore cases that normally lead to just material damages have been marked. Furthermore, the most problematic cause for each type of damage or injury has been mentioned. How "problematic" an element is, is based on the probability of a particular component failing and its criticality in the bow-tie reliability model. It is interesting to note that these causes can mostly be dealt with by improved blast and cover design and proper ventilation design. Avoiding misfires can best be done by selecting the right materials; this means using electronic detonators, given the opportunity to pre-test them and the relative easiness of charging. Awareness of the right driving styles would be most useful for the last part; using driving monitoring systems may be an effective technological measure to combat this problem.

Given that missing cover is the only hazardous element that is expected to occur relatively often in the blasting process it is the only topic that is looked more closely into with the Five-Whys technique. Also, issues considered to be problematic in the sense that explosives would be accessible to unauthorised people, have been delved into in this manner. See Appendix IX.U to see what steps have been undertaken in this analysis. The main results flowing from this analysis is that it is important to more frequently practice rare types of blasts near vulnerable areas (such as the crusher station or important haul roads) in order to stay experienced with such operations. The main problem with explosives being at the wrong places, cars used to transport explosives within the mine and access to storage (keys) appear to be related to less clear delineation of responsibilities in this field. This would best be solved by the assignment of dedicated powdermen.

The most important conclusion in relation to legal requirements is that there is the paradox of the vast majority of specific legal requirements being related to the hazard of unintended detonation, whereas in practice this does not appear to be problematic; it is assumed that it is the strict compliance with these regulations, in combination with the materials used, that ensure this. Continued strict compliance with these requirements is therefore recommended, whereas for other topics the drafting of rules and procedures should be based primarily on the knowledge and experience of experts in the field, such as blasting engineers, Blasting Foreman's, suppliers and chargers.

10.3. Combined Recommendations

The approach to the functional stages in the explosives handling and blasting process is to delineate clear phases. Each phase is to be ended by some kind of check, to ensure the person responsible for a specific phase undertakes some assessment of his works, and to make it possible for a possibly different person in the next stage to rely on the prior phase. Therefore, the set-up for each phase is the same. Figure 35 shows a distinction in stages for the explosives handling cycle; each stage first has a description of the activity, and at the end, the topic that should be checked before one can move to the next stage in the explosives handling cycle. For each component in this cycle, the riskiness has been assigned based on the previous chapter and subchapter; also, based on this, a risk-assignment has been made for the entire stage. See Figure 34 for this labelling. Then, as minimum legal requirement, the applicable legislation for each stage has been connected to each stage, following the Combined Legal Requirements (CLR). Additional recommended procedures/rules have been added in white letters on a blue background, based on issues that went wrong. Thirdly, if applicable, recommended technology use to improve the performance of a stage have been added as well. If a stage is assumed to be low-risk, it is recommended to keep working with existing rules. For the more concerning issues, new procedures and SOP's are to be drawn up in collaboration between blasting foremen, health and safety officers, chargers and other people involved, based on the minimum legal requirements listed in this report and taking into account the other suggestions.

The assignment of the necessary responsible persons, as outlined in Part 1 of the CLR, is the responsibility of the mine management, and should, when executed, not influence the actual operation of both cycles.

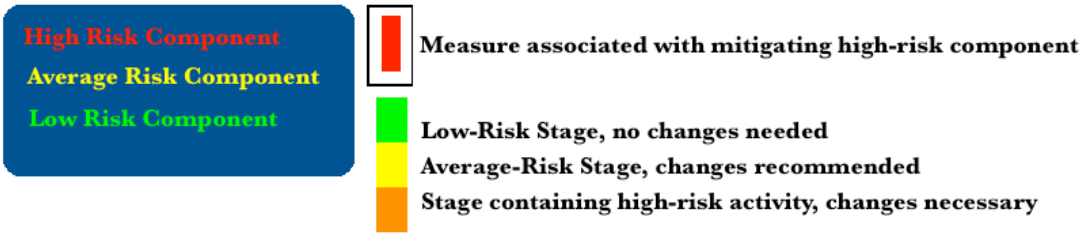


FIGURE 34: LEGEND COMBINED RECOMMENDATIONS

10.4. Explosives Handling

Although technological solutions may be less helpful to solve safety risks in the explosives handling cycle than in the blasting cycle, there are still some measures that should be looked into. Some of these measures are already explicitly required by law, such as not having open fire near blasting activities, using vehicles without sparking hazards and equipped with fire extinguishers and the need to maintain a stable climate in storage. It is suggested that additionally having a real-time track&trace system might also be useful, and not only from a security perspective. Also, having systems in place monitoring driving behaviour and being aware of the location of cars and equipment would be highly recommended, given the previous analyses.

Maintaining a track & trace system is already required by law. The form in which the track & trace system is implemented is not specified by the European directive; there are example of miners just taking pictures before each shift in quarries to maintain the registration of explosives, and many Boliden mines still maintain paper records. However, there appear to be considerable advantages in having a system that would allow for real-time insight in the whereabouts of explosive materials. If explosive materials would be lost on the way, as has happened now and then, this would be noticed when checking out all explosive materials prior to usage. This could reduce the risk of these explosive materials lying around over a longer period of time. It could also, if implemented effectively, save bureaucratic work, since scanning is easier than maintaining paper logs, by people responsible for explosives handling, leaving more time for other important issues.

The three most pressing concerns in this regard, people gaining access to a storage that should not be there or doors left open, explosives lying at places where they should not be and wrongly parked vehicles and/or dangerous driving have been singled out as issues that can all very effectively be dealt with by assigning dedicated powdermen, whose sole task is to know all about the whereabouts of explosive materials and have sole access to storages. They are also expected to check the quality of materials used, such as cars, and the (climatic) conditions in the storages and other facilities.

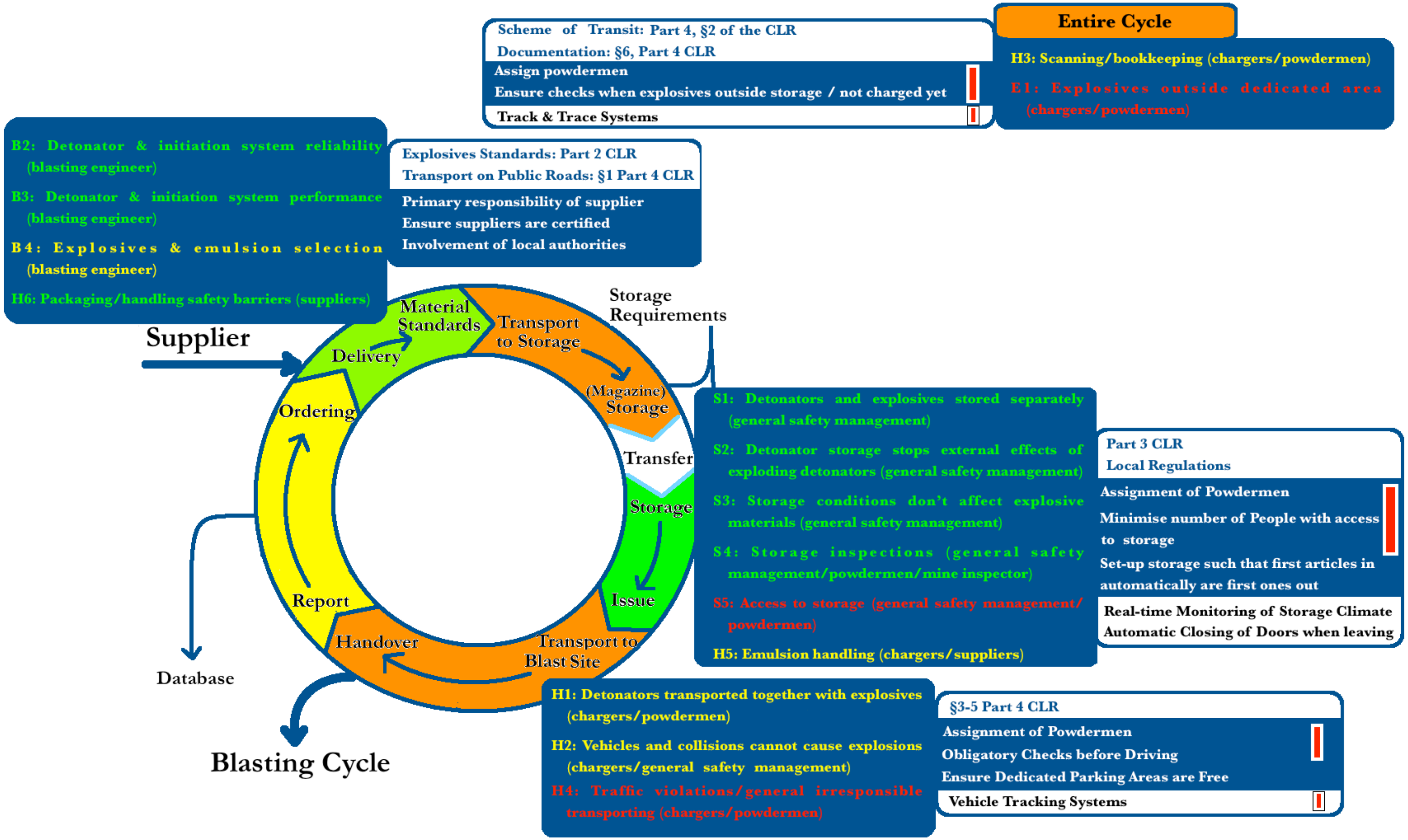


FIGURE 35: EXPLOSIVES HANDLING COMBINED RECOMMENDATIONS

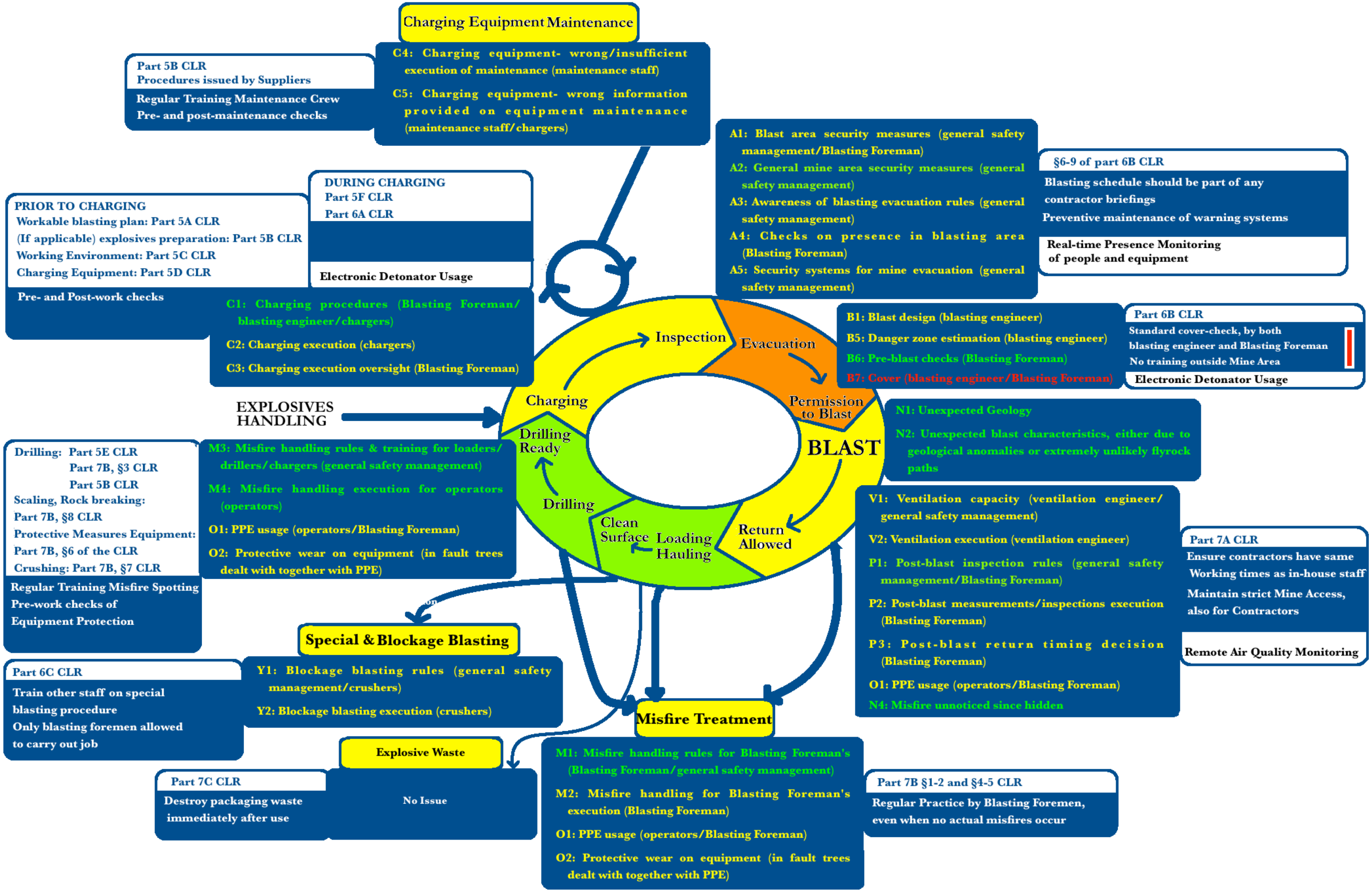


FIGURE 36: BLASTING COMBINED RECOMMENDATIONS

10.5. Blasting Recommendations

Compared to the explosives handling cycle, there is only one really concerning issue, namely missing or misjudged need of cover. Connected to this is the predictability of the reach of flyrock, which can be improved with better blasting materials, and lack of communication between different departments. In general, ensuring that a mine is completely evacuated during the blast is essential to ensure zero LTI's. As for some miscommunications that occurred with contractors, it seems necessary to primarily focus on awareness of evacuation procedures for both contractors and in-house staff. It would also be safe to use systems that check the whereabouts of equipment and people in real-time, so that vehicles and people cannot be left at the wrong places prior to a blast. Since it is expected that the number of misfires will decrease when using electronic detonators, it is recommended to train more frequently on the dealing with misfires, to ensure that these skills remain practiced with blasting foremen. Also, other rarer events, such as blasting trainings or blasting near vulnerable places should be practiced more frequently, to avoid miscommunications during such events.

10.5.1. Blasting Systems

Many of the safety concerns that seem best solvable by technological improvements related to blasting seem solvable by using electronic detonators. As discussed previously, the main advantages of electronic detonators are that they have very precise timing, which leads to an increase in blasting efficiency and thereby reducing vibrations, flyrock and fumes released due to the lower amount of emulsion needed to blast a stope of the same size. Because of their better fragmentation characteristics, many mines already use electronic detonation systems, but in the case of Boliden this is still not so in the majority of cases. According to findings in the field electronic detonators can be around five times as expensive as NONEL-initiation systems, and for that reason are not economically competitive. At the same time, they bring advantages for more complicated blasts, since they leave more room for precise blast designs. It is therefore recommended to make an integral assessment of the pros and cons of this system, since it seems that the initiation system selection is primarily made on purely blasting performance so far. It could however be the case that when safety considerations would be included the outcome of material selection might be different. In order to do this, it would however be important to gather more information on the quantity of misfires that could be avoided by using electronic detonators, using two detonators and primers per hole also proves to be a rather effective way to keep the number of misfires low, as Aitik and Kevitsa show. As a positive side effect, the number of required special blasts or mechanical destruction of boulders could also be reduced when blasting could be carried out more precisely using electronic detonators. Although it does not seem that special blasting operations cause many different situations, having less smaller rock destruction operations during shifts would by definition mean that there are less hazardous situations. Another concern that followed Chapter 9 were failing communication systems during or prior to blasting; decreasing the number of radio failures would therefore also be a good way to ensure a safer working environment.

10.6. Conclusion

To start with, it should be noted that the recommendations made in this chapter are far from complete. People with more specific knowledge and experience should better be able to identify all the potential hazards and come up with effective ways to mitigate them. An attempt has been made to provide a structure that could be helpful to introduce and further improve more standardized safety practices, and to prioritise the measures to be taken. Following the risk analysis undertaken in the previous chapter, it was possible to indicate what areas deserve most attention, on top of the minimum legal requirements. This was followed by an outline of possible technological improvements that could help to improve legally required safety standards, recommending a more wide-spread implementation of electronic detonators and digital track & trace systems. Finally, a structure has been suggested that makes it possible to quickly check if all safety requirements have been met, and that could be helpful when comparing and improving specific safety procedures. The basis is the distinction of an explosives handling cycle and a blasting cycle, split up into separate phases. Each phase has been assigned with a clear objective, and an end-check to ensure that all works have been carried out properly and that the next stage is safe to commence. The comprehensive legal requirements that have been identified previously have all been assigned to one of these specific stages as a minimum requirement for regulations, together with recommended technological changes and working methods, based on the previously undertaken incident reporting and risk assessments.

11. Conclusions and Recommendations

This research set off with the aim of making recommendations to improve the safety of explosives handling and blasting in Boliden Mines in Sweden, Finland and Ireland, that meets multinational legal, operational and safety requirements. In order to do this, the research had three main objectives, worked out in three different parts, with the final part connecting the first two. The aim of the first two chapters after the introduction was to find out what the legal requirements entail, the third, fourth and fifth part to discuss the actual practices, and the aim of the sixth chapter was to make recommendations based on the first two parts. The aim of this final chapter is to connect these different chapters in order to see what the most important lessons learned are, how they should be valued, and what an appropriate way to move forward on this topic would be. It therefore consists of four parts; the first part draws conclusions from the most important findings of the different chapters, the second part discusses how these findings should be interpreted, the third part what recommendations for further improvements can therefore be made, and the fourth part discusses what future research into this topic would be useful.

11.1. Conclusions

This chapter will go through the research by discussing the answers to the respective sub-research questions. In the end of this paragraph, the overall conclusion reached will be discussed.

Objective 1: Find out what legal requirements apply to explosives safety in Boliden Mines.

Sub-research question 1.1: *What law is applicable to mining operations in Sweden, Finland and Ireland regarding explosives safety?*

The legal sources applying to explosives and blasting safety in mining environments have been identified. It turned out that all three countries have similar sources of law, namely an international and European layer related to material standards that is the same, a backbone of general mining, workplace and explosives legislation and subsequently more specific requirements in government regulations related to explosives utilisation in mining, storage and handling and some smaller related issues and permitting procedures. Sweden and Finland have one blasting safety regulation applicable to both underground and surface mining and civil engineering, whereas Ireland has a blasting safety regulation that specifically applies to underground mining.

Sub-research question 1.2: *What do international and national regulations in Sweden, Finland and Ireland require regarding explosives safety in mines?*

Legal requirements in Sweden and Finland are stated in a relatively general and discretionary manner, but put significant responsibilities on the employer. Irish regulations tend to be more specific. Importantly, all three jurisdictions assign a central role to the Blasting Foreman, and have some kind of regulation on any stage in the explosives handling and blasting process. European legislation puts extensive responsibilities on suppliers of explosives in regards of their product standards and delivery; storage and handling on site is the responsibility of the mine. Key requirements include the separate storage and transportation of detonators and explosives, required checks by Blasting Foremen and limitations on drilling near charging/charged sites.

Sub-research question 1.3: *Is it possible to align the explosives and blasting safety legislation of Sweden, Finland and Ireland?*

A fundamental different approach between the Irish and Nordic approach of storing explosives is in regards to the distinction that is made in Ireland between the magazine and reserve station. Such a distinction is not made in Nordic law. Also, Irish legislation is much older, which means regulation on modern explosive materials is less detailed in this case. The legal requirement to develop a comprehensive scheme of transit in Ireland seems to be worthy of consideration in the Nordic countries as well. In general, no contradictions occur, and some more complicated issues, such as regulations on the number of detonators per blasthole, the distinction between detonator types and requirements in Nordic law aimed at blasting in urbanized areas could be aligned.

Objective 2: Identify the main issues relevant to explosives safety in mining, the way in which Boliden Mines take care of these issues and the complications that occur with this implementation.

Sub-research question 2.1: *What are the key safety issues and prevention and mitigation measures and practices when storing, transporting and using explosives in mining?*

A distinction has to be made between material selection and practices; selection of the right materials can already help a lot in securing the goal of ensuring a safe working environment. A successful implementation of digital track & trace systems and an increased utilisation of electronic detonators is deemed to be helpful in this regard. In terms of practices, governmental authorities and the explosives industry have outlined various standards that may be helpful in the process of risk assessments and establishment of new internal working practices.

Sub-research question 2.2: *What rules, guidelines and practices does Boliden have regarding explosives safety?*

All researched Boliden mines have elaborated a large set of SOP's, guidelines and other internal rules to ensure working safety. In the case of Sweden this has been done centrally from Boliden to a certain extent. In the case of Kevitsa, Finland, this is for a large part the responsibility of blasting contractor Orica. In all cases internal rules go well beyond in terms of level of detail compared to the specific legal requirements. Incident reporting is carried out centrally in Boliden and separately in Finland and Ireland.

Sub-research question 2.3: *What are practical complications and incidents that pose a threat to the fulfilment of safety requirements?*

It appears that blasting operations increasingly become safer, both within Boliden and in metal operations worldwide. All Boliden Mines have not had any injuries requiring medical treatment in the past six years in their blasting- and explosives handling activities, although there have been a few cases of near-misses. Misfires are singled out universally by staff as the main cause of concern, although it should be said that actual misfire rates are low. The implementation of digital track & trace systems in Ireland also seem to be worthy of improvement, given that the ordering system has suffered disruptions making scanning impossible. Based on data from the US, flyrock and noxious fumes appear to be the main threats to health and safety, and increasingly becoming the main cause of concern given that early detonation seems not to be a problematic issue anymore, and the use of electronic detonators may be an effective way to reduce the probability of misfires occurring. Fault Tree Analysis (FTA) has pointed out that the most critical activities in the blasting process are the appropriate selection of explosive materials, checks on presence in the blasting area and appropriate use of PPE. For underground mines, risk assessment of separate components showed that explosive materials lying at the wrong locations and blast area security procedure and the execution thereof that form the main concern. Concluding, maintaining stricter explosives handling procedures, more reliable blasting and the successful enforcement of existing blasting area security measures therefore appear to be critical to live up to the highest safety standards.

Objective 3: Find a way to develop an explosives and blasting safety policy for Boliden mines of the highest standards compliant with legal and safety requirements and practical conditions.

Sub-research question 3.1: *How can legal requirements, existing and recommended practices be aligned to ensure no LTI's occur in Boliden's blasting operations?*

It is deemed useful to distinguish the practices between large underground, small underground mines and surface mines to a certain extent. Large underground mines were dealt with as a case on how to make significant improvements, based on typical causes. Three main categories of causes have been discussed, namely material, procedural and external causes. Material causes may be dealt with relatively easily, by using electronic detonators on a wider scale. The procedural category is most closely aligned to legal matters, and may sometimes be hard to implement, following the findings in the second part of this research on incident causes. It is important to note that the most densely regulated safety hazard, early detonation, is also the one not leading to any accidents. Continued close compliance with the various legal requirements is therefore deemed most important for this hazard, whereas protection from other hazards is much less based in specific legal requirements, the only legal basis for the need to do this is the general requirement to ensure safe working environments. These different hazards therefore require a bigger reliance on the expertise of staff and suppliers, and the selection of the right materials. Therefore, in order to further improve explosives handling and blasting standards, a clear structure has been suggested that focusses on clear responsibilities per phase in both cycles, and since it would be standardised across different mines could be improved and compared by having the same responsibilities at different sites working towards the same goal. External causes are assumed to be non-mitigatable at their root, and therefore can only be dealt with by putting material and procedural mitigating measures in place. It was however found that external causes are responsible for only a tiny fraction of all incidents.

The overall objective of this research was to work out a workable safety practice regarding explosives handling and blasting that is compliant with all three jurisdictions. This was translated into the following main research question:

Is it possible to develop a multinational policy with regards to explosives- and blasting policy for Boliden Mines of the highest standards that is compliant with legal, operational and safety requirements?

Concluding, it can be said that it indeed is possible to develop such a policy. Guidance has been provided to achieve this policy; first of all, it is based on three different Compliance with the highest legal standards has been achieved by adding up and combining all legal requirements. Then, safety statistics have been used to assess safety concerns and incidents that are present, to see where additional measures would be necessary. Thirdly, ongoing development of explosives handling and blasting technology will in many cases help to mitigate these risks. On this basis, company-wide standards and reporting systems can be developed. Operational requirements are suggested to be met by using this structure, from which people that actually do have the operational knowledge and experience can work. This could then achieve a universally legally compliant explosives handling and blasting policy that would ensure a zero-harm working environment.

11.2. Discussion

The fact that it does seem possible to develop some form of multinational policy does not mean there are no critical points to be made. Perhaps the most important issue in this regard is that all operations and the legal landscapes in which they operate are changing continuously; the adoption of a new law could render important aspects of these suggestions useless. Also, the implementation of other technologies might raise further safety issues that do not play a role in this point, and different mine planning might change a lot as well. Regular updates, of both knowledge of multinational legislations and applied mining techniques and technologies used is therefore important.

Another difficulty may be the different mining cultures from three different countries; although on paper many issues appear to be similar, this does not mean they will be translated into practice in the same way. This could also mean that some of the assumptions in this research might be wrong, since a lot of the assessments have been made based on "paper" policies, interviews, and reliance on reported incidents. Each mine, or even each person, might have different ways of interpreting the same text, or answering the same question.

As for the specific Irish regulations on explosives utilisation in mining it should be noted that this legislation comes from 1972, and therefore appears to be outdated in regards of some of the conditions and technologies mentioned; it might be useful for the regulator to do a thorough overhaul in this regard, but this is of course not the responsibility of Boliden. A major overhaul of this old Irish legislation could however make many important legal findings in this research obsolete.

On a more general notice, it is to be realised that in practice the issue of explosives handling and blasting safety and its compliance with the law does not seem to be a very concerning issue for Boliden Mines. As far as could be judged in the course of this research, there are no cases of breaches of legal requirements at any Boliden Mines visited, all mines seem to take their responsibility in developing safety documents seriously, and no significant issues following explosives handling and blasting appear to have occurred. It could therefore be said that things might be going fine as they go, and that it might not be necessary to make any major changes, since these could cause other problems by themselves.

11.3. Recommendations

Given that explosives handling and blasting already seems a rather safe aspect of the studied mining operations, in the sense that no physical injuries have occurred, and that it would theoretically be possible to meet the various different legal requirements without major adaptions, it seems reasonably possible to move towards a universally legally compliant and zero harm safety policy. The most important steps that should be taken to achieve this goal are recommended below. Recommendations are distinguished in three types; an alignment of legal requirements, improvements of working practices and the implementation of new technologies.

Legal alignment seems helpful to meet legal requirements and meet safety standards, primarily because what is law in one country may already be a best practice or soft law in another. Also, given European integration overlap between national requirements, law is already getting aligned more and more by the regulators. Topics that seem especially suitable to align are the following:

- Assignment of responsibilities for different explosives handling and blasting tasks, since this could also help to improve exchange of best practices for specific tasks by these people.
- Requirements following law with a European background, in other words the requirements on transportation, explosives standards and marking and track & trace systems. Since the law is the same in this case anyway it seems to be inefficient to let all mines interpret these requirements separately.
- Other issues, that are explicitly national, such as permitting and licensing procedures can better be dealt with separately. Also, the implementation of the Irish storage regulation in other countries seems too much of an expense for other mines.
- The biggest difference between Ireland and the Nordic countries are the legal explosives handling requirements; although it may be too much to ask to build separate short-term and long-term storages as is required in Ireland, assigning dedicated powdermen for larger mines appears to be a successful way to reduce the number of incident related to explosives handling.

As for practices, this may be the most critical aspect in terms of safety performance, since most causes for incidents that occur appear to be related to actual practice.

- Since most incidents appear to be related to people being unaware of blasting of blasting procedures, or simple negligence, creating wider awareness of the practices and procedures in place, instead of revising the practices and procedures themselves, might be a very effective way as well to improve safety performance.
- In order to monitor safety performance a multinational incident reporting system should be put in place, including the most minor incidents and near-misses, so that mines can learn from each other across borders.

In the past, different explosive material usage has already greatly enhanced explosives safety. Therefore, technological changes may prove to be most effective. The most significant technological improvement could be reached by:

- Ensuring successful implementation of digital track&trace systems at all mine sites to have a real-time eye on the whereabouts of all explosive materials at the mine site.
- Implementing a more wide-spread use of electronic initiation systems in order to avoid hazards of misfires and flyrock, which have been deemed to be the most significant.

Methodological improvements would follow the two structural concepts discussed in Chapter 10. This means to base any methodological improvement on a structural safety analysis, such as the bow-tie analyses made. From there each category should be checked for compliance with the legal requirements, that have been discussed before. Then, to turn these requirements in working practices, the model suggested based on the explosives handling cycle and the blasting cycle seems a good start. From this distinction of phases, with clear beginning and end-markings, experts from different mines could work out a standardised policy. Key suggestions in this regard are the implementation of a comprehensive scheme of transit, clear communication from one phase to another and working from a single legal basis that would allow for ongoing updates of requirements from different jurisdictions to be made.

The implementation of all these measures should also be seen in the light of other aspects, such as economic considerations or operational conditions. For this reason, it is judged best to assess these aspects first before prioritising any of these measures over the other.

11.4. Further Research

Following the findings of this research, many new questions have been raised, on matters that may require a more detailed or extended approach. First of all, explosives handling and blasting safety issues form just one aspect of the works carried out in a mine. Already during this research overlap was found with other operations in mining, such as with drilling and loading and hauling operations and ventilation requirements. Since these requirements might also affect explosives handling and blasting operations, and some people might be involved in all these different operations, a similar research in these other topics could be useful to further improve understanding into the legal safety landscape of Boliden Mines and European mines in general.

Secondly, the two main recommendations regarding technological matters that were deemed to be helpful in regards of improving safety standards were related to the potential of track&trace systems and electronic initiation systems. Given that for track & trace the practical application seems to give difficulties of implementation, it should be found out how these can be solved, before the advantages of this system can become fully beneficial. Secondly, electronic detonators are already applied in most Boliden mines, mainly for reasons of improved blasting performance. This research has discussed this topic from the safety and legal standpoint, it might be worth it to undertake a more thorough comprehensive assessment of the viability of a more wide-spread implementation technology, combining the different operational and economic angles to assess this topic.

Thirdly, in order to improve understanding and practices, it could be very useful to benchmark both the legal requirements and safety practices with other jurisdictions and other mining companies; this might offer insights that are yet unknown. Also, a more thorough analysis of incidents facing other operations would be helpful in setting the right strategy to prevent any harmful events from occurring.

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VIII. Legal Sources

TREATIES AND OTHER DOCUMENTS OF INTERNTIONAL ORGANISATIONS

EUROPEAN DIRECTIVES

GUIDELINES ISSUED BY GOVERNMENTAL ORGANISATIONS

INDUSTRIAL BEST PRACTICES

BOLIDEN INTERNAL RULES

IX. Appendices

A. Specific Legal Requirements

1. Responsible Persons

TABLE 26: RESPONSIBLE PERSONS

	Sweden	Finland	Ireland
Who is responsible for a blasting round?	-Each blasting activity requires the assignment of a "sprängarbas"[1]. -It is possible that the employer is himself the sprängarbas.	-Each blasting activity requires the assignment of a " räjäytys työnjohtaja ". -The identity of the räjäytys työnjohtaja shall be clear to all workers and his name be displayed in the working place.	The person responsible for firing a shot is called the "shotfirer". This person needs to be a competent person appointed by the Mine Manager[2].
Legal basis	*§4 AFS 2007:1, note to §4*	*§8 16.6.2011/644*	*§7(1) Mines (Explosives) Regulations 1972; §13 Mines and Quarries Act 1965*
Responsibilities of the Blasting Foreman	-Verify safe storage and dealing of explosives and associated equipment. -Verify that works are executed professionally and according to the given instructions. -Instruct other people involved in the blasting process.	-The räjäytys työnjohtaja directs and oversees blasting activities. -The räjäytys työnjohtaja shall agree with the blasting plan. -The räjäytys työnjohtaja has to ensure that blasting activities are carried out according to the blasting plan.	-The shot-firer shall retain the removable handle or key of the blasting machine in his personal possession until he has completed his shot-firing duties.
Legal basis	*§4 AFS 2007:1*	*§8 16.6.2011/644*	*§21(1) Mines (Explosives) Regulations 1972*
Eligibility of the Blasting Foreman	-Documented theoretical knowledge around blasting. Preferred option is the education by the "Rådet för sprängteknisk utbildning, RfSU"	-Needs to have a license for "ansvarig laddare" (responsible charger) when blasting within 200 meters from areas where people live, otherwise he needs to have a license for "äldre laddare" (elder charger).	-Has had at least 12 months of practical experience below ground during which he has been trained in the use of explosives. -A Mine Manager can only appoint a shot-firer to fire shots with a delay detonator or more than six shots

[1] The "sprängarbas" in Sweden, "räjäytys työnjohtaja" in Finland and "shotfirer" in Ireland have comparable roles, and will be referred to as "Blasting Foreman" when it is not necessary to emphasize the national differences.

[2] The required qualifications and tasks of the Mine Manager are described in sections 13-22 of the Mines and Quarries Act 1965. The Mine Manager is appointed by the owner of the mine, the owner is the person who is in the end responsible for compliance with the Mines and Quarries Act 1965 and other relevant legislation (section 12). In daily operations, it is therefore the Mine Manager that is responsible for the compliance of mine practices with the relevant law, on behalf of the owner (section 13(2)). Following this, for the purpose of this research it is assumed that the roles of the employer under Swedish and Finnish law and Mine Manager under Irish law are comparable. "Employer/Manager" is the term that will be used for multinational rules to avoid confusion.

	(Council for blasting engineering education).	-The blasting license has to be taken to the job. -An "yngre laddare" is allowed to use at most 25kg of explosives per day and at most 1 kilo of explosives per charge.	unless he has practiced this particular type of shot-firing for at least five shifts under the close and exclusive personal supervision of a qualified shot-firer.
Legal basis	*§6 AFS 2007:1*	*§8 16.6.2011/644; §27 3.6.2016/423*	*§8(3); §9 Mines (Explosives) Regulations 1972*
Blasting Licenses	The education should include terminology, types of explosives, detonators, calculations and designs around the field of blasting and explosives engineering, geological impacts of blasting, relevant legislation, measurements of resistances and practical assignments. The course has to be completed with a test, and the results have to be certified. -At least 1 year of experience in blasting. -In case of uncomplicated activities documented theoretical knowledge around the specific task and at least 2 years of general industry experience.	-Are issued by a RSAA. -Will be issued to people; -over 20 years old; -is healthy (as proven by a doctor); -has a good reputation[3]; -has the right education and competence; -with sufficient working experience. Each license can only be obtained when the lower license has been obtained previously as well. -Yngre Laddare: >6 months experience -Äldre Laddare: >12 months experience -Överladdare: >18 months experience -Ansvarig Laddare: >24 months experience -Procedures on the acquisition, renewal and (temporary) withdrawal of blasting licenses are listed in §11-17 of 3.6.2016/423. -Rules for the RSAA are listed in §22 and 23 of 3.6.2016/423.	
Legal basis	*Note to §6 AFS 2007:1*	*§5-10, 3.6.2016/423*	
Other people involved in the blasting process		Other people can work with explosives as well, as long as they are under direct oversight of a qualified charger.	-No one else than the shot-firer is allowed to blast by means of a delay detonator or in a round of more than six shots unless he is a shot-firer appointed by the Mine Manager, unless he is; -A person other than the shot-firer is only allowed to fire shots with an electronic detonator when he is in training, under close supervision of an experienced

[3] The requirements with regards to health and reputation (criminal record) are worked out in detail in §6 and 7, but judged to have limited relevance for this research. Since it is impossible to apply similar standards to the blasting license acquisition in all three countries and has no effect on blasting procedure in practice this has not been included.

			shot-firer and provided with written authority by the Mine Manager[4]. -For training purposes the trainee shot-fire can be in possession of the blasting machine key or handle as well, as long as he remains under the oversight of the trained shot-firer.
Legal basis		*§3 3.6.2016/423*	*7(1)(b); §7(2); §9; §21(3) Mines (Explosives) Regulations 1972*
Person Responsible for Explosives Storage		People responsible for explosives storage and other people working with these shall be properly instructed and trained.	The Mine Manager shall appoint such number of people and arrangements so that each place where explosives, blasting agents and detonators are stored has a competent person in charge.
Legal basis		*§37 14 20.8.2015/1101*	*§12(3) Mines (Explosives) Regulations 1972*
Registration responsible people			-Particulars of the qualifications required for the above discussed tasks and functions shall be kept at the office of the relevant mine or at a similar place as approved by an inspector. -The Mine Manager shall keep a record of all shot-firers appointed by him, and if a shot-firer is appointed to fire shots by means of a delay detonator or in a round of more than six shots this shall be included in the record.
Legal basis			*§7(5); §10 Mines (Explosives) Regulations 1972*

[4] In all requirements mentioned in this report following from the Mines (Explosives) Regulations 1972 regarding tasks of the shot-firer the same rights and responsibilities will apply to the trainee-shot-firer, unless mentioned otherwise.

2. Oversight

TABLE 27: OVERSIGHT

	Sweden	Finland	Ireland
Responsibilities Employer	-Provide sufficient information about the object to be blasted to the sprängarbas. Information must include rock mechanical characteristics such as faults, brittle rock or other forms of deformations or inhomogeneity's in the rock mass. -Notify the sprängarbas about any issues that may be relevant for blasting. -Verify that the sprängarbas indeed is well-prepared and qualified to perform his task.	-In case the employer has reason to believe that the validity of a blasting license could be affected due to certain issues he has the right to report this to the RSAA in written form. -The employer has to report any cases of accidents with explosives to the work environment authority.	
Legal Basis	*§5 and 7 AFS 2007:1, note to §5*	*§19 2016:423; §30 644/2011*	
Inspector, Police		-In case the police has reason to believe that the validity of a blasting license could be affected due to certain issues it has the duty to report this to the RSAA immediately[5]. -Any legal person working with explosives shall request a permit and be ready to provide any information to the applicable authority, and be open to inspections.	-The Minister[6] or inspector may exempt a mine to apply any of the regulations in the Mines (Explosives) Regulations 1972 if he is satisfied that the safety of people working in the mine will not be negatively affected. -If a scheme of transit (see Transportation Requirements Table 31) does not meet the legal requirements according to the inspector he can require the Mine Manager to amend the scheme. -If a misfire plan does not meet the legal requirements according to the inspector he can require the Mine Manager to amend the scheme.
Legal Basis		*§20 2016:423; Chapter 14 3.6.2005/390*	*§5; §18(5); §51(3) Mines (Explosives) Regulations 1972*
Permits	-The municipality where explosives will be utilised needs to issue a permit allowing this. If explosives are used in more than one municipality a permit needs only to be obtained in the official residence or main place of works of the business. -A risk plan is required to undertake, this shall be documented. The people drawing up this plan shall have good experience with this type of work.		

[5] Similarly, healthcare professionals have the *right* to report concerns regarding a person with a blasting license to the RSAA, despite patient confidentiality requirements (§21 2016:423).
[6] "The Minister" means the Minister for Labour of the Republic of Ireland (§3(1) Mines (Explosives) Regulations 1972).

Legal Basis	*§16 Lag (2010:1011); Kap.2 §2, Kap. 5 §2 MSBFS 2016:3*		
Certifying bodies	-Certifying bodies shall make a certificate for each class of object they have inspected, stating that the inspected object meets the legal requirements. The certificate is only valid for other objects that have been made in exactly the same way. -Certification of electrical initiation systems can be executed by a body that is accredited according to law 2011:791, type A, or a certification body from another EEZ-country if this body follows SSEN ISO/IEC 17020:2005 or EN 45011that applies the requirements of ISO/IEC 17011:2004. If the certification for a particular object has been granted in another EEZ-country or Turkey and with similar safety standards this is acceptable in Sweden as well.		
Legal Basis	*40, 41 AFS 2007:1*		

3. Quality Requirements with Regards to Explosives

TABLE 28: QUALITY REQUIREMENTS OF BLASTING MATERIALS

	Sweden	Finland	Ireland
Quality requirements detonators/ blasting machine	Detonators for both electric and non-electric detonation and all types of testing and measuring equipment needs to be certified by a certification body of type A that is accredited according to Lagen 2011:791. The check shall prove that unintended ignition is made impossible as much as possible according to AFS 2014:1, and that intended initiation is reliable.	It is the duty of the employer to select the explosive material that causes the least danger.	-The electric blasting machine is to be provided by the owner of a mine with the required cable and shall be suitable in all ways for single shots or for firing shots in a round. It is not allowed to blast anything with an electrical blasting machine, unless it is provided this way. -If a blasting machine appears to be defective or when it becomes defective while in use shall not use it further and return it to the surface immediately and report the circumstances to the manager in writing. If the blasting machine fails to fire a properly connected round in one go it shall be considered defective, although it still may be used to fire the misfires in accordance with the other regulations in the Mines (Explosives) Regulations 1972.
Legal basis	*§27 AFS 2007:1*	*§8 3.6.2005/390*	*§19(1), 20; §22 Mines (Explosives) Regulations 1972*
Initiation systems of different manufacturers	When electronical detonators are used, it is not allowed to use different detonation systems or manufacturers.	Initiation systems and detonators of the same manufacturer shall be used, unless the different systems are compatible.	
Legal basis	*§26 AFS 2007:1*	*§9 16.6.2011/644*	
Clarity on explosive materials used		The operator has a duty to obtain all the information from the manufacturer to ensure that he can work with the material.	No blasting material or device shall be taken or used below ground in a mine other than material or a device provided by the owner of the mine.
Legal Basis		§7 3.6.2005/390	*§66(2) Mines and Quarries Act 1965*
Requirements on explosives to be used		-When working in an open pit mine, or underground workings less than 100m from the tunnel opening, in an urban area only cartridge explosives or explosives of similar safety level may be used.	No explosive or blasting agent is allowed to be taken into or used in the mine, except when; -in accordance with the Mines (Explosives) Regulations 1972 and mine-specific regulations. -Have correct marking (*see* §0 of this chapter).
Legal Basis		*§9 16.6.2011/644*	*§11(1)(2) Mines (Explosives) Regulations 1972*
Cleaning/ maintenance			-The Mine Manager shall ensure that the blasting machine is thoroughly cleaned and overhauled at least once every three months by the manufacturer or a competent person appointed by the Mine Manager. All multi-shot blasting machines shall be tested at the surface according to the

			guidelines of the manufacturers, when failing this test, it shall not be taken below ground. Reports and dates on cleaning, overhaul and testing are to be registered. -Below ground, only in a certified workshop can be tampered with blasting machines.
Legal Basis			*§23; §24(1) Mines (Explosives) Regulations 1972*
Ignition cables			-No cable with iron or steel wire covering shall be used unless during shaft-sinking or when initiation is done by means of electric current from a lighting or power circuit. -If a cable is used for another purpose than blasting it shall be used no more for blasting.
Legal Basis			*§19(3); §24(2) Mines (Explosives) Regulations 1972*
Defective explosives			Defective explosives or blasting agents shall be deposed of in a safe manner.
Legal Basis			*§12(5) Mines (Explosives) Regulations 1972*
General Requirements on explosives usage		-Explosive goods shall be used in such a way that they don't cause damage, the prescribed safety instructions of the supplier shall be followed.	
Legal Basis		*§78 3.6.2005/390*	

4. Marking and Packaging of Explosives

TABLE 29: MARKING AND PACKAGING OF EXPLOSIVES

	Sweden	Finland	Ireland
Marking of detonators			Period of delay has to be marked on a detonator to be allowed to be used or taken below ground.
Legal Basis			*§15(2); §29(3) Mines (Explosives) Regulations 1972*
Packaging of explosives.			-No explosives shall be taken or used into a mine except in cartridges. -The maximum amount of any explosive to be taken below ground is 2.27 kilograms (5 pounds) of cartridges. This has to be packaged in a secured case or canister, until they are about to be used for charging, and at no point in time more than one case or canister can be open. Deviation from this can only be done when there is a conveyance plan.
Legal Basis			*§17 Mines (Explosives) Regulations 1972*
Packaging of Detonators			-No detonator shall be taken below ground otherwise than in a securely fastened detonator cases provided by the owner of the mine. -The Mine Manager shall ensure no detonator case is issued unless it is impossible for any detonator or its leads to touch any metal part of the case exposed to the outside. -It is the responsibility of the shot-firer to keep the detonator in a securely fastened case, nothing else than a check sheet for recording shots is in the case, and that the case is kept separate from any other receptacle, and when not on his person or in his immediate vicinity the detonator is in a locked box without explosive on a safe place.
Legal Basis			*§15(1)(3); §16(1)(a)(b)(c)(d) Mines (Explosives) Regulations 1972*
Ignition cables			Ignition cables shall be kept well in a case.
Legal basis			*§24(2) Mines (Explosives) Regulations 1972*
Opening cases			When opening explosives or blasting agent cases or cartons only implements of copper, wood, fibre or other suitable materials shall be used. This does not apply to cutting wire or other binders.
Legal Basis			*§12(6) Mines (Explosives) Regulations 1972*

5. Storage Requirements

TABLE 30: STORAGE OF EXPLOSIVES

	Sweden	Finland	Ireland
Risk management	-Explosive materials should be stored in such a way that the risk of fire or explosions are minimised. -Areas where explosives are used in such a way and quantity that there is a risk for explosions shall be divided in risk zones E1, E2 and E3 according to Swedish standard SS 421 08 24 or a similar standard. -The zone division shall be documented in a classification plan, which shall be accessible at the risk site, at least the set-up of the area and their horizontal and vertical dimensions and temperature shall be included. -The plan shall be continuously updated. -Electrical and mechanical equipment shall be adapted for each zone.	-The operator shall identify possible sources of initiation of materials that are expected to be permanently or temporarily in the storage. The specific initiation of the materials stored shall be considered. -Surface temperatures shall never exceed the temperature where the explosive materials or other materials can initiate or catch fire. -It is never allowed to have open fire around explosive materials. -Static charging shall be prevented. -Other initiation sources such as electromagnetic waves, ionic radiation or ultrasound shall be considered as well.	A licensee shall write an assessment of the site and activities related to the storage. This for the purpose of identification of fire and explosive hazards, assessment of the risks presented by them, identification of the persons that might be harmed by them and a decision on safety measures needed to minimise these risks. This shall be forwarded to the competent authority with application or with a new assessment. The assessment shall be reviewed from time to time by a competent person. Appropriate mitigation measures shall be taken. General safety precautions and procedures, emergency, security and working procedures shall be provided as well. Any person on the site shall be provided by the licensee with adequate training and safety measures.
Legal basis	*§32 AFS 2010:1; Kap. 6 §1-4 MSFBS 2016:3*	*§43-§47 20.8.2015/1101*	*§15 Stores for Explosives Order 2007*
Dedicated storage	Explosives shall be stored in a certified storage, separate from working rooms.		-No storage at a mine site is allowed unless the Mine Manager appoints a dedicated surface to this extent. This storage needs to have been licensed under the Explosives Act 1875. This storage is referred to as the "Explosives Store". -The storage shall be certified by competent persons.
Legal basis	*Kap. 9 §1; §2 MSFBS 2016:3*		*§12(1) Mines (Explosives) Regulations 1972; §10(13) Stores for Explosives Order 2007*
Permit	If a temporary storage stays at the same place for more than 5 days a permit has to be requested at the local municipality.	A permit has to be obtained for the temporary storage of explosive goods from the Safety and Chemicals Service.	The storage of explosives requires a permit. -This permit is issued by a local authority. If the storage permit is awarded it can remain valid for at most 5 years. It contains provisions on the maximum quantity of explosives to be stored and the way in which this should be done. The conditions of storage can be changed by the local authority with prior approval of the Minister, when safety concerns arise.

			-The permit may even be revoked in case of noncompliance with the conditions or this order, or the site or store itself is no longer suitable.
Legal basis	Kap. 9 §39 MSFBS 2016:3	*§58b 3.6.2005/390*	*§15 Explosives Act 1875; §7-9 Stores for Explosives Order 2007*
Storage outside dedicated storage facilities	-Explosive materials may be stored in a movable storage if the operations require this. -If an interruption of works occurs for more than three days the explosive materials shall be returned to the permanent storage or be guarded permanently.	-A maximum of one workday load of explosives can be kept outside the explosives storage. The explosives should be clearly marked and constantly guarded. If the needed amount is less than 25kg a maximum of 25kg of explosives can be kept. After working hours, all explosives have to be returned to the dedicated storage. Nevertheless, a charger can keep a maximum of 60kg of explosives at the blasting site. -Explosive materials that will be used during the day and explosive materials that the charger may store on the blasting site shall be marked and supervised continuously in a proper way and kept in a temporary or permanent storage with appropriate protection. The explosive materials can also be stored in a separate transport unit compliant with safety requirements. In the storage room, no other materials than explosive materials can be stored. The name and contact details of the person responsible for the storage shall be known on the blasting site and reported outside the storage. The storage shall be indicated in the blast site protection plan or another safety document for the working place. Detonators shall be placed such that they cannot initiate other explosives. The storage shall be at least 10 meters from a breakroom or other places where other people normally come. A risk assessment has to be made prior to the start of storage. -Temporary storage for ammonium nitrate solutions and other raw materials for emulsions shall be stored in dedicated spaces with sufficient spillage collectors. The storage shall be on a protected location, and at least 5 meters away from break rooms and offices. In the vicinity of the storage there may not be matters that can cause a fire hazard or burnable materials. The storage site has to be indicated in the relevant safety	-The Mine Manager shall appoint at least one place which shall be situated conveniently near the top of each shaft or outlet normally used for the deposit of explosives, blasting agents and detonators brought out of the mine, and may appoint another place for the issue of explosives, blasting agents or detonators, the reserve station. -The person in charge of the reserve station has to ensure that; (a) any explosive is to brought back to the main storage if the mine is not to be worked for a period of fourteen days. (b) if the mine is worked, the explosive materials are to be handed over to the person responsible immediately after his own shift, brought back to the explosives storage or locked securely in the reserve station. (c) the key to this reserve station is either delivered to a person in charge of the explosive during the shift immediately following his shift, or deposited in the explosives store.

		plan. The storage shall have the appropriate signs and be locked when not in use.	
Legal Basis	Kap. 9 §1; §2 MSFBS 2016:3	*§11 16.6.2011/644; §38; §39 20.8.2015/1101*	*§12(2); §17(7) Mines (Explosives) Regulations 1972*
Distance from protected objects	The distance of an explosive storage, for explosives of category 1.1, to protected objects such as urban areas and busy traffic shall be at least A meters, with. $$A = 30\sqrt[3]{Q}$$ And at least A meters to other traffic roads. $$A = 9\sqrt[3]{Q}$$ with Q=netto weight explosive In case there is natural protection such as rock walls, the distance can be smaller, but never less than half of the distances mentioned above. The type of explosives stored also need to be considered.	The distance of explosives and objects outside is the following for the respective categories: 1.1 and 1.5: $l = k * m * {}^{1}/_{3}$ 1.2 and 1.6: $l = k * m * {}^{1}/_{6}$ 1.3: $l = k * m * {}^{1}/_{10}$ with: $$l = \text{ distance in } m$$ $$k = \text{ explosive coefficient according to Annex } 1 \text{ of } 20.8.2015/1101$$ $$m = \text{ mass of explosive in } kg$$ For underground storages, the distance shall be at least 60% of the above-mentioned distances. Minimum distances should in any case be at least 100-500 meter from public roads, railways etc., special buildings and urban areas, depending on the type of material stored. Check §13 and 15 for details on this. - The explosive of the highest risk class shall determine the natural separation distance, and the entire amount of explosive materials should be counted as being from the highest risk class. Explosives from categories 1.1, 1.2 and 1.5 shall be at least 100m from high tension cables and gas pipelines.	Separation distances to other buildings shall be in accordance with Schedule 4 of the Stores for Explosives Order 2007. Any explosive not in its ADR-packaging shall be treated as a class 1 explosive. The explosive of the highest risk class shall determine the natural separation distance. -In excavated storages, a consultant shall determine the appropriate distance.
Legal Basis	*Kap. 9 §16; Annex A, MSBFS 2016:3*	*§9-13, 15; 14 20.8.2015/1101*	*§13 Stores for Explosives Order 2007*
General storage requirements	-Explosives shall be stored such that they cannot be affected by impact, tearing, heating or anything else that can cause them to explode. -Explosive materials shall be stored in an environment where they cannot age unnecessarily.	-Storages shall be built such that: 1) explosions cause as little dangerous debris as possible spread 2) emergency services have unhindered access 3) spread of accidents to other spaces is prevented as much as possible 4) a possible explosion cannot get into other buildings 5) outer walls have pressure reductions if necessary -The storage shall not have windows. -The storage shall comply with standard SFS 4397 (permanent) or SFS 4298 (temporary).	-The storage shall prevent the ingress of moisture and protect against climatic effects. -Internal walls, ceilings, other surfaces, furniture, fittings etc. shall be made such that they can easily be cleaned. -No iron or steel shall be exposed.

			-Additional requirements apply to storages for oxidising controlled substances[7].
Legal Basis	*Kap. 9 §6-7MSFBS 2016:3*	*§27; §28 20.8.2015/1101*	*§10(3);(9);(10) Stores for Explosives Order 2007*
Way of storing explosives	-Explosives shall be stored decently, and as long as possible in unopened original transportation packaging. -Packages shall be placed such that there is a good overview of the storage, and that there is sufficient place to load and unload.		
Legal Basis	*Kap. 9 §4-5 MSFBS 2016:3*		
Other objects/electricity/ equipment in the storage	-In a storage only material objects that do not increase the risk of fire or explosion can be left. -Explosives shall be placed at such a distance from electrical equipment that they cannot cause initiation of the explosives. -Electricity in the storage shall be switched off when there is no work going on. -A space in a storage cannot be used as a place to leave motorised equipment for more than the time necessary to load/unload needed materials.		(Electrical) equipment shall be compliant with the standard "HSE Guidance Note PM 82" or a similar standard.
Legal Basis	*Kap. 9 §8-11 MSFBS 2016:3*		*§10(7) Stores for Explosives Order 2007*
Separation of types of explosive materials	-Explosive materials shall be divided in groups according to annex 6 of MSFBS 2016:3; explosive materials in groups C, D, E and G should be stored together. Explosive materials of group S can be stored together with explosive materials from other groups except from groups A and L. Other groups cannot be stored together. -Detonators shall be stored separately from other explosive materials.		

[7] *§11 Stores for Explosives Order 2007* lists a series of requirements in this regard. Since emulsions are supplied by a contractor that is also responsible for its manufacturing in Boliden mines it is kept outside the scope of this research. It is however important to notice that controlled substances shall not be stored on the same site as conventional explosives, unless separation distances are maintained according to Table 10 of Schedule 4; different controlled substances shall be stored separately from each other unless they are known to be incompatible, and oxidising substances shall be stored separately from fuels and other incompatible substances (*§14 Stores for Explosives Order 2007*).

Legal Basis	*Kap. 9 §14; §15 MSFBS 2016:3*		
Storage of mobile aggregates		Storage of mobile aggregates shall be such that they do not cause danger to other works in the area. The distance between rooms storing mobile aggregates and other objects and rooms shall be at least 5 meters. Unauthorised access is not allowed, and it shall be easy to notice leakage. Rests of explosive materials that occur with cleaning of the aggregate shall be stored according to the specific permit requirements.	
Legal Basis		*§9-13, 15; 14 20.8.2015/1101*	
Access to the storage	-Keys, codes etc. shall be stored such that unauthorised people cannot get them, or they shall be under constant supervision. The doors to the storage shall be locked except for (un)loading or other necessary activities. -Each storage shall be protected against access by unauthorised people; the protection shall be adapted to the level of desirability. For mining explosives, this is level A according to Annex 7 of MSFBS 2016:3, which means that the access should be able to withstand an attack with handheld tools and electrical tools for at least 80 minutes.	-Storages shall be burglar-proof. They shall be installed with a functioning warning system that transfers the signal to a person that is close or in a security shift. The possible impact of radio-waves of the system on the materials stored shall be considered. -Explosive materials shall be stored and handled so that unauthorised people cannot get access or danger the workings. It shall always be clear how many people are in danger in case of accidents. Rooms shall be equipped with systems that warn when unauthorised people get in.	-Unauthorised access shall be prevented. Doors, openings, security systems etc. shall comply with a standard approved by the Commissioner of the Garda Síochána.
Legal Basis	*Kap. 9 §12; §17-23 MSFBS 2016:3*	*§28; §35 20.8.2015/1101*	*§10(4)(5) Stores for Explosives Order 2007*
Anchoring	-Storages shall be anchored or weigh at least 500 kg when they store explosives of desirability level A.		
Legal Basis	*Kap. 9 §24 MSFBS 2016:3*		
Protection against fire	-A storage shall have fire protection of at least fire technical class EI 30. This does not apply when there is no risk for fire in the area. -Trucks with combustion engines accessing the storage shall have both fixed and handheld fire extinguishers. Such trucks	The storage shall be able to withstand at least 120 minutes of fire on the outside.	-The licensee shall ensure that the fire authority concerned confirms that the fire detection, alarm safety, resistance, escape routes, fire-fighting equipment are in accordance with the "Guidance Document on Fire Safety".

	shall also have a main switch for their battery current.		
Legal Basis	*Kap. 9 §25-26 MSFBS 2016:3*	*§28 20.8.2015/1101*	*§10(8) Stores for Explosives Order 2007*
Protection against thunderstorms	Surface storages storing at least 500kg of explosives shall have sufficient protection against thunderstorms.	Surface storages storing at least 500kg of explosives shall have sufficient protection against thunderstorms.	-Lightning protection shall be fitted.
Legal Basis	*Kap. 9 §27 MSFBS 2016:3*	*§46 20.8.2015/1101*	*§10(11) Stores for Explosives Order 2007*
Storage underground	-Storage in rock excavations shall be placed and constructed such that there is no hazard for explosions by rock loosening, flyrock with blasting or collision with vehicles. -For a storage in a tunnel roadheading shall the storage be surrounded with a thick layer that protects against impact. For storage in a tunnel or roadheading that follows progress the distance to the blasting face shall always be sufficient.	Underground storages shall be located as far as possible from regular working places and in such a way that blasting that is executed in the area does not damage the storage. Spreading of fire to the storage shall be prohibited, there shall be no burnable materials around the storage. The location of the storage shall be motivated, and a risk assessment of the storage on the location and protection by a comparison of different alternatives shall be undertaken. The minimum distance between the storage and other rooms shall be at least 30 meters and the rock roof at least 15 meters. The storage should not be closer than 100 meter from the tunnel mouth. The storage shall have its own cave that can be locked and prohibits unauthorised people from entering. Detonators shall be placed such that they cannot initiate other explosives.	
Legal Basis	*Kap. 9 §32-33 MSFBS 2016:3*	*§22 20.8.2015/1101*	
Signs	-A storage shall have shields that indicate the risk of explosion, a prohibition of smoking and open fire, and the largest quantity of explosives that can be stored there. -The shields shall be weather and impact resistant. They shall be in accordance with Annex 9 of MSFBS 2016:3. They shall be placed and adapted to their environment and also visible in the dark. -Signs shall be removed when they are no longer relevant.	Storages shall have the appropriate signs so that it is clear what hazard the storage poses. At least the necessary prohibitions and the contact details of the responsible person shall be mentioned.	The licensee shall display in a prominent position near the entrance to the storage- fire safety and dangerous goods hazard signs, maximum quantity of the hazard type or types authorised by the license to be kept in the storage, maximum number of both employees and all persons permitted by the licensee to be present in the store, the general and special rules for explosives, procedures, and a copy of the current license.
Legal Basis	*Kap. 9 §28-30 MSFBS 2016:3*	*§28; §30 20.8.2015/1101*	*§10(12) Stores for Explosives Order 2007*
Supervision			-All detonators shall be in the sole charge of the Mine Manager, or when the Mine Manager has

			appointed this person, a person that is in charge over the store. -An explosives storage shall at any time be under the supervision of a competent person.
Legal Basis			*§14(1) Mines (Explosives) Regulations 1972; §12 Stores for Explosives Order 2007*
Taking explosives from storage	-When using explosives from a store, those that have been longest in shall be taken out first.		-When using explosives from a store, those that have been longest in shall be taken out first. -No one shall be in possession of a detonator outside the store, except for a shot-firer (or one in training), or a person with written permission of the Mine Manager.
Legal Basis	*Kap. 9 §5 MSFBS 2016:3*		*§12(4); §14(2) Mines (Explosives) Regulations 1972*
Reporting Requirement	-He who stores explosive materials, shall keep a log containing and continuously updating information on the amount of each explosive material that is stored. Daily updates shall be accessible at another appropriate place than the storage.		Any accident by explosion in connection with an explosives storage shall be reported to the safety authority, who may decide on further measures.
Legal Basis	*Kap. 9 §13 MSFBS 2016:3*		*§63-66 Explosives Act 1875*

6. Transportation Requirements

TABLE 31: TRANSPORTATION OF EXPLOSIVES

	Sweden	Finland	Ireland
Delivery and unloading of explosives	-It is not allowed to transport any explosive material when it is not following the rules in Lag 2006:263, and necessary precautions have been taken to ensure negative impacts on life, health, environment and property, and verified that all vehicles, packaging and other materials used are appropriate. -It is necessary to have at least one safety advisor for each task, who has the sole risk to avoid damage resulting from the transport and delivery. -Authorities exercising oversight duties have the right to require any information, stop a transport or access sites in order to inspect the safety situation[8]. If necessary transports can be forbidden or additional measures required by the overseeing authority.	-For road transport permission shall be requested. The driver shall have an appropriate license. -Safety precautions should be taken for the transport of explosives. Rules can be established on this, documentation on the necessary precautions and these rules should be taken along by the transporter. -It is necessary to have at least one safety advisor for each task. -The Ministry of Communication is in the end responsible for overseeing explosives transports.	
Legal Basis	§2, 6; §11; §13, 14 2006:263	§11(b); §10c; §11(c) 2.8.1994/719	
Internal Conveyance plan			The Mine Manager may decide to convey explosives[9] in bulk from a storage to a reserve station, if he makes a plan. This "scheme of transit" should include provisions on; -Location, construction and marking of each reserve station, detonator store and custody of the keys thereof; -Design and construction of the special carriage; -Supervision and precautions to be taken during transit of the carriage; -Supervision of explosives at a reserve station and detonators at a detonator store; -Manner of conveying explosive and detonators to any working face; -Maximum quantity of explosive and the maximum number of detonators permitted at their respective stores.

[8] Requirements related to oversight can be found in §12-20 2006:263, but they apply to governmental authorities or legal disputes about issued permits and are therefore left out since they do not directly affect working practices on a mine site.

[9] In this table, "explosive" includes blasting agents.

			-Issue of explosive and detonators from their respective stores; -Return of explosives and detonators to their respective store; -Ways to ensure that explosives are moved in accordance with this plan.
Legal basis			*§18(1)(2);(3)(b) Mines (Explosives) Regulations 1972*
Size of Transport			The quantity of explosives moved shall not exceed the amount needed in the coming 48 hours.
Legal basis			*§18(3)(a) Mines (Explosives) Regulations 1972*
Protective measures	-Explosive materials that are moved within the mine have to be protected against mechanical impact, heat and anything else that can cause fire or explosions. -Each powered vehicle shall be equipped with fire extinguishers.	-Vehicles transporting explosives have to have been certified by the Transport Safety Agency.	
Legal basis	§8 AFS 2007:1; §34 AFS 2010:1	§7a 2.8.1994/719	*§18(3) Mines (Explosives) Regulations 1972*
People involved in transport	Only people that are strictly necessary for the transport are allowed to travel along the vehicle or lift transporting the explosives.		A scheme of transit can impose duties and prohibitions on employed persons, it is the duty of the Mine Manager to ensure compliance.
Legal basis	§8 AFS 2007:1		*§18(4) Mines (Explosives) Regulations 1972*
Restrictions on other goods	Explosive materials cannot be transported together with other hazardous materials.		
Legal basis	§8 AFS 2007:1		
Documentation		Documentation shall be kept on all explosives that are being transported to a working place or returned to the dedicated storage. The form and content shall be described.	The Mine Manager shall ensure that a copy of the scheme of transit is posted and kept posted so that anyone can read it clearly, and one is supplied to any shot-firer and store manager.
Legal basis		§12 16.6.2011/644	*§17(8) Mines (Explosives) Regulations 1972*

7. Planning

TABLE 32: PLANNING REQUIREMENTS

	Sweden	Finland	Ireland
Planning requirements	Each object to be blasted requires planning. Planning and execution should be such that physical harm as a consequence of the blasting will be avoided.	The employer shall develop the blasting safety plan. It shall include the following aspects: 1. Characteristics of the rock to be blasted. 2. Electrification, lighting, communication, extraction techniques and other technical specifics. 3. Roads, exits and safe havens. 4. Equipment selection and maintenance. 6. Safe working methods. 7. Explosives that are used. 8. Emergency plan. 9. Other factors that may be of importance.	A danger zone has to be defined.
Legal basis	§3 AFS 2007:1	§3 16.6.2011/644	*§37 Mines (Explosives) Regulations 1972*
Risk Management	Risk assessment necessary for each object to be blasted.	-Risk assessment has to be undertaken following the rules in §10:1 of the Finnish Workplace Safety Law 738/2002. This means it should be a systematic approach identifying the difficulties and risks related to the job, working place, environment and time. -If it is not possible to remove these risks the possible negative impact has to be assessed. All effects on both health and safety have to be included. -Any activity that includes exceptional hazards cannot be executed without explicit safety measures having been ordered by the management.	
Legal basis	§3 AFS 2007:1	§3 16.6.2011/644; §10:1 2002/738; §4 16.6.2011/644	
People to be involved	The sprängarbas has to be involved in the development of the blasting plan.	The räjäytys työnjohtaja has to agree on the blasting safety plan.	
Legal basis	Note to §3 AFS 2007:1	§8 16.6.2011/644	
Form and reporting of the risk management plan		The blasting plan has to be formulated in an understandable manner and discussed with the people that will have to work with it. Before a new activity is undertaken the employer has to ensure that all employees are aware of the suggestions in the plan.	
Legal basis		§4 16.6.2011/644	
Updates to the blasting plan		The blasting safety plan has to be continuously checked and updated.	
Legal basis		§4 16.6.2011/644	

8. Preparation of Blasting Materials

TABLE 33: PREPARATION OF BLASTING MATERIALS

	Sweden	Finland	Ireland
General duties on the preparation of explosive materials		-The employer has a duty of care regarding the manufacturing of explosives. -It is necessary to prevent accidents and take measures regarding the entire process of explosives used in the mining process. -The Safety & Chemicals Service has to grant a permit for the preparation of explosives, both in the case of permanent and temporary facilities.	
Legal basis		§9; 10; 58,58a 3.6.2005/390	
Preparation fuses/detonators			A safety fuse should not be capped with a detonator at any place at a mine other than a workshop duly used and located in pursuance of and in accordance with §47 of the Explosives Act, 1875.
Legal basis			*§13 Mines (Explosives) Regulations 1972*
Preparation of explosives on site[10]	-There shall be a sufficient distance between the place of manufacturing and protected objects.		-Preparation of a blasting agent shall not be carried out below ground in a mine. -Preparation of blasting agents is only allowed with written permission of the Minister or an inspector.
Legal basis	*Kap. 10 §4 MSFBS 2016:3*		*§11(3)(4) Mines (Explosives) Regulations 1972*
Permit for Explosives preparation			-It is not necessary for someone who holds a permit for an explosives storage to request a full permit for an explosives factory for the preparation of explosives on site, as long as the explosive of one description is not converted into an explosive of another description, and the explosives are solely for use at the mine site. The workshop where this task is done shall also be separate from the explosives store.
Legal basis			*§47 Explosives Act 1875*

[10] There are more detailed requirements on the preparation of emulsions and manufacturing of explosives in general to be found in MSFBS 2016:3 (Sweden), 20.8.2015/1101 (Finland) and Explosives Act 1875 and associated regulations (Ireland). This preparation is however never carried out by Boliden (as was found in chapter 3), and is therefore not discussed in this research. Only regulations that direct affect mining operations or Boliden's own activities have been listed here.

9. Working Environment during charging

TABLE 34: WORKING ENVIRONMENT REQUIREMENTS DURING CHARGING

	Sweden	**Finland**	**Ireland**
Lighting	The workplace should have sufficient and suitable lighting.	The workplace should have sufficient lighting. The minimum standard is lighting carried along by miners.	
Legal basis	*§9 AFS 2007:1*	*§19 16.6.2011/644*	
Information on hazardous places		The räjäytys työnjohtaja shall indicate and mark where shelters and the hazardous area around the blasting object are located.	
Legal basis		*§16 2011 644*	
Electricity in the Environment	In case electrical detonators are used: -If the blasting takes place in the vicinity of for examples of power lines or electrified railway the operator has to be contacted. -Safe distances with electricity cables, transformer stations, welding facilities and other electrical facilities has to be ensured -In case of possible influence by thunderstorms the affected area has to be evacuated immediately	Electrical detonators cannot be used in the vicinity of power lines, electrified railways, transformer stations, thunderstorms or anything else causing electromagnetic waves.	
Legal basis	§12 and 13 AFS 2007:1	§10 16.6.2011/644	
Surveillance charged area		An area that has been charged has to be kept under surveillance and unauthorised people should be stopped from entering.	
Legal basis		§4 16.6.2011/644	

10. Charging Equipment

TABLE 35: CHARGING EQUIPMENT

	Sweden	**Finland**	**Ireland**
Charging tools	Any cleaning and charging tools used need to be such that unexpected sparks do not occur and unwanted initiation does not occur. -If gunpowder or gas generating substances are charged the charging rod has to be made of wood.		
Legal basis	§14 and 16 AFS 2007:1		
Charging Equipment for pumpable emulsions	Charging equipment for ANFO and pumpable emulsions may only be operated by operators trained by the producer of the explosive or their official representative.		
Legal basis	§20 AFS 2007:1		
Charging hose	-The charging hose has to be made in such a way that electrostatic charging is impossible during explosive charging. -When the hose is used to charge ANFO or other forms of explosives in powder form the charging hose should have a resistance of 1-30 kΩ/m, and be marked clearly with information regarding the type of hose, dimensions and the type of explosive for which it is intended.		
Legal basis	§15 AFS 2007:1		
Equipment in touch with explosive materials	Equipment that is used to prepare explosive materials shall be such that the risk for unintended initiation is as small as possible and such that it is easy to maintain, clean and repair.		
Legal basis	*Kap. 10 §25 MSFBS 2016:3*		
Maintenance	-Maintenance of equipment that is of special importance from a safety standpoint shall be carried out and checked according to a maintenance plan. -Before each modifying, repair or maintenance job a risk assessment shall be made. Rooms, tools etc. shall be cleaned so that the work cannot cause initiation of explosive materials. -There shall be documented routines describing ongoing maintenance, returning service and checks of safety functions. -Carried out maintenance, services shall be documented. -After each moving of mobile preparation equipment the operator shall check if there is leakage or other visible damage, and that the inbuilt safety functions function properly.	-The operator shall draw up plans, that ensure by preventive maintenance, inspections, testing etc., that materials and rooms for explosives are in a good state. The hazards of parts of a system or entire systems malfunctioning on the safety shall be taken into account shall be discussed, together with the age of the system and possible information on the history of previous inspections. Inspections and tests and possible failures shall be recorded. There shall also be a maintenance record.	
Legal basis	*Kap. 10 §26; §28; §38-40 MSFBS 2016:3*	*§36 20.8.2015/1101*	

Security	-Places where mobile preparation equipment is located shall, when explosives preparation goes on, be clearly separated from other activities and people in the area. -Vehicles carrying mobile preparation shall have, on top of the ordinary lock, have a system that can prohibit unauthorised people to start the vehicle. - Vehicles carrying mobile preparation shall have a system that can prohibit unauthorised people to start the preparation equipment.		
Legal basis	*Kap. 10 §35-37 MSFBS 2016:3*		

11. Charging

TABLE 36: CHARGING REQUIREMENTS

	Sweden	Finland	Ireland
General		-Blasting activities shall be carried out professionally, according to plan and cautiously. -Instructions of the manufacturer and legal requirements are to be followed when handling with them.	-Charging shall not commence before it is ensured that the blasthole has been cleaned out thoroughly, air is only to be used for cleaning when dust can be minimised. -A blasthole shall not be charged by anyone except the shot-firer or someone under supervision of the shot-firer. It shall only be charged when it is necessary to blast soon after. It shall be ensured that the hole is both placed and drilled so to be safe for blasting. Charging shall not commence before all holes in the face of a heading, drift, raise, ripping, shaft or winze have been drilled.
Legal basis		*§9 16.6.2011/644*	*§26; §27 Mines (Explosives) Regulations 1972*
Stoppers and Preloading	-Preloading and separating stoppers between charges in a borehole shall be made of such material and executed in such a that the explosives can still be accessed if necessary. -If powder explosives are used for preloading it is necessary to be aware of the demolition sensitivity of the powder and to avoid unintended ignition.		
Legal basis	*§17 AFS 2007:1*		
Drilling near charges	-Charging near drilling activities shall be avoided, appropriate distance required.	-Before drilling commences it has to be checked whether this can be carried out according to the blasting plan. -Drilling activities have to be immediately stopped when it is suspected that there are explosive materials in there, or when the drilling is taking place close to a charged hole. -The räjäytys työnjohtaja has to be informed immediately if such and other issues affecting safety occur during drilling, it is only allowed to continue working after he has permitted this and if necessary changed the blasting plan.	-Drilling shall not be carried out within 1.52m (5 feet) of a hole containing any explosives or blasting agent. -Drilling and charging operations shall not be carried out simultaneously on the same face within 7.62 meters (25 feet of each other).
Legal basis	*§11 AFS 2007:1*	*§13 16.6.2011/644*	*§25(3); §25(4) Mines (Explosives) Regulations 1972*

Cleaning of/moving into blastholes	Is not allowed to be done with drilling rigs.		-No tool other than one made entirely of wood shall be inserted into a blasthole, unless it is a device for pneumatic stemming approved by the Minister, or a device approved by the Minister to remove a cartridge from a blasthole in case of a misfire. -Any tool to move into a blasthole shall be approved by the owner of the mine.
Legal basis	*§10 AFS 2007:1*		*§30(2); §25(6) Mines (Explosives) Regulations 1972*
Amount of explosives charged		The amount of explosive charged shall not be less or more than necessary.	
Legal basis		§14 16.6.2011/644	
Stemming			The charger of a shot-hole shall ensure that it is stemmed when necessary, with suitable and non-flammable stemming sufficient to prevent a blow-out.
Legal basis			*§30(1) Mines (Explosives) Regulations 1972*
Cartridges			Cartridges shall be put in a blasthole as a complete cartridge. The cartridges shall be of the same diameter and form of explosive, unless the blasting technique requires otherwise. The cartridges shall not be pushed in violently, and shall not overcharge, in which case a partial cartridge may be inserted.
Legal basis			*§28(2)(3) Mines (Explosives) Regulations 1972*
Unfinished charging; removal of blasting materials	When the charging of a hole has been unfinished without the insertion of a detonator the hole has to be marked.		-Stemming shall not be removed from a charged blasthole otherwise than by means of water and air. -A detonator lead shall never be taken out any charged blasthole. -An explosive shall not be removed from a blasthole, unless: a) explosive forming a part or portion of a cartridge is left protruding from the hole as a result of blasting. b) in case of misfires (*see* Subchapter 16).
Legal basis	§10 AFS 2007:1		*§31 Mines (Explosives) Regulations 1972*
Taking the detonator from the case			A detonator shall not be taken from its case unless it is immediately required for charging of a blast-hole.
Legal basis			*§16(2) Mines (Explosives) Regulations 1972*
Risk for non-detonation; number of detonators	The risk for non-detonation has to be minimised. If there is a risk of non-detonation two detonators have to be used.		Not more than one detonator per blasthole shall be used, except in case of misfires (*see* Subchapter 16) or where the method of blasting determines otherwise.
Legal basis	§18 AFS 2007:1		*§29(1) Mines (Explosives) Regulations 1972*

Isolation of ignition cables	It is required to properly isolate all ignition cables to avoid short-circuiting, breach of cables or touch with conductive materials.		
Legal basis	§23 AFS 2007:1		
Communication and oversight	If possible direct regular contact between people working should be maintained. If direct personal contact is impossible remote communication devices have to be used.	-If an employee has to work alone, the employer shall have contact with him at least once during the working day and at the end of his shift. -Blasting activities shall be organised such that there are regular visual and audio interactions with short time intervals, if necessary with telecommunication. -The räjäytys työnjohtaja shall visit the blasting object at least once a shift, unless the blasting safety plan indicates that less or more visits are necessary.	
Legal basis		§6 16.6.2011/644	
Charging and Blasting Preparations in Shafts and Winzes			-Only explosives or blasting agents shall be taken into a shaft or winze that are immediately required for charging. -Only the shot-firer shall take a primer cartridge with a detonator into a shaft being sunk, and this only in a thick felt bag or another form of appropriate shock protection.
Legal basis			*§40,41 Mines (Explosives) Regulations 1972*
Opened casings			No more than one canister of explosive shall be open at any time unless provided otherwise in the conveyance plan and reserve station rules.
Legal basis			*§28(1) Mines (Explosives) Regulations 1972*
Unused explosive materials	Materials that have not been used shall be returned to the explosives storage or guarded on site.		If there are still detonators unused at the end of the period of duty of the shot-firer, the case with the detonator(s) shall be returned to the explosives storage.
Legal basis	Kap. 9 §3 MSFBS 2016:3		*§16(1)(e) Mines (Explosives) Regulations 1972*

12. Initiation Techniques

TABLE 37: INITIATION TECHNIQUES

	Sweden	**Finland**	**Ireland**
Initiation methods	It is required to use methods that cause detonation immediately after initiation. -It is allowed to use delayed methods only when it is certain that no one can enter the blasting area in the period between initiation and detonation.		The person firing shall ensure that; -the detonators are connected in series and no wire is used for connecting detonators other than the wire manufactured solely for that purpose when using electric initiation methods. >The firing cable is not in and cannot make contact with any other cable or electric apparatus; >No person other than the (trainee) shot-firer shall couple a shot-firing cable in a mine to a detonator or blasting apparatus. -The firing cable shall not be connected to a blasting apparatus before it has been connected to a detonator (circuit).
Legal basis	*§22 AFS 2007:1*		*§34(3);(4);(5);(6) Mines (Explosives) Regulations 1972*
Electric detonation			Before blasting by means of electric initiation the person blasting has to check the circuit for continuity by means of an approved testing device. -This test cannot be undertaken before all persons in the vicinity have withdrawn to a place of safety and he has taken proper shelter himself, this provision does not apply when only approved testing devices are used. -An approved testing device that a) produces a current automatically limited to one tenth of the minimum current required to explode a low-tension detonator and; b) is approved by an inspector.
Legal basis			*§34(7);(8) Mines (Explosives) Regulations 1972*
Detonation systems by means of current from lighting/power circuits			-The Mine Manager shall appoint one or more responsible persons to have charge of the blasting device and ensure this person is in charge when shots are fired. -No blasting is to be undertaken except with written permission of an inspection determining the conditions of the blasting machine. This shall include the device switch mechanism returning automatically to the open position, the live side of the device is installed in a fixed locked box accessible only to the shot-firer, the leads to the face of the mine are short-circuited when the blasting device is in the open position, the devices are mounted in a lockbox that can only be opened when both the contacts of the device are open and the short-circuiting device is open. The device is electro-magnetically operated when the voltage exceeds 550 volts.

			-It is necessary that the shot-firer ensures himself that all precautions have been taken that the drilling and charging done have been performed safely in accordance with the Mines (Explosives) Regulations 1972. -The detonators are to be connected in series and no wire other than wire connected solely for this purpose is used.
Legal basis			*§45-48 Mines (Explosives) Regulations 1972*
Fuses	-If detonating fuses are used for initiation the initiation system shall be set up with a ring line and branches from here. The branches shall be coupled perpendicular to the ring line and the distance between the branches shall be such that the branches cannot initiate each other. -When blasting around urban areas or in tunnels the charge weight cannot be more than 20g per meter fuse.		-A fuse needs to be at least 0.91m (3ft) long for a single shot, and 1.22m (4ft) long for a round. -No more than four shots at one time shall be fired by fuse unless that is approved by an inspector. -The shot-firer shall ensure that, when fuses are used a) no naked lights or a person smoking are allowed above nor within 1.22m (4ft) in any direction of any blasthole, explosive or detonator. b) any surplus explosive is removed from the vicinity of the blasthole before a naked light is brought to it for the purpose of lighting the fuse.
Legal basis	*§32, 33 AFS 2007:1*		*§35 Mines (Explosives) Regulations 1972*
NONEL	If NONEL-systems are used this should be done such that unintended ignition cannot occur.		
Legal basis	*§31 AFS 2007:1*		

13. Blasting

TABLE 38: BLASTING

	Sweden	Finland	Ireland
Blasting of charged holes			Each shot-firer shall fire each hole that has been charged by him or by someone under his supervision, unless this is done by a trainee shot-firer or is prevented from doing so for circumstances beyond his control. The blasting shall occur in a cautious and safe manner.
Legal basis			*§32 Mines (Explosives) Regulations 1972*
Removing handle/key			The handle or key of a blasting machine shall not be put in position in the blasting machine before he is about to fire and shall remove this immediately after.
Legal basis			*§21(2) Mines (Explosives) Regulations 1972*
Cover	When harm can result as a consequence of blasting it is required to cover the blasting area. It is necessary to assess rock characteristics and the expected direction of rock debris after blasting in this assessment.	The need for cover is to be judged in the blasting plan, and has to be executed accordingly if deemed to be necessary.	
Legal basis	*§36 AFS 2007:1*	*§15 16.6.2011/644*	
Restrictions on size/number of blasts			The inspector can prohibit a mine in writing of firing more than six shots in a round.
Legal basis			*§34(1)(b) Mines (Explosives) Regulations 1972*
Special blasting	-Powder-based tools used to blast muck, concrete etc. shall have a maximum charge weight of 75g. Gas-generating compositions can be used in quantities up to 150g per blasthole. If charges are bigger all other provisions in AFS 2007:1 apply. -The supplier of the tool shall provide instructions around usage and safety of the tool to anyone working with them, and these people need to study this carefully. This knowledge shall be tested by the manufacturer, and he shall keep a proof of the test results. Workings need to be planned safely, precautions need to be taken especially regarding unintended fly-rock and risk for personal injury.		-It is only allowed to use electric detonators in shafts and winzes. The shot-firing cable shall not be connected to the detonator until a bucket or kibble is placed so that it is possible to conveniently enter the bucket or kibble, and the person operating this is ready to lift.

	-If these tools are to be used this has to be reported to the person responsible to the particular working area, who shall make clear under what conditions the tools can be used.		
Legal basis	*§34; §35 AFS 2007:1*		*§42, 43 Mines (Explosives) Regulations 1972*
Blasting near power cables	It is required with electrical ignition near power cables to make sure that ignition lines and splice wires cannot be thrown up to power cables during the blast.		
Legal basis	*§24 AFS 2007:1*		
Dust Explosions	If there is a risk for dust explosions measures have to be in place that prevent such explosions and limit the consequences if they would occur.		
Legal basis	*§38 AFS 2007:1*		
Blasting procedure	-There has to be a procedure in place around evacuation, coverage and initiation of blasting rounds. -A warning has to be given when blasting is about to take place to anyone who can potentially be affected by the blast. -Initiation can only take place when it is confirmed that no one can be harmed by the blast.	-The räjäytys työnjohtaja has to ensure that there are no people or surplus explosives in the blasting hazard area. -A clear sound signal has to be given until the moment of detonation.	-In case a blast may blow into a place in the mine other than that where the shot is fired, the person firing the shot has to give due warning before blasting to all people in that place, and after blasting notice has to be given to such persons that the danger is over. -The danger zone shall either; be either guarded by a person who cannot leave that place before he has been given permission by the responsible person to leave that place at each entrance, or; an appropriate fence marked with the words "DANGER", "SHOTFIRING" or "BLASTING" shall be placed at each entrance. It is not allowed to pass this fence without explicit permission by the responsible permission. It is to be ensured that no people are present in the danger zone, or that they have taken proper shelter. -The person responsible for the blast shall also have shelter before initiation.
Legal basis	*§37 AFS 2007:1*	*§16 16.6.2011/644*	*§36, 37 Mines (Explosives) Regulations 1972*
Registration			The shot-firer shall keep a separate record of all shots fired during a shift in a book provided by the owner of the mine.
Legal basis			*§33 Mines (Explosives) Regulations 1972*

In this subchapter, legal requirements on three aspects that are important after the blast are being discussed; the actions to be taken immediately after a blast, the regulations on what to do with explosive materials and sites used and finally mitigation measures related to misfires.

14. Return to Blast Site and Inspections

TABLE 39: RETURN TO BLAST SITE AND INSPECTIONS REQUIREMENTS

	Sweden	Finland	Ireland
Return not allowed	Entry to the blasting area not allowed as long as there still is a risk for personal harm due to delayed detonation, gases or rockfall.	-Entry to the blasting area is not allowed before it is certain that all charges have detonated or after at least five minutes after the blast. -If the blasted object still is a hazard because of loose rocks etc. return to the working area is not allowed before it has been made harmless.	-Entry to the blasting area is not allowed within 5 minutes after the blast for anyone in case a full round has been fired.
Legal basis	§39 AFS 2007:1	§17; §18 16.6.2011/644	*§39(3)(a) Mines (Explosives) Regulations 1972*
Post-blasting inspecting	-The sprängarbas shall assess the area after blasting, take necessary steps if required and only then allow people to return to the area. - Reinforcement measures are required to be implemented right after blasting depending on the need.	-The räjäytys työnjohtaja has to assess the blasted area and report formally that the area is safe to enter. -If blasting can produce gases that are harmful to worker's health their levels in the air have to be measured, and it should be assured their levels are low enough to re-enter the area.	After blasting, a competent person appointed by the Mine Manager, shall: -check if the firing cables/wires have been disconnected from the blasting apparatus, and the cables/wires have been short-circuited, before anyone else can enter. -ascertain whether it is safe for ordinary work to be resumed; -ensure that necessary action is taken to make each place safe for working. -Examine if there are misfires, sockets in the face or other explosives remaining or if there are reasons to assume there are still unexploded charges in the muck. -If the person making the examination finds any explosive remaining in any socket in the face, he shall (if he is a shot-firer) forthwith explode that explosive by a fresh primer, and if he is not a shot-firer forthwith report the circumstances to the shot-firer who shall then explode it.
Legal basis	§39; §47 AFS 2007:1	§17 16.6.2011/644	*§39 Mines (Explosives) Regulations 1972*

15. Explosive Waste

TABLE 40: EXPLOSIVE WASTE

	Sweden	Finland	Ireland
Destruction of explosives and materials affected by explosives	-Manufacturers of explosive materials shall have the ability to destroy explosives materials of their making. There shall be routines and instructions on how to do this. -Sites or equipment dealing with explosive materials shall be dealt with so that they are free of explosive materials afterwards. Used measures shall be documented. -Waste and packaging that has been polluted by explosive substances shall be treated as an explosive material.		
Legal basis	*Kap. 10 §5-7 MSFBS 2016:3*		

16. Misfires

TABLE 41: MISFIRES

	Sweden	Finland	Ireland
Misfire mitigation plan			The Mine Manager shall ensure that there shall be a scheme in force specifying misfire procedure, ensuring the safety of all people involved. The plan shall be posted in the mine visible to everyone and supplied to each shot-firer working in the mine.
Legal basis			*§51 Mines (Explosives) Regulations 1972*
Ascertain misfire			-With fuse detonation: When a fuse has been lighted successfully, but a shot has not succeeded, the case is treated as a misfire. -With electrical detonation: The shot-firer shall disconnect the blasting machine from the ignition cable and remove the handle or key, wait five minutes, examine the cable and connection for any defect and remedy, and then make a further attempt to blast. If this fails the case is to be treated as a misfire.
			§49 Mines (Explosives) Regulations 1972
Handling Misfires	-If it is impossible to make a misfire harmless immediately, it has to be marked and reported, before destruction of the misfire. -Misfires can be stored in a certified explosives storage.	Misfires shall be removed from the working place immediately. If this is impossible, necessary instructions shall be given about the hazard and the precautionary measures about this irremovable misfire shall be given to all people	No one shall approach the blasthole, until; -with a fuse: at least thirty minutes since firing the fuse have passed; -with electric initiation: the removable handle or key and shot-firing cable from the shot-firing apparatus and since the last attempt at least five minutes have past. -It shall not be tried to remove any part of the charge from the blasthole unless it is a cartridge or explosive sticking out of the blasthole.

		who have to be in the area of the misfire.	
Legal basis	*Note on misfires, AFS 2007:1; §???? MSFBS 2016:3*	§17 16.6.2011/644	*§50 Mines (Explosives) Regulations 1972*
Cleaning rock/drilling	-Measures have to be implemented that avoid drilling in misfires. The rock surface has to be cleaned carefully before a new drillhole starts.	-An old blasthole cannot be drilled before it is assured there are no explosives materials in there.	-Before drilling is commenced the exposed face shall be washed with water and carefully examined for misfires and cut-off holes and old sockets. -Drilling shall not be done within 1.52m (5 feet) of a (remnant of) a blasted hole. -A person shall not drill in a blasthole or any part of a blasthole with a drill with a diameter that is not at least exceeding the diameter of the cartridge to be used with 3.2mm (1/8 inch).
Legal basis	*§36 AFS 2010:1*	§13 16.6.2011/644	*§25(1); 25(2); 25(5) Mines (Explosives) Regulations 1972*
Loading equipment exposed to (possible) misfires	-Because it is hard to spot misfires in a muck, equipment used to load this need to have armoured glass.		
Legal basis	*Note on misfires, AFS 2007:1*		
Rock to be crushed	-When hydraulic hammers and other equipment are used to scale rock surfaces or decrease rock sizes measures shall be taken to protect workers from dust, fly-rock and misfires. -People working at the crushing plant shall be protected against explosions resulting from misfires.		When a misfired shot is dislodged by the firing of another shot, before any person can work near this place or another blast is undertaken, it is necessary to search the entire place for missing detonators and charge. If these are not found the rock needs to be conveyed out of the mine separately from the other rock.
Legal basis	*§42; §44 AFS 2010:1*		*§50(3) Mines (Explosives) Regulations 1972*
Reporting manufacturer	-If it is suspected that the misfires are a result of the materials used, the manufacturer should be notified.		
Legal basis	*Note on misfires, AFS 2007:1*		
Reporting Mine Manager			The Mine Manager shall be informed if a misfire has been identified but not yet dealt with.
Legal basis			*§50(4) Mines (Explosives) Regulations 1972*
Reporting requirements	The sprängarbas has to provide the person responsible for moving blasted rock with information regarding possibly undetonated explosives and necessary measures to secure safe operations.		-In case of misfire, the person who has fired the shot or the person competent for inspections shall, before leaving the mine, report the circumstances to a senior official on duty at the mine, and shall record the fact of misfire in the record of shots.
Legal basis	§39 AFS 2007:1		*§39(4) Mines (Explosives) Regulations 1972*

B. Combined Legal Requirements on Explosives Safety

1. Responsible Persons

A: Assignment and Tasks of Responsible Persons

§1: Each blasting activity requires the assignment of a Blasting Foreman. This function is referred to nationally as the "sprängarbas", "räjäytys työnjohtaja" or "shotfirer" respectively.
1a: This person shall be appointed by the person responsible for managing the mine.
1b: The identity of the Blasting Foreman shall be clear to all workers and his name shall be displayed in the working space.

§2: It is the responsibility of the Blasting Foreman to:
1. Verify the storage and dealing of explosives and associated equipment, unless another person is explicitly made responsible for storage and equipment.
2. Be involved in and agree on the blasting safety plan.
3. Verify that blasting activities are executed professionally and according to the blasting plan. Instruct other people are involved in the blasting process.
4. Keep the blasting machine under his guard.

§3: The eligibility of the Blasting Foreman, and way of obtaining the required licenses shall be verified according to national requirements. In general, at least one year of experience and the possession of a blasting license is required.

§4: Other people can work in blasting activities as well, as long as they are under supervision of the Blasting Foreman. Other people can never be in possession of the blasting machine and/or carry out the blast, unless it is a Blasting Foreman in training under direct supervision of the Blasting Foreman.

§5: People responsible for the explosives storage(s) shall be appointed separately by the Employer/Manager.

§6: Documentation on the licenses and other qualifications necessary for the various responsible people shall be kept at the mining office.

B: Oversight and Responsibilities Employer/Manager

§1: Ensure that the Blasting Foreman has sufficient information on the rock mass to be blasted. Information must include rock mechanical characteristics such as faults, brittle rock or other forms of deformations or inhomogeneity's in the rock mass. Notify the Blasting Foreman about any other issues that may be relevant for blasting.

§2: Verify that the Blasting Foreman indeed is licensed, well-prepared and qualified to perform his task.

§3: Prepare permitting requests and necessary risk assessments required to store and utilise explosives according to national law.

§4: Prepare and maintain contacts with certifying bodies and mine inspectors.

2. Explosives Standards

§1: Blasting machines, detonators and other parts of and complete initiation systems shall have been certified by the appropriate bodies, to be judged nationally. It is the duty of the employer to select the explosive materials and tools that causes the least danger.
1a: Any blasting machine that appears to be or is defective shall not be used anymore and reported to the Employer/Manager. If the blasting machine fails to fire a properly connected round in one go it shall be considered defective.

§2: It is required to use blasting machines, initiation systems and detonators of the same manufacturer, unless it can explicitly be verified that they are compatible.

§3: Explosives to be used should be in accordance with national regulations, have correct marking. In urban areas in open pits only cartridge explosives or explosives of a similar safety level should be used.

§4: Only explosives compliant with Directive 2014/28 EU are allowed to be used in the EU. Manufacturers have the obligation to ensure that their explosives are in accordance with Annex II of the Directive.
4a: Nonconformities of explosives should immediately be reported to the competent authority by manufacturers; authorities can always request manufacturers to prove the conformity.
4b: Importers have a duty to ensure that manufacturers have met these requirements before placing the explosive on the market.
4c: Explosives are assumed to be in conformity with harmonized standards published in the *Official Journal of the European Union* shall be presumed to be in conformity with safety requirements.
4d: The EU-declaration of conformity shall state the fulfilment of essential safety requirements.

§5: When an explosive is compliant with applicable requirements a CE-marking shall be affixed stating the EU declaration of conformity. A CE-marking has to be affixed visibly, legibly and indelibly to the explosive, or when this is not possible, to the packaging and accompanying documents. The CE-marking has to be in accordance with the principles set out in Article 30 of Regulation (EC) No 765/2008.
5a: Distributors have to ensure that the appropriate CE-marking is used.

§6: It is necessary that each smallest packaging unit is marked with a unique identification. Each manufacturing site, also these outside the European Community, shall have their own three-digit state attributed by the member state of manufacture or import. The unique identification shall be marked on or firmly affixed to each single product. For cartridges or explosives in sacks this identification shall be placed on each cartridge or sack, and an associated label on each case of cartridges.

§7: Two-component explosives, plain detonators and fuses, detonators, primers and boosters, detonator cords and safety fuses, cans and drums containing explosives all require (if possible) an adhesive or printed label with the ID on its smallest packaging unit, and always a copy of this label on the case or other unit containing one or more of these items.

§8: Copies of original labels may be attached for their clients. It must be clear that they are copies and not originals.

§9: Manufacturers shall ensure that explosives they have placed on the market are accompanied by instructions and safety information in an understandable manner. Distributors have to ensure that the appropriate CE-marking is used.

§10: Each undertaker using explosives shall have a system for data collection in relation to unique identification throughout supply chain and life cycle. The system shall enable undertakings to keep track of the explosives and their holder at any time. The record shall be kept for 10 years after the delivery or the end of the lifecycle of the explosive.
10a: The location of each explosive is to be known as well. The data system has to be regularly tested on quality and effectiveness, the data shall be protected against malicious uses or destruction, and provide competent authorities with all sorts of information on the explosive previously mentioned and contact details of people able to provide this information.

§11: Economic operators shall be able to identify these parties they have supplied explosives to or have obtained explosives from. They shall keep this record for 10 years after the supply. Economic operators shall adhere to a uniform system to identify and trace their explosives based on shape, size, design. This does not apply to explosives transported and delivered unpackaged or in pump trucks for direct unloading into the blasthole or explosives manufactured at blasting sites that directly used.

§12: Approval to transfer explosives shall be obtained by the consignee from the competent authority. This authority shall ensure that the consignee is authorised to acquire explosives and in the possession of the necessary licenses.

§13: No blasting material or device shall be taken or used below ground in a mine other than material or a device provided by the operator of the mine. The operator has a duty to obtain all the information from the manufacturer to ensure that he can work with the material.

§14: The Employer/Manager shall ensure that the blasting machine is thoroughly cleaned and overhauled at least once every three months by the manufacturer or a competent person appointed by the Employer/Manager. All multi-shot blasting machines shall be tested at the surface according to the guidelines of the manufacturers, when failing this test, it shall not be taken below ground. Reports and dates on cleaning, overhaul and testing are to be registered. Only in a certified workshop can be tampered with any blasting machine below ground.

§15: No cable with iron or steel wire covering shall be used unless during shaft-sinking or when initiation is done by means of electric current from a lighting or power circuit. If a cable is used for another purpose than blasting it shall not be used for blasting anymore.

§16: Defective explosives or blasting agents shall be deposed of in a safe manner.

§17: Explosive goods shall be used in such a way that they don't cause damage, the prescribed safety instructions of the supplier shall be followed.

§18: The period of delay has to be marked on a detonator to be allowed to be used or taken below ground.

§19: No explosives shall be taken or used into a mine except in cartridges. The maximum amount of any explosive to be taken below ground is 2.27 kilograms (5 pounds) of cartridges. This has to be packaged in a secured case or canister, until they are about to be used for charging, and at no point in time more than one case or canister can be open. Deviation from this can only be done when this has been discussed in the scheme of transit.

§20: No detonator shall be taken below ground otherwise than in a securely fastened detonator cases provided by the owner of the mine. No detonator case shall be issued unless it is impossible for any detonator or its leads to touch any metal part of the case exposed to the outside. It is the responsibility of the Blasting Foreman to keep the detonator in a securely fastened case, with no other materials in it except for the necessary administrative documents, and should be locked when not under direct supervision.

§21: Ignition cables shall be kept well in a case.

§22: When opening explosives or blasting agent cases or cartons only implements of copper, wood, fibre or other suitable materials shall be used. This does not apply to cutting wire or other binders.

3. Storage

§1: When constructing a new storage, a thorough risk assessment is necessary. All specific legal requirements on storage dimensions, construction methods, permitting procedures etcetera are provided in national regulations.

§2: The employer/manager shall appoint one or more people to be in charge of the storage.

§3: Explosives shall be stored decently, and as long as possible in unopened original transportation packaging.
§4: Packages shall be placed such that there is a good overview of the storage, and that there is sufficient place to load and unload.

§5: In a storage only material objects that do not increase the risk of fire or explosion can be left. Explosives shall be placed at such a distance from electrical equipment that they cannot cause initiation of the explosives. Electricity in the storage shall be switched off when there is no work going on. A space in a storage cannot be used as a place to leave motorised equipment for more than the time necessary to load/unload needed materials.

§6: Explosive materials shall be divided in groups according to the UN Chemicals Classification; explosive materials in groups C, D, E and G should be stored together. Explosive materials of group S can be stored together with explosive materials from other groups except from groups A and L. Other groups cannot be stored together. Detonators shall be stored separately from other explosive materials.

§7: Storages shall have the appropriate signs so that it is clear what hazard the storage poses. At least the necessary prohibitions and the contact details of the responsible person shall be mentioned.

§8: Keys, codes etc. shall be stored such that unauthorised people cannot get them, or they shall be under constant supervision. The doors to the storage shall be locked except for (un)loading or other necessary activities. Each storage shall be protected against access by unauthorised people; the protection shall be adapted to the level of desirability, which for mining explosives means that the access should be able to withstand an attack with handheld tools and electrical tools for at least 80 minutes.

§9: When using explosives from a store, those that have been longest in shall be taken out first.

§10: He who stores explosive materials, shall keep a log containing and continuously updating information on the amount of each explosive material that is stored. Daily updates shall be accessible at another appropriate place than the storage. Any accident by explosion in connection with an explosives storage shall be reported to the safety authority, who may decide on further measures.

4. Transport

§1: For transport on public road a permit shall be requested following national procedures. Precautions shall have been taken to ensure negative impacts on life, health, environment and property, and verified that all vehicles, packaging and other materials used are appropriate. It is necessary to have at least one safety advisor for each task, who has the sole risk to avoid damage resulting from the transport and delivery. Necessary signs have to be carried following the ADR-standards.

§2: A plan has to be drafted on the way in which explosive materials are moved within the mine. This "scheme of transit" should include provisions on;
1. Location, construction and marking of each reserve station, detonator store and custody of the keys thereof;
2. Design and construction of the special carriage;
3. Supervision and precautions to be taken during transit of the carriage;
4. Supervision of explosives at a reserve station and detonators at a detonator store;
5. Manner of conveying explosive and detonators to any working face;
6. Maximum quantity of explosive and the maximum number of detonators permitted at their respective stores.
7. Issue of explosive and detonators from their respective stores;
8. Return of explosives and detonators to their respective store;
9. Ways to ensure that explosives are moved in accordance with this plan.

§3: Explosive materials that are moved within the mine have to be protected against mechanical impact, heat and anything else that can cause fire or explosions. They cannot be transported together with other hazardous materials.

§4: Vehicles transporting explosive materials shall be equipped with fire extinguishers. The vehicles have to be certified for this purpose by the appropriate national body.

§5: Only people that are strictly necessary for the transport are allowed to travel along the vehicle or lift transporting the explosives.

§6: Documentation shall be kept on all explosives that are being transported to a working place or returned to the dedicated storage. The form and content shall be described. A copy of the scheme of transit is to be posted and kept posted so that anyone can read it clearly, and one is supplied to any Blasting Foreman and storage manager.

5. Charging

A: Charging Plan

§1: The employer shall develop the blasting safety plan. Planning and execution should be such that physical harm as a consequence of the blasting will be avoided. It shall include the following aspects:
1. Characteristics of the rock to be blasted.
2. Electrification, lighting, communication, extraction techniques and other technical specifics.
3. Roads, exits and safe havens.
4. Equipment selection
5. Maintenance.
6. Safe working methods.
7. Explosives that are used.
8. Emergency plan.
9. Other factors that may be of importance.

§2: Risk assessment has to be undertaken following the requirements in Workplace Safety Law.
This means at least that it should be a systematic approach identifying the difficulties and risks related to the job, working place, environment and time.
-If it is not possible to remove these risks the possible negative impact has to be assessed. All effects on both health and safety have to be included.
-Any activity that includes exceptional hazards cannot be executed without explicit safety measures having been ordered by the management.

§3: The Blasting Foreman has to be involved in the development of the blasting plan and agree on it.

§4: The blasting plan has to be formulated in an understandable manner and discussed with the people that will have to work with it. Before a new activity is undertaken the employer has to ensure that all employees are aware of the suggestions in the plan.

§5: The blasting safety plan has to be continuously checked and updated.

B: Preparation of Blasting Materials

§1: The employer has a duty of care regarding the manufacturing of explosives if they would be prepared on site.

§2: It is necessary to prevent accidents and take measures regarding the entire process of explosives used in the mining process.

§3: A safety fuse should not be capped with a detonator at any place at a mine other than a workshop duly used and located.

§4: The appropriate national body has to grant a permit for the preparation of explosive materials, both in the case of permanent and temporary facilities.

C: Working Environment during Charging

§1: The workplace should have sufficient lighting. The minimum standard is lighting carried along by miners.

§2: The Blasting Foreman shall indicate and mark where shelters and the hazardous area around the blasting object are located.

§3: In case electrical detonators are used:
3a: If the blasting takes place in the vicinity of for examples of power lines or electrified railway the operator has to be contacted.
3b: Safe distances with electricity cables, transformer stations, welding facilities and other electrical facilities has to be ensured
3c: In case of possible influence by thunderstorms the affected area has to be evacuated immediately

§4: An area that has been charged has to be kept under surveillance and unauthorised people should be stopped from entering.

D: Charging Equipment

§1: Any cleaning and charging tools used need to be such that unexpected sparks do not occur and unwanted initiation does not occur. If gunpowder or gas generating substances are charged the charging rod has to be made of wood.

§2: Charging equipment for ANFO and pumpable emulsions may only be operated by operators trained by the producer of the explosive or their official representative.

§3: The charging hose has to be made in such a way that electrostatic charging is impossible during explosive charging. When the hose is used to charge ANFO or other forms of explosives in powder form the charging hose should have a resistance of 1-30 kΩ/m, and be marked clearly with information regarding the type of hose, dimensions and the type of explosive for which it is intended.

§4: Equipment that is used to prepare explosive materials shall be such that the risk for unintended initiation is as small as possible and such that it is easy to maintain, clean and repair.

§5: Vehicles carrying mobile preparation shall have, on top of the ordinary lock, have a system that can prohibit unauthorised people to start the vehicle. Vehicles carrying mobile preparation shall have a system that can prohibit unauthorised people to start the preparation equipment.

§6: After each moving of mobile preparation equipment the operator shall check if there is leakage or other visible damage, and that the inbuilt safety functions function properly.

§7: Maintenance of equipment that is of special importance from a safety standpoint shall be carried out and checked according to a maintenance plan.
7a: Before each modifying, repair or maintenance job a risk assessment shall be made. Rooms, tools etc. shall be cleaned so that the work cannot cause initiation of explosive materials.
7b: There shall be documented routines describing ongoing maintenance, returning service and checks of safety functions.
7c: Carried out maintenance, repair services, cleaning shall be documented.

E: Drilling

§1: Underground: Drilling shall not be carried out within 1.52m (5 feet) of a hole containing any explosives or blasting agent. Drilling and charging operations shall not be carried out simultaneously on the same face within 7.62 meters (25 feet of each other).

§2: Both surface and underground: Charging near drilling activities shall be avoided, appropriate distance required.

§3: Before drilling commences it has to be checked whether this can be carried out according to the blasting plan.

§4: Drilling activities have to be immediately stopped when it is suspected that there are explosive materials in there, or when the drilling is taking place close to a charged hole.

§5: The Blasting Foreman has to be informed immediately if such and other issues affecting safety occur during drilling, it is only allowed to continue working after he has permitted this and if necessary changed the blasting plan.

F: Charging Works

§1: Charging shall not commence before it is ensured that the blasthole has been cleaned out thoroughly, air is only to be used for cleaning when dust can be minimised.

§2: A blasthole shall not be charged by anyone except the Blasting Foreman or someone under supervision of the Blasting Foreman. It shall only be charged when it is necessary to blast soon after. It shall be ensured that the hole is both placed and drilled so to be safe for blasting. Charging shall not commence before all holes in the face of a heading, drift, raise, ripping, shaft or winze have been drilled.

§3: Instructions of the manufacturer and legal requirements are to be followed when handling with them.

§4: Preloading and separating stoppers between charges in a borehole shall be made of such a material and executed in such a that the explosives can still be accessed if necessary.

§5: If powder explosives are used for preloading it is necessary to be aware of the demolition sensitivity of the powder and to avoid unintended ignition.

§6: No tool other than one made entirely of wood shall be inserted into a blasthole, unless it is a device for pneumatic stemming or a device to remove a cartridge from a blasthole in case of a misfire approved by the appropriate national authority.

§7: The amount of explosive charged shall not be less or more than necessary.

§8: The charger shall ensure that it is stemmed when necessary, with suitable and non-flammable stemming sufficient to prevent a blow-out.

§9: Cartridges shall be put in a blasthole as a complete cartridge. The cartridges shall be of the same diameter and form of explosive as the blasthole, unless the blasting technique requires otherwise. The cartridges shall not be pushed in violently, and shall not overcharge, in which case a partial cartridge may be inserted.

§10: When the charging of a hole has been unfinished without the insertion of a detonator the hole has to be marked.

§11: Stemming shall not be removed from a charged blasthole otherwise than by means of water and air.
11a: A detonator lead shall never be taken out any charged blasthole.
11b: An explosive shall not be removed from a blasthole, unless:
a) explosive forming a part or portion of a cartridge is left protruding from the hole as a result of blasting.
b) in case of misfires

§12: A detonator shall not be taken from its case unless it is immediately required for charging of a blast-hole.

§13: The risk for non-detonation has to be minimised, if necessary by using two instead of one detonator per blasthole.
13a: Underground: no more than one detonator per hole shall be used, unless this can be proven to be advantageous in avoiding misfires.

§14: It is required to properly isolate all ignition cables to avoid short-circuiting, breach of cables or touch with conductive materials.

§15: Only explosives or blasting agents shall be taken into a shaft or winze that are immediately required for charging. Only the Blasting Foreman shall take a primer cartridge with a detonator into a shaft being sunk, and this only in a thick felt bag or another form of appropriate shock protection.

§16: No more than one canister of explosive shall be open at any time unless provided otherwise in the conveyance plan and reserve station rules.
§17: If an employee has to work alone, the employer shall have contact with him at least once during the working day and at the end of his shift. Blasting activities shall be organised such that there are regular visual and audio interactions with short time intervals, if necessary with telecommunication.

§18: The Blasting Foreman shall visit the blasting object at least once a shift, unless the blasting safety plan indicates that less or more visits are necessary.

§19: Materials that have not been used during a shift shall be returned to the reserve station/storage.

6. Blasting

A: Initiation Techniques

§1: It is required to use methods that cause detonation immediately after initiation. It is allowed to use delayed methods only when it is certain that no one can enter the blasting area in the period between initiation and detonation.

§2: There shall be no open fire or smoking around the area where blasting preparations are undertaken.

§3: The manager/employer shall assign persons to be responsible of the blasting machine. They shall ascertain themselves that the blasting machine is in perfect condition before utilising it.

§4: If detonating fuses are used for initiation the initiation system shall be set up with a ring line and branches from here. The branches shall be coupled perpendicular to the ring line and the distance between the branches shall be such that the branches cannot initiate each other. When blasting around urban areas or in tunnels the charge weight cannot be more than 20g per meter fuse. A fuse needs to be at least 1.22m (4ft) long.

§5: If NONEL-systems are used this should be done such that unintended ignition cannot occur.

§6: No other wire than that specifically intended for this purpose is to be used to set up initiation systems.

B: General Blasting Procedure

§1: A Blasting Foreman shall only undertake a blast when charging has been done by himself or by someone who they supervise, and has ensured that all the works have been executed properly according to all the applicable legal requirements and internal rules.

§2: The handle or key of a blasting machine shall not be put in position in the blasting machine before he is about to fire and shall remove this immediately after.

§3: When harm can result as a consequence of blasting it is required to cover the blasting area. It is necessary to assess rock characteristics and the expected direction of rock debris after blasting in this assessment.

§4: It is required with electrical ignition near power cables to make sure that ignition lines and splice wires cannot be thrown up to power cables during the blast.

§5: If there is a risk for dust explosions measures have to be in place that prevent such explosions and limit the consequences if they would occur.

§6: There has to be a procedure in place around evacuation, coverage and initiation of blasting rounds.

§7: The danger zone shall either; be either guarded by a person who cannot leave that place before he has been given permission by the responsible person to leave that place at each entrance, or; an appropriate fence marked with the words "DANGER", "SHOTFIRING" or "BLASTING" shall be placed at each entrance. It is not allowed to pass this fence without explicit permission by the responsible permission.

§8: Initiation can only take place when it is confirmed that no one can be harmed by the blast, there are in general no people in the area and there are no surplus explosives in the area.

§9: A warning has to be given, when a blast is about to take place, to anyone who can potentially be affected by it.

§10: The Blasting Foreman shall keep a record of all blasts undertaken.

C: Special Blasting

§1: Powder-based tools used to blast muck, concrete etc. shall have a maximum charge weight of 75g. Gas-generating compositions can be used in quantities up to 150g per hole. If charges are bigger all usual regulations shall apply.

§2: The supplier of the tool shall provide instructions around usage and safety of the tool to anyone working with them, and these people need to study this carefully. This knowledge shall be tested by the manufacturer, and he shall keep a proof of the test results. Workings need to be planned safely, precautions need to be taken especially regarding unintended fly-rock and risk for personal injury.

§3: If these tools are to be used this has to be reported to the person responsible to the particular working area, who shall make clear under what conditions the tools can be used.

7. Post-blasting

A: Return to Blast Site and Inspections

§1: Entry to the blasting area is not allowed before it is certain that all charges have detonated, at least five minutes after the blast. If the blasted object still is a hazard because of loose rocks etc., return to the working area is not allowed before it has been made harmless.

§2: The Blasting Foreman shall ensure that the blasting machine has been disconnected from the initiation system.

§3: The Blasting Foreman shall assess the area after blasting, and examine if;
1. –there are gases that are harmful to worker's health their levels in the air, they have to be measured by the Blasting Foreman, and it should be assured their levels are low enough to re-enter the area.
2. -there are misfires, sockets in the face or other explosives remaining or if there are reasons to assume there are still unexploded charges in the muck. Misfires shall be dealt with by a blasting manage according to the rules set out in Section B.
3. -take the measures necessary and only then report formally that it is safe for other people to enter the blasting area.

§4: Reinforcement measures are required to be implemented right after blasting depending on the need.

B: Misfires

§1: There shall be a SOP in place to deal with misfires. This SOP shall be known to all Blasting Foremans and displayed visibly.

§2: Misfires shall be removed from the working place immediately. If this is impossible, it shall be marked. Necessary instructions shall be given about the hazard and the precautionary measures taken, and given to all people who have to be in the area of the misfire. The misfire can be stored in a certified explosives storage.

§3: An old blasthole cannot be drilled before it is assured there are no explosives materials in there. Before drilling is commenced the exposed face shall be washed with water and carefully examined for misfires and cut-off holes and old sockets.
3a: Drilling shall not be done within 1.52m (5 feet) of a (remnant of) a blasted hole.
3b: A person shall not drill in a blasthole or any part of a blasthole with a drill with a diameter that is not at least exceeding the diameter of the cartridge to be used with 3.2mm (1/8 inch).

§4: When a misfired hot is dislodged by the firing of another shot, before any person can work near this place or another blast is undertaken, it is necessary to search the entire place for missing detonators and charge. If these are not found the rock needs to be conveyed out of the mine separately from the other rock.

§5: Misfires shall be notified to:
5a: The manager of the mine, or the senior official in function at that time. The misfire shall be recorded in the official records of blasting.
5b: The manufacturer, in case it is suspected the misfire was the result of the products used.

§6: Equipment loading muck shall be equipped with armoured glass. The Blasting Foreman has to provide the person responsible for moving blasted rock with information regarding possibly undetonated explosives and necessary measures to secure safe operations.

§7: People working at the crushing plant shall be protected against explosions resulting from misfires.

§8: When hydraulic hammers and other equipment are used to scale rock surfaces or decrease rock sizes measures shall be taken to protect workers from dust, fly-rock and misfires.

C: Explosive Waste

§1: Manufacturers of explosive materials shall have the ability to destroy explosives materials of their making. There shall be routines and instructions on how to do this.

§2: Sites or equipment dealing with explosive materials shall be dealt with so that they are free of explosive materials afterwards. Used measures shall be documented.

§3: Waste and packaging that has been polluted by explosive substances shall be treated as an explosive material.

C. Exponential Density Function

The exponential density function is given by:

$$f(t;\lambda) = \begin{cases} \lambda e^{-\lambda \mathrm{t}} & t \geq 0, \\ 0 & t < 0. \end{cases}$$

What we want to know is the probability that some component will fail over the course of a shift. What we do know is the average level of failure, denoted by λ, also we know we want to know the likelihood of failure over an entire shift, i.e., t will be equal to 1 for the entire studied period. To get to the likelihood of failure, a few functions have to be considered. To start with, the hazard function h(t), expresses the hazard associated with a certain component and is defined as (Gheorge & Mock, 1999, p. 31):

$$h(t) = \frac{f(t)}{R(t)}$$

f(t) was discussed before, $R(t)$ is the so-called reliability function, in other words the chance that a certain component will not have failed by a given time t, which is given by:

$$R(t) = 1 - F(t)$$

With $F(t)$ being the so-called failure distribution function (Gheorge & Mock, 1999, p. 31):

$$F(t) = \int_0^t f(t)dt$$

Therefore, filling this formula in for the exponential density function, $F(t)$ becomes:

$$F(t) = \int_0^t \lambda e^{-\lambda \mathrm{t}} dt = 1 - e^{-\lambda \mathrm{t}}$$

To confirm that the failure rate indeed is constant, working out the initial function it follows that:

$$h(t) = \frac{\lambda e^{-\lambda \tau}}{e^{-\lambda \tau}} = \lambda$$

It should therefore be concluded that $h(t)$ indeed is a constant and equal to λ, which we know for all components. The exponential density functions can therefore be worked out for all components, always considering the entire shift length.

D. Examples of Best Practices Issued by Government and Industry

On the Risk Assessment to be undertaken as part of Blasting Plans
Guidelines to the Safety, Health and Welfare at Work (Quarries) Regulations 2008
The risk assessment should take into account the following factors:

- Control measures required to ensure the safety of persons determining the burden from either the top or bottom of the quarry face;
- Height of the face;
- Planned burdens and spacings;
- Diameter, angle and azimuth of the shotholes;
- Type and quantities of explosive used and the initiation systems;
- Geology of the face and the history of the quarry in relation to geological anomalies; and
- Proximity of the public, dwellings, roads, railway lines, commercial buildings or other places of work to the blast area.

On reducing the risks of Misfires *AFS 2007:1*
In order to minimise the risk for misfires it is important to follow the blasting plan with drilling and to check the initiation system before blasting.

- It is also important to clean the hole before charging activities start.
- When a misfire is discovered it is important to apply great care. The area around the misfire is to be treated as a dangerous area. Only staff that shall make the misfire harmless are allowed into the dangerous zone. That he who shall make the misfire harmless is experienced and used to such works, is a prerequisite for the work to be carried out safely.
- It is important to first try to decide on the location, size and spread and composition of the misfire. Explosive materials can have seeped into nearby fractures. The misfire can be composed of for example detonators with a smaller amount of explosive or be part of an entire charge. The misfire can even be explosive encompassed in muck, just like parts of detonating fuses.
- In the case a misfire cannot be made harmless immediately it is important to mark and report it to be made harmless as soon as possible.
- When it can be suspected that the misfire follows a production failure the supplier shall be notified.

After a blast is it important to as much as possible verify that no undetonated detonators are left by gathering all visible detonators.

The United States Mine Health & Safety Administration lists the following set of best practices as key principles to ensure safe explosives handling and blasting practice in industrial mineral and metal mines (Mine Health & Safety Administration, 2016):

1. Follow manufacturers' guidelines for the storage, handling, transportation and use of explosive materials.
2. Keep all explosive storage areas clean, dry and orderly.
3. Rotate the inventory of explosive materials, making sure to use the oldest stock first.
4. Never use damaged or deteriorated explosive materials, including initiation (detonating) devices, boosters, dynamite and blasting agents. Contact the explosives manufacturer if damaged, deteriorated or outdated explosives are discovered.
5. Ensure that all locations where explosives are stored or used are properly ventilated before miners enter.
6. Utilize technology such as face profilers and borehole probes to obtain specific details about areas of weak burden and potential borehole deviation.
7. Communicate with the driller and understand the geology of the blast site.
8. Review and follow the site-specific blast plan prior to loading any explosives. Develop a drill pattern appropriate for the location, and adjust stemming depth and/or decking to maintain adequate burden for the blast.
9. Establish the blast area and remove all persons from the area before the blast is fired.

10. Guard or barricade all access routes to the blast area to prevent people and vehicles from entering.
11. Before firing a blast, give ample warning to allow all persons to be evacuated from the blast area.
12. Conduct a post-blast inspection to be certain the blast area is safe before anyone re-enters.

On reducing the risks of Misfires (*AFS 2007:1*)
In order to minimise the risk for misfires it is important to follow the blasting plan with drilling and to check the initiation system before blasting.

- It is also important to clean the hole before charging activities start.
- When a misfire is discovered it is important to apply great care. The area around the misfire is to be treated as a dangerous area. Only staff that shall make the misfire harmless are allowed into the dangerous zone. That he who shall make the misfire harmless is experienced and used to such works, is a prerequisite for the work to be carried out safely.
- It is important to first try to decide on the location, size and spread and composition of the misfire. Explosive materials can have seeped into nearby fractures. The misfire can be composed of for example detonators with a smaller amount of explosive or be part of an entire charge. The misfire can even be explosive encompassed in muck, just like parts of detonating fuses.
- In the case a misfire cannot be made harmless immediately it is important to mark and report it to be made harmless as soon as possible.
- When it can be suspected that the misfire follows a production failure the supplier shall be notified.
- After a blast is it important to as much as possible verify that no undetonated detonators are left by gathering all visible detonators.

On the Risk Assessment to be undertaken as part of Blasting Plans
Guidelines to the Safety, Health and Welfare at Work (Quarries) Regulations 2008
The risk assessment should take into account the following factors:

- Control measures required to ensure the safety of persons determining the burden from either the top or bottom of the quarry face;
- Height of the face;
- Planned burdens and spacings;
- Diameter, angle and azimuth of the shotholes;
- Type and quantities of explosive used and the initiation systems;
- Geology of the face and the history of the quarry in relation to geological anomalies; and
- Proximity of the public, dwellings, roads, railway lines, commercial buildings or other places of work to the blast area.

Determine acceptability of ANE location
Storage and Handling of UN3375, Code of Practice AEISG
Ammonium Nitrate Emulsion (ANE) is a commonly used secondary explosive. Deciding on the location of a storage is an important consideration, giving the enormous amounts of emulsions that are commonly stored on mine sites.
First of all; It is important to not consider the risk of explosion from ANE in isolation from other explosive materials stored. Other siting and layout issues that need to be considered:

- The risk of fire generating toxic decomposition products;
- And the potential impact on the environment from spills or firefighting

See Figure 37 for a flowchart on the decision-making process. PES=Potential Explosive Site

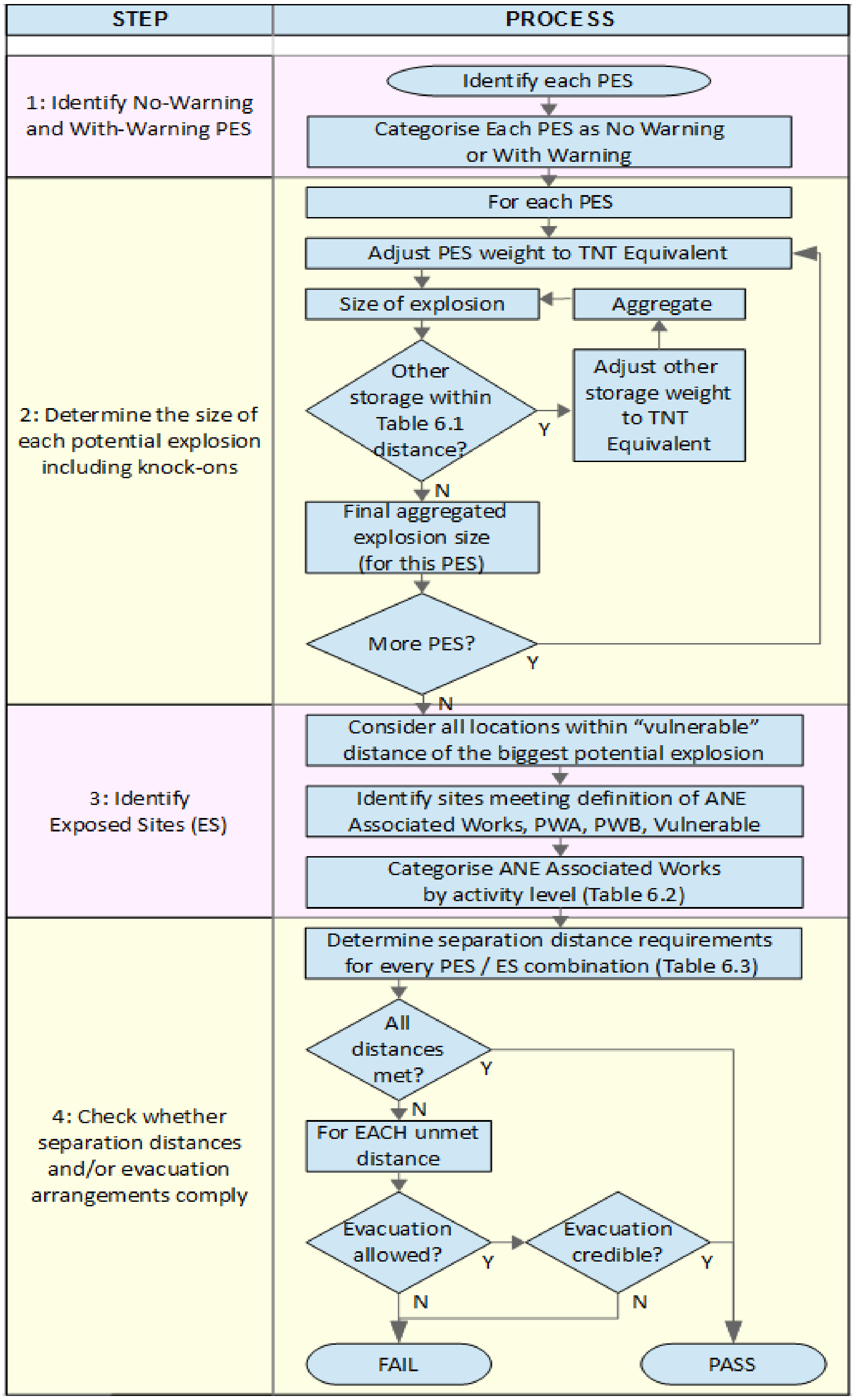


FIGURE 37: FLOWCHART TO DETERMINE THE ACCEPTABILITY OF ANE LOCATION

E. Elements of the Explosives Handling and Blasting Process

A1: Blast area security measures (general safety management/Blasting Foreman)
A2: General mine area security measures (general safety management)
A3: Awareness of blasting evacuation rules (general safety management)
A4: Checks on presence in blasting area (Blasting Foreman)
A5: Security systems for mine evacuation (general safety management)
B1: Blast design (blasting engineer)
B2: Detonator & initiation system reliability (blasting engineer)
B3: Detonator & initiation system performance (blasting engineer)
B4: Explosives & emulsion selection (blasting engineer)
B5: Danger zone estimation (blasting engineer)
B6: Pre-blast checks (Blasting Foreman)
B7: Cover (in the fault tree diagrams treated together with B5)
C1: Charging procedures (Blasting Foreman/blasting engineer/chargers)
C2: Charging execution (chargers)
C3: Charging execution oversight (Blasting Foreman)
C4: Charging equipment cleaning execution (maintenance staff, not discussed in fault trees)
C5: Charging equipment cleaning reporting (maintenance staff, not discussed in fault trees)
E1: Explosives outside dedicated area (chargers/powdermen, not discussed in fault trees)
H1: Detonators transported together with explosives (chargers/powdermen)
H2: Vehicles and collisions cannot cause explosions (chargers/general safety management)
H3: Scanning/bookkeeping (chargers/powdermen)
H4: Traffic violations/general irresponsible transporting (chargers/powdermen)
H5: Emulsion handling (chargers/suppliers)
H6: Packaging/handling safety barriers (suppliers)
M1: Misfire handling rules for Blasting Foremans (Blasting Foreman/general safety management)
M2: Misfire handling for Blasting Foremans execution (Blasting Foreman)
M3: Misfire handling rules & training for loaders/drillers/chargers (general safety management)
M4: Misfire handling execution for operators (operators)
N1: Unexpected Geology
N2: Unexpected blast characteristics, either due to geological anomalies or extremely unlikely flyrock paths
N3: External people moving into mine site
N4: Misfire unnoticed since hidden
O1: PPE usage (operators/Blasting Foreman)
O2: Protective wear on equipment (in fault trees dealt with together with PPE)
P1: Post-blast inspection rules (general safety management/Blasting Foreman)
P2: Post-blast measurements/inspections execution (Blasting Foreman)
P3: Post-blast return timing decision (Blasting Foreman)
S1: Detonators and explosives stored separately (general safety management)
S2: Detonator storage stops external effects of exploding detonators (general safety management)
S3: Storage conditions don't affect explosive materials (general safety management)
S4: Storage inspections (general safety management/powdermen/mine inspector)
U1: Cause misfire unclear (not discussed in fault tree)
V1: Ventilation capacity (ventilation engineer/general safety management)
V2: Ventilation execution (ventilation engineer)
Y1: Blockage blasting rules (general safety management/crushers, not discussed in fault tree)
Y2: Blockage blasting execution (crushers, not discussed in fault tree)

F. Background to Blasting Technology

1. General Theory on Rock Fragmentation

The purpose of using explosives is to fragment rock in effective way. Having an explosive that performs very effectively, by expanding very rapidly and generating a fierce wave is the first factor that is important. Figure 38 displays a simplified view on how a crater forms from a drillhole, and turns into fractured rock over a wider area. There are two main effects of a detonating charge; a gas bubble/wave from the expanding gases and a stress wave that move through the rock, which leads to tension fractures and release fractures. It is now commonly assumed that it is the combination of these two effects that lead to rock fragmentation (Hartman, 2002). An important aspect is that it is the free face that is essential in securing the success of the blast; if an initial compression wave first hits the free face, it reflects, increasing tension in the rock, which in turn leads to fracturing of the rock. It is therefore crucial to have free faces throughout the blast, for surface mining this means that there needs to be an open side on the bench, blast direction therefore always moves from the side-bench to the new wall, and not the other way around, because then a free face would only be there at the end of the blast. In underground blasting this objective is reached by having large holes in the middle of the face, from where the blast expands outwards. For this reason, timing of the detonators is essential; if detonators detonate to early or too late a free face might not develop on time, leading to large rocks remaining (Persson, et al., 1994).

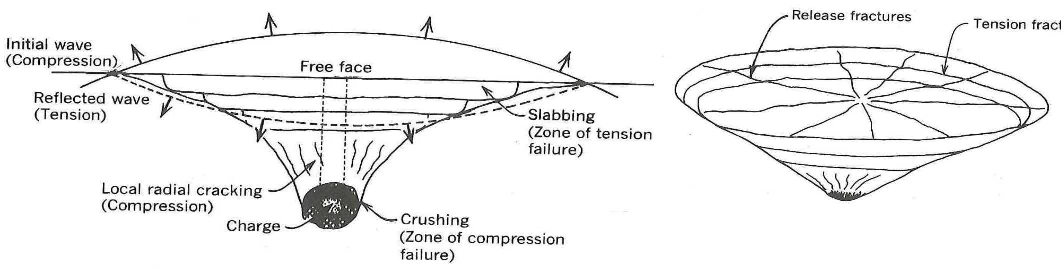


FIGURE 38: CRATER-FORMING (HARTMAN, 2002, P. 389)

For a blasting engineer, an issue that may be a very relevant issue, apart from fragmentation size and vibration considerations, is how the rock that has not been blasted adjacent to the blasted area looks after the blast; after all, this, together with the geological characteristics of the rock, determines the need for rock reinforcement to create safe drifts (Maier, 2000). For this reason, it is essential that vibrations around the area to be blasted are kept to a minimum, and also that flyrock is reduced. The only way to achieve this aim is by making sure that as much explosive energy as possible is used to only fracture the rock to be blasted, and very little energy is released by other means, in other words as flyrock and vibrations. This can be achieved by perfecting blast designs, which is only possible if the scatter of detonators is minimal and blast design and execution is done carefully (Persson, et al., 1994). Concluding, there are two main parameters that influence the effectivity of a blast to fragment rock, except for the quantity of explosive used per rock mass. The first is the "explosive performance", the second the way in which different blast waves interfere.

2. Initiation Systems

Different initiation systems are currently in use at Boliden mines, as discussed previously. In order to reach the goal of minimising the risk of unintended detonation and at the same time minimising the risk of failing detonation (misfires), the characteristics of the different initiation system need to be considered before rules on the avoidance of accidents can be drawn up. Initiation systems also determine operational working methods, because of the way in which they need to be prepared, and therefore need to be considered in this regard as well. To recap the introduction in Chapter 2, more specifically paragraph 2.2.3, there are three different initiation systems commonly in use in mining, electrical systems, NONEL-systems and electronic systems. This topic is considered from three different angles; the aim of maximising blasting performance, the aim of minimising the discussed risks, and what system is most "workable".

A. Blasting Performance

As was discussed before, the performance of a blast is greatly influenced by the timing of detonation. Reliability in timing of detonators is therefore essential. Using large quantities of detonators, there will always be some deviations from intended delay times. Figure 39 displays case A, where the deviation of detonation times stays within the accepted margins, and detonators supposed to detonate at time 1 detonate then, without overlap with those detonating at time 2. In case B however, detonators that detonate at time 1 overlap with detonators that are supposed to detonate at time 2; either because of large deviations from the average production value (B1), or because of a structural bias (B2). In this case B the success of the blast would therefore be harmed by the unpredictability of the detonator delays. Given that electrical and NONEL-detonators both use pyrothechnic delays, they tend to have relatively large deviations from their intended delay. Electronic delays solve this problem, since their delay is programmed digitially, and therefore very precise (Singh, et al., 2017). Typically, average scatter percentage variation of NONEL-detonators is inbetween 3.5% and 5.5%, i.e. 17.5 milisecond per 500 milisecond delay. For electronic detonators this scatter is only around 0.01% (i.e. 0.5 milisecond deviation on average) (Grobler, 2001).

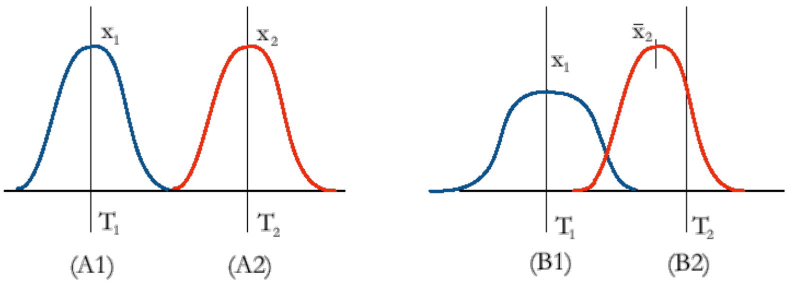


FIGURE 39: DEVIATION OF INTENDED DELAY TIMES

B. Avoid unintended Detonation

Different initiation systems have different associated hazards of unintended detonation; the fact that mines have mostly shifted from electrical detonation systems to NONEL-systems lies primarily in the fact that electrical systems are sensitive to all sorts of static and electromagnetic impulses, and therefore pose a hazard (Persson, et al., 1994), when they have to function in environments with for example power supplies. NONEL-systems are much safer in this regard, since they are practically impossible to detonate unintendedly. Electronic detonators do not have the same issues has electrical detonators, since, although it is possible that an unintended current would occur in the wiring, this current will never reach the explosive charge in the charge. This is the case because the chip, that processes the digital signal that is sent to the detonator when the blast is commenced, only transmits the ignition signal to the charge when it matches the ID of the particular chip. A regular pulse will therefore be filtered out.

C. Workability

Workability of different initiation systems, in the sense of how easy, straightforward and verifiable the set-up of the initiation system is. Electronic detonation is in this sense relatively complicated, since the entire system has to be programmed after it has been set up, using the unique ID's each detonator has, whereas electrical and NONEL-systems can be connected immediately to the blasting apparatus when they are ready. Still, for anyone who is trained to program a blast it is not difficult, and as an extra advantage it is also possible to make last-minute changes in the blasting set-up, which would not be possible with other initiation systems.

D. Misfires

Another advantage of electronic detonators is that it can even be possible to pinpoint misfires after the blast (Kiernan, 2011); this makes it much more likely that, when misfires have occurred, they will be found immediately, thereby reducing the risk of misfires coming up during loading, crushing or drilling. In Figure 40 the different types of set-up can be seen. Binding of wires of electrical and electronic systems is similar, since a circuit has to be set up. NONEL-systems can be easier in that sense, on the other hand they usually rely on groupings of sets of detonators, this set-up has therefore to be thought through well.

An advantage of electrical systems and electronic detonation systems is that the set-up can be checked after installation; this ensures that no connections are missing, which significantly reduces the chance of misfires. For this reason, simpler special blasting electrical systems are still commonly used.

It is important also to remember how the delays are positioned; in the case of electrical and NONEL initiation systems, the right detonator has to be put in the right hole. For electronic systems, universal detonators can be used, since their delay time can be programmed afterwards. This makes the chance for mistakes with delays much smaller.

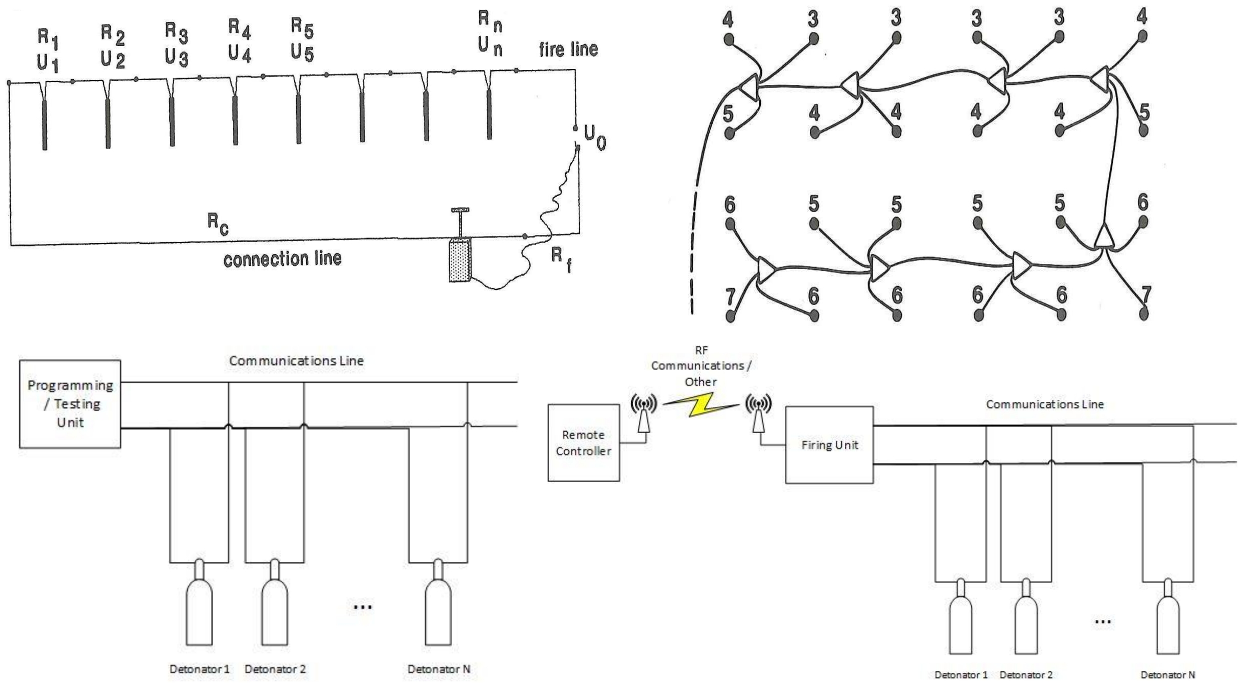


FIGURE 40: INITIATION SYSTEM SET-UP (ELECTRICAL, NONEL, ELECTRONIC)

3. Electronic Detonators

Given that electronic detonation systems are somewhat more complicated than traditional detonation systems, a quick impression of its functioning is given here. Electronic detonation systems get an electric firing pulse, similarly to electrical detonators. However, the electric signal is a digital signal sent from the blasting machine to a microcontroller in the detonator. Each detonator is unique, and only processes the signal if it matches the microcontrollers ID, thereby unlocking the switch. This gives two main advantages; first of all, random signals caused by for example electromagnetic waves will not reach the explosive part of the detonator, significantly reducing the risk for unwanted initiation. Secondly, the same type of detonators can be used for the entire set-up, and their delay times can be implemented after the charging is complete. The delay is digital, enabling it to be very precise compared to pyrotechnic delays that are used in NONEL and electrical detonators. See

Figure 41 for the internal circuit of electronic detonators.

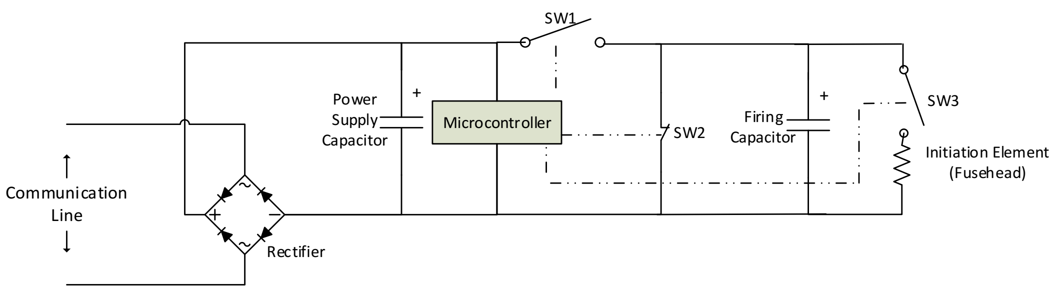


FIGURE 41: INTERNAL CIRCUIT ELECTRONIC DETONATOR (CHAMBERS, ET AL., 2017)

When setting up the system, all detonators are switched off, making it impossible for anyone but the responsible person to initiate the detonators. Prior to the blast, the system must be programmed, and can be tested on its functioning, without unlocking the main switch. This greatly reduces the chance of misfires, since it can be seen in advance whether the system has been set up correctly (Chambers, et al., 2017). Only when it has been confirmed that the system functions perfectly, the firing unit/blasting machine can be attached. This machine can then be fired by remote control.

G. Internal Standards Sweden

TABLE 42: BOLIDEN REQUIREMENTS ON PEOPLE INVOLVED IN EXPLOSIVES HANDLING AND BLASTING

Topic	Rule	Source
Responsibilities Employer	The employer has to assign at least a sprängarbas for any blasting activity and a person responsible for the preparation of explosives, and if necessary coordinate.	C0046, general
Responsible Person for blasting	For each activity, a "sprängarbas" has to be assigned. It is his responsibility to execute the job professionally and according to the given instructions.	C00406
Eligibility of the sprängarbas	-The sprängarbas can both be a shift boss or a specifically for this job assigned person that oversees all blasting activities in his assigned area of responsibility. It is necessary that this person has participated in the required education, owns a valid blasting license and has specific competence for the blasting activity. - On top of the previous general requirements, the sprängarbas needs to have participated in a course certified by the Council for Blasting Education.	C0046
Requirements on anyone working with explosives.	-Only competent people may be involved in works with explosives. -Theoretical competence has to be documented, for example by certifications from the educational institute or internal company education. -Anyone working in a blasting job needs to have practiced the particular type of blasting job that will be undertaken under supervision of an instructor with a valid blasting license.	C0046
Coordinating manager and location manager[11]	The employer needs to appoint a coordinating manager, and if necessary a location manager. They must: -Have experience in the production/ handling of explosive materials and appropriate education. -Be in a leading position in the overall organization. -Not have a criminal record, this needs to be verified.	C0046
Storage manager	-Needs to have a documented education by a recognised educator. This course needs to have a size of around 16 lecture hours. -The storage manager needs to be accepted by the local municipality or other authority that has issued the storage permit. -A deputy storage manager needs to be assigned as well, having the same requirements regarding competence.	C0046, C00360
Drivers	Drivers of vehicles with explosive materials need to have the required license.	C00360

TABLE 43: BOLIDEN STORAGE AND EXPLOSIVES STANDARDS

Topic	Rule	Source
General	Prior to any storage and usage of explosives on site a permit needs to be obtained at the municipality where the explosives are used (if several municipalities are involved the main use municipality is the relevant authority), together with a transfer permit for the supplier to be able to deliver explosives for the municipality where the explosives are delivered. If a preparation permit has been obtained from the MSB the MSB can also be requested to issue a permit. The permit issuer is responsible for oversight.	C00360
Permit specific storage	Any explosives storage has to have been inspected by the overseeing authority. The permit obtained has to be displayed visibly on the site.	C00360
Management of storage	A log has to be kept regarding explosives taken in and out, if preferred electronically.	C00360
Access	Access to the storage site needs to be restricted, and should be locked at any time when explosives are not brought in or taken out. The key needs to be stored such that unauthorised people cannot obtain it.	C00360
Waste	-Waste has to be treated as explosives, in accordance with law 2010:2011 and ordinance 2010:1075 on flammable and explosive goods.	C21286

[11] The coordinating manager has overall responsibility for production and shall ensure that all delegated location managers shall perform the tasks that the law prescribes. The location manager has responsibility for a particular location where explosives are produced. This is necessary when there is no coordinating manager present (Reg. nr. C00406).

	-EWC code 16 04 03: Discarded explosives. Waste containing this substance is hazardous waste as H1. -Explosives contaminated packaging/material should be regarded as explosive waste. Destruction requires permission, in case of doubt contact supplier. - Emulsion Waste arising from the deflation / unwinding and then loaded into the rated intermediate bulk containers, will be returned promptly to the supplier for disposal. -In open-pit mining spill of emulsion is suitably handled (destroyed) by shoveling it into charged not plugged holes. Spills on the place of filling the emulsion transport vehicle shall be disposed of in IBC containers.	

TABLE 44: BOLIDEN STANDARDS ON PREPARATION AND TRANSPORTATION

Topic	Rule	Source
Permission to prepare	A certain explosive material may only be prepared when permission has been given by the supplier of the explosive.	C00406
Person responsible	The person responsible for mixing of blasting agents a specific education has to have been completed a specific education done in collaboration with the manufacturer/supplier. This person needs to be at least 18 years old.	C00360
Special explosives	When explosives and initiation systems that are not listed in Chemsoft, testing has to have been undertaken in a local chemical facility in accordance with relevant regulations.	C00360
Production standards	The responsible person is responsible for the production of explosives according to the requirements in LBE 2010:1011 and MSBFS 2016:3.	C00406
Task description	The task description for the responsible person shall be clear, and his responsibilities and powers shall be described.	C00406
Transportation general	Transportation shall always be carried out in such a way that any damage to people, animals, property or the environment does not occur. Vehicles and other transportation equipment shall be such that they can handle impacts.	C00360
Packaging	Explosives shall be packed safely for transport. If not indicated otherwise in accompanying documents shall the explosive materials be packaged in outer- and inner packaging.	C00360
Vehicle, conduct during transport	The vehicle transporting explosive materials shall: -be designed such that cargo cannot fall off; -keep explosive materials and detonators at least 1 meter apart, or keep them separated with a wall; -have yellow warning lights, orange shields on the front and back and shields with the most dangerous explosives classes transported attached on both sides of the vehicle; -have sprinkler installations, two hand-held powder extinguishers (6kg of type 43A 233BC) and have a spark arrestor in the exhaust. Open fire, smoking etc. are not allowed in the vicinity of the explosive goods.	C00360

TABLE 45: BOLIDEN STANDARDS ON EQUIPMENT

Topic	Rule	Source
Charging materials	-Charging materials shall be made such that they don't cause initiation or damage the detonator or ignition cord. A charging rod shall be smaller than 10mm of the diameter of the blasthole in order not to damage the conductor. -Only operators that have been educated by the manufacturer or their representative, may use charging equipment meant for pumpable emulsions.	C00371
Charging apparatus and production equipment	The charging apparatus and production equipment can only be used when they have been verified by a third-party control agency or a certifying body accredited for this type of checks and in this test show to: -give reliable security against unintended fire or explosion; -avoid unnecessarily intensive working positions and movements, and; -workers working with the equipment are not hurt by noise, vibrations or rotating parts.	C00371
	On those occasions an emptying or cleaning the loading equipment must occur, for example, when repairing or servicing: -The remaining amount of emulsion in loading equipment emulsion tank, should be pumped into IBC containers approved for transport on public roads under ADR Class (1.1). Note that the equipment must be checked by the director to make explosives before Hot Works is done.	C21286

	-loading equipment rinsed in the cleaning area, which collects the emulsion residue and dirt can be done in a way, validated.	
	Over filling and suction hoses for matrix and fumigants must be kept clean and must be handled so that risk of wrinkling is avoided.	C21286
	Every time an overflow hose is used, the hose condition is checked and if any damage exists, have the hose replaced immediately with a new one.	C21286
	Links must be kept clean and their lids should be used, to avoid gravel, stone or other foreign objects from entering the hose.	C21286
	Ensure all connections between pump, tank / IBC and loading equipment are well connected, so that no risk of emulsion spillage may occur. - IBC containers must always have the filler cap screwed on.	C21286
	Emulsion tank shall have inspection / man-doors closed.	C21286
	Intermediate bulk containers shall be stored in one of the director designated location and shall under no circumstances, be used for purposes other than storage of emulsion / explosive waste.	C21286
Maintenance of charging vehicles	Prior to maintenance of charging vehicles, they have to be completely cleaned from any explosive materials. No maintenance can commence before an official Proof of Cleaning has been documented. -The maintenance manager on call has responsibility that cleaning is done specifically for the type work to be done on the vehicle. This has to be done in accordance with C26895, on instructions for reparation and maintenance of charging vehicles. -When cleaning the pumping system, the Proof of Cleaning of the manufacturer be issued by the manufacturer or his representative. -Staff working on the vehicle has to be informed on the rules applicable to both the vehicle and the area where the work is done. -The Proof of Cleaning shall be archived for at least 30 days by the responsible manager. -These rules apply to any vehicle working with or transporting explosives.	C26898

TABLE 46: BOLIDEN STANDARDS ON CHARGING

Topic	Rule	Source
General	Charging shall be executed such that the risk for unintended initiation is effectively avoided.	C00371
Charging environment	-Charging in warm environments shall be avoided since sensitivity of the explosive increases with higher temperature. If it is unavoidable special measures have to be taken. -In case of risk for thunderstorms charging with electrical initiation systems have to be interrupted, if necessary warning systems have to be in place.	C00371
Drilling	-Charging near drilling shall be avoided. -Only the operator may be in the drilling unit, no one may be in front of the unit with horizontal or overhead drilling.	C00371
Cleaning of blastholes	-Try to flush blockings with pressured water, if this is not available use pressurized air, if possible with spooling water on it. Move the hose in carefully. The hose can only be made of copper, brass, plastic or other materials allowed by the AV. It is not allowed to use rock drills or any other iron objects in holes where explosives have been charged previously.	C00371
Unfinished charging	If charging a blasthole has been stopped before a detonator has been inserted the blasthole shall be marked with yellow paint.	C00371
Spillage	Spillage and other rests shall be dealt with as quickly as possible and made harmless in such a way that people or the environment are not exposed to danger. Limit spreading to for example sewage systems or groundwater. Follow instructions by the supplier.	C00371
Size of charge	No larger quantities of explosive are allowed to be used than that which is safe. Issues that need to be taken into account for this judgment are the characteristics of the rock, vegetation, number of free faces, location and distribution of the charge, characteristics of the explosive and risks for the area round.	C00371
Charging itself	-Charging shall be done with care. The size of cartridges shall also be of such diameter that they can easily be inserted in the blasthole. -Cartridges shall be inserted without violent jabbing, such they fill the hole. -Chargers should not stand in front or bended over the blasthole opening.	C00371
Frozen charges	When frozen charges have to be thawed the supplier has to contacted on the way how to do this.	C00371

Smoke from blasthole	In case smoke comes from the blasthole the charging activities have to be stopped immediately, staff has to bring itself in safety and simultaneously warn people in the area.	C00371
Interruptions	With shift changes shall the outgoing shift explain the incoming shift about the progress of the work. When charging has commenced for a blasthole, this shall be completed before the end of the shift.	C00371
Oversight	-Charges that have not been fired shall be marked, in a manner known to all staff, or guarded until it is fired. -If charging is partially finished and has to wait until the next working day the area has to be guarded or blocked for unauthorised access, if the working place can be accessed by unauthorised people.	C00371

TABLE 47: BOLIDEN POST-BLASTING STANDARDS

Topic	**Rule**	Source
Pre-drilling inspections	-Clean rock surface to be bored shall be cleaned, possibly with water. If the surface is still covered by rocks or other materials these have to be cleaned so it can be verified that no explosive materials are left. -Undetonated blastholes have to be looked for. If holes are found of more than 15cm deep with an invisible bottom, it can be checked with a charging rod if there are explosives left. If there is any doubt or reason to assume that explosives are left after this test, the hole has to be cleaned with water.	C00411, §1, 2
Undetonated Charges/Misfires	Explosive materials that cannot be used immediately for blasting have to be collected. Misfires have to be made harmless as soon as possible and otherwise marked and reported to the management.	C00411, notes, C00371
Cleaning undetonated charges	Flushing pipes for cleaning of undetonated charges should be made of the prescribed materials such as copper, brass, plastic etc. It is not allowed to use objects made of iron/steel to clean.	C00411, notes
Undetonated detonators	Detonators that are still left in a blasthole can only be taken out when they are loose.	C00411, §7
Explosive remains	Explosive materials or explosive initiation materials that are found shall be treated in accordance with the requirements of the AV. In case explosive materials have penetrated the drilling rod it has to be marked and reported to the driller. It has to be cleaned using nothing else than wood, copper or water. Before it has to be verified that no remaining explosive materials are left.	C00411, §3
Difficulties in drilling/blasting	If certain rock cakes and has a lot of misfires, alternative drilling plans have to be available so that a next phase of drilling does not hit on pre-existing blastholes, thereby minimising the risks of drilling in explosive remains.	C00411, §4
Undetonated blasthole drilling	It is forbidden to drill in undetonated blastholes	C00411, §4
Start of drilling	Drilling always has to start with flushing water switched on.	C00411, §5
Drilling without prior checks	If drilling has to be done in an area where no satisfactory prior check for misfires could be done, the drilling has to be operated from a sheltered location.	C00411, §6
Reporting requirements	Misfires have to be reported as deviation in Boliden's reporting system.	C00411, notes
Doubt on action to take	In case doubt arises around the correct way to deal with the problem the responsible boss has to be contacted to take a decision.	C00411, notes

H. Examples Boliden Safety Documents

BOLIDEN

Q=kvalitet, HS=hälsa säkerhet, ME=miljö energi

Utfärdare/Dokumentägare	Titel		
Torbjörn Krigsman	G5: Arbetsbeskrivning Spränga i dagbrott		
Godkänd av/Processägare	Giltig från:	Utgåva	Reg.nr
Peter Palo	09/02/2017	3	C30766

	TILLHÖR DELPROCESS:		PERSPEKTIV: Q HS ME	
NR	**ARBETSSTEG**	**STYR DOK**	**UTFÖRS AV**	**REDOV DOK/KOMMENTAR**
	Området är färdigt för sprängning			
1	Planera och ta fram karta för avspärrat område (sprängkarta)	Underlag till kartor och "spränglapp" levereras till Securitas som placerar dessa på strategiska ställen. Karta skickas även ut via e-post	Sprängansvarig	
2	Informera om planerad sprängning	Aktuell checklista för utrymning finns i prodadmin dokument HMS-regel Utrymningsansvarig vid sprängning i dagbrott	Sprängansvarig	Checklista sprängning, Checklista för justeringssprängning
3	Placera ut sprängposter	G5: HMS-regel postning vid sprängning i Aitik	Arbetsledare Tillredningsteam	
4	Ta fram skjutkabel till skyddat område	G5: HMS-regel salvsprängning i dagbrottet Aitikgruvan G5: HMS-regel justeringssprängning i dagbrott i Aitikgruvan	Sprängarbas	
5	Sätta igång sprängsignalering		Arbetsledare Tillredningsteam	
6	Spränga		Sprängarbas	G52: Riskanalys spränga i dagbrott
7	Invänta klartecken från		Arbetsledare Tillredningsteam	
8	Kontrollera spränggaser	AOG HMS-regel spränggaser G52 Instruktion Avspärrning vid gaser i gruvan	Arbetsledare Tillredningsteam	Gasmätningsrapport
9	Kontrollera salva	G5: Anvisning för hantering av dola	Sprängarbas	
10	Rapportera		Arbetsledare Tillredningsteam	Ifylld checklista och gasmätningsrapport lämnas efter utförd sprängning till sprängansvarig
	Området klart för lastning			

FIGURE 42: FLOW-CHART BLASTING PROCEDURE AITIK

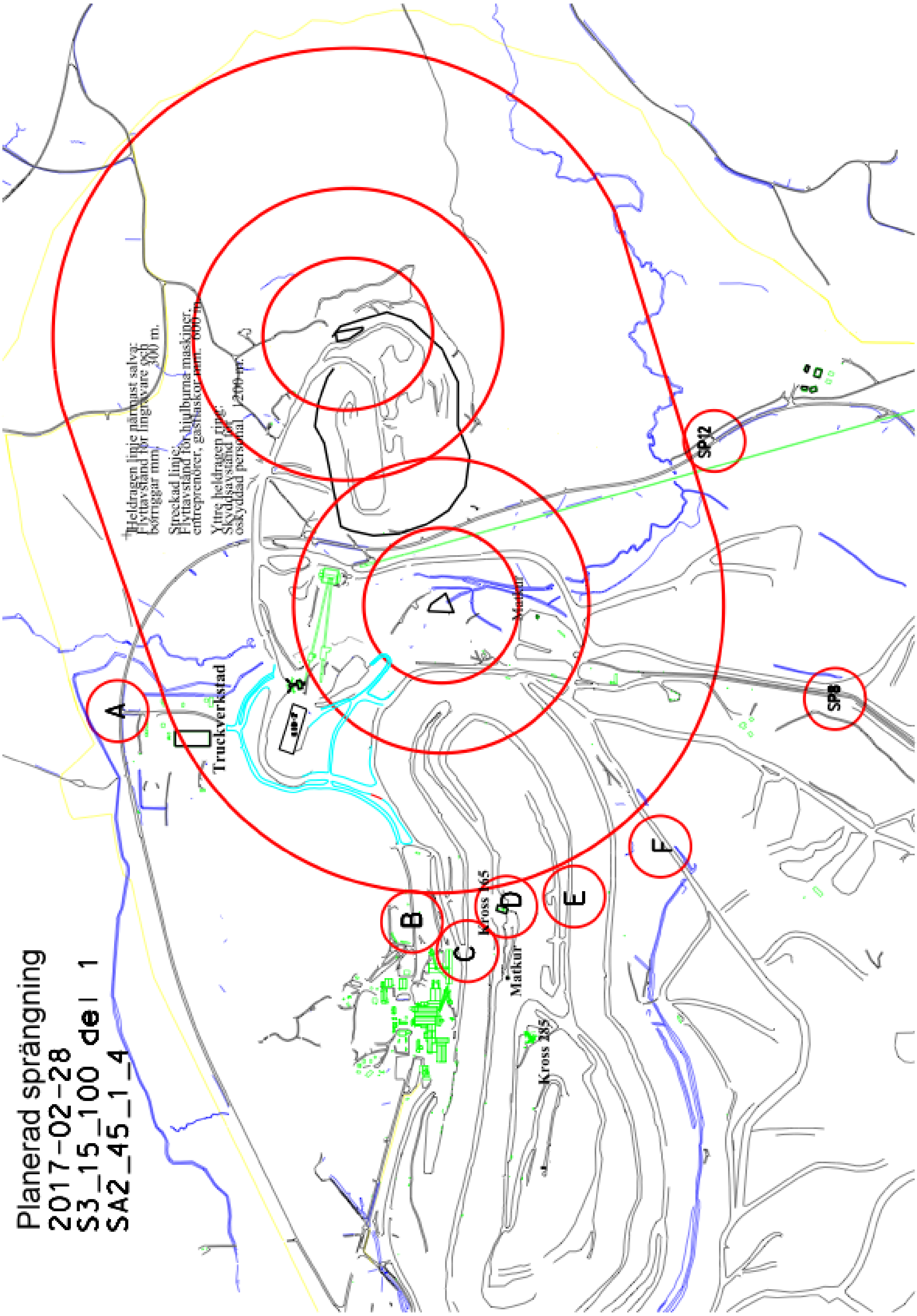


FIGURE 43: BLASTING MAP AITIK

I. Introductory Email Interviews

Kankberg email, 28 March 2017, Kent Hedin, Production Manager at Kankberg Mine
-Brytningsmetoder som används i de olika gruvorna
- Vi håller bara på med igensättningsbrytning med gråberg som återfyllnadsmaterial.

-Vilka olika typer av explosiv (och hjälpare) används
- Kankberg använder Austin Indetshock, Firex eltändare, Primer X-pipe 25g, stubin riocord 5g, emulsion levererar Forcit.

-Vilka typer av tändledningar, sprängkapsel och stubin används
- Se ovan.

-Vad för en lagring för explosiv används
- Godkänt sprängförråd under jord.

-Hur många människor jobbar med explosiv och deltar i sprängarbeten, och utförs jobbet (delvis) av entrepenörer?
- Uppskattningsvis 1-2 personer/dygn är inblandade i laddningsarbete.

-Allmän sprängingsförfarande; hur ofta spränger ni, ska den hela gruvan utrymmas eller bara en del?
- Varje natt, skjuttid 01:00, då är gruvan utrymd, uppstart 06:00 igen.

Garpenberg email, 30 March 2017, Kent Hedin, Chief Mine Planning Engineer at Garpenberg Mine
-Brytningsmetoder som används i de olika gruvorna
- Skivpall, igensättning och ortdrivning

-Vilka olika typer av explosiv (och hjälpare) används
- Emulsion, primer (X-pipe) 15mm, SLP-primer och 1 kg Booster

-Vilka typer av tändledningar, sprängkapsel och stubin används
- Nonelkapslar, elektronikkapslar, 5g Cord och krutstubin

-Vad för en lagring för explosiv används
- Sprängämnesförråd, 3 stycken i gruvan

-Hur många människor jobbar med explosiv och deltar i sprängarbeten, och utförs jobbet (delvis) av entrepenörer?
- 12 laddare på ort och 12 laddare på skivpall

-Allmän sprängingsförfarande; hur ofta spränger ni, ska den hela gruvan utrymmas eller bara en del?
- Spränger två gånger per dygn, kl.16.05 och 04.05. Hela gruvan ska vara utrymd

Aitik email, 27 February 2017, Torbjörn Krigsman, Blasting Engineer at Aitik Mine:
-Brytningsmetod?
- Pallsprängning

-Vilka olika typer av explosiv (och hjälpare) används?
- Aitik använder nonelsystem för upptändning (1000ms fördröjning i kapslarna) För att få igång sprängämnet apteras en 1,7 kg booster på tändaren. 2 st booster-tändare placeras i vart borrhål (311 mm) som sedan fylls med Emulsionssprängämne (ca 1000 kg) av vår leverantör Forcit. Vid sk. Förspräckning används en produkt kallad Riogur.

-Vilka typer av tändledningar, sprängkapsel och stubin används?
- Se ovan.

-Vad för en lagring för explosiv används?
- Tändmedel, booster och annat sprängämne (dynamit och riogur) förvaras i ett godkänt sprängförråd på plats i Aitik

-Hur många människor jobbar med explosiv och deltar i sprängarbeten, och utförs jobbet (delvis) av entrepenörer?
- Laddpersonalen jobbar K2 och är 3 personer/skift (boostersätter, kopplar och spränger salvorna.

-Allmän sprängingsförfarande; hur ofta spränger ni, ska den hela gruvan utrymmas eller bara en del?

- Vanligtvis spränger vi 1-2 ggr/vecka kl. 19:00 Farligt område minst 1200 m. utryms innan sprängning. Skickar med en checklista för salvsprängning samt en sk. Sprängkarta för sprängningen i morgon tisdag 28/2 som exempel på hur det kan se ut.

Tara email, 8 March, Pascal Walsh, Health & Safety manager at Tara Mine.

-Mining techniques applied in Tara

- Open Stoping and Drift and Slash technique.

-Types of explosives used (including boosters, in what conditions do you use different types of explosives).

- Emulsion + gas agent, use Non-L primed.

-What detonators, ignition systems, fuses etc. you use.

- Bunch connectors-primer chord connected to an electric detonators to initiate explosion (with rio primers)

-What kind of storage do you have to store explosives and other blasting materials?

- We have secured magazines in the mine with very restricted access. We have reserve station with restricted access.

-How many people are involved in charging and blasting tasks? Is (part of) the work carried out by a contractor?

- Charging and blasting the operation could have up to 22 people in charging and blasting. Yes contractors are also involved in charging and blasting.

-General blasting procedure (do you blast daily or with another frequency, do you evacuate the entire mine or just an area?)

- Blast twice (2 times a day) Morning and evening. The mine is empty except for blasting team.

-Have you developed your own safety policy based on Irish safety legislation?

- Yes, we use the European legislation as adopted into Irish Law and general our own procedure to comply.

Kevitsa email, 22 February 2017, Arto Suokas, Mine Superintendent at Kevitsa Mine

-Mining techniques applied in Kylylahti

- Open pit mining, bench height 12 m. 165 and 225 mm dia blastholes. Vertical 24 m long dia 165 mm holes in presplit. Subdrilling about 1.5 m. PF 1.1 – 1.9 kg/m3. Stemming height 3.5 – 4.5 m, 8-25 mm gravel used as stemming.

-Types of explosives used (including boosters, in what conditions do you use different types of explosives)

- Fortis Extra emulsion, 500 g and 1000g primers. Secondary blasting with Senatel. Presplit with Maxam 45 mm continuous packaged product.

-What detonators, ignition systems, fuses etc. you use

- NONEL detonators and surface delays. Two primers and dets per hole.

-What kind of storage do you have to store explosives and other blasting materials?

- Steel containers modified to comply with Finnish legislation for packaged products and detonators. Insulated and heated storage tanks for emulsion.

-How many people are involved in charging and blasting tasks? Is (part of) the work carried out by a contractor?

- We do D&B planning ourselves. 36 drillers of our own, contractor has 12 drillers. Orica is our blasting contractor, they have 2+11 people on site.

-General blasting procedure (do you blast daily or with another frequency, do you evacuate the entire mine or just an area?)

- Evacuate the whole pit. 300 m safety distance for equipment, 500 m for blasters. Blast 1-3 times a week.

-Have you developed your own safety policy based on Finnish safety legislation?

- Yes.

Kylylahti email, 22 February 2017, Jari Kolehmainen, Manager Health & Safety at Kylylahti Mine

-Mining techniques applied in Kylylahti

- Sublevel stoping backfilled with waste rock or crf.

-Types of explosives used (including boosters, in what conditions do you use different types of explosives)

- Main explosive is Kemiitti 810, in some cases we use also Anfo, but ratio is app. 90-10 to Kemiitti. Both in drifting and long holes we use also some pipecharges for smooth wall blasting and in waterholes.

As a booster, we use Forprime.

-What detonators, ignition systems, fuses etc. you use

- Both millisecond non-electronic and electronic detonators, supplied by Forcit.

-What kind of storage do you have to store explosives and other blasting materials?

- Storages are mined or after-use tunnels.

-How many people are involved in charging and blasting tasks? Is (part of) the work carried out by a contractor?

- All together ~10 people, in one shift there's normally two miners doing blasting works. After blasting the smoke check is partly done by contractor. Shift supervisor is of course important part of the blasting tasks and smoke checks.

-General blasting procedure (do you blast daily or with another frequency, do you evacuate the entire mine or just an area?)

- Blasting is performed daily (17:45) and we evacuate entire mine.

-Have you developed your own safety policy based on Finnish safety legislation?

- Yes, safety policy has been developing like any other thing during life of mine. It is mixture of Australian, Finnish and now Swedish safety cultures. And of course it's based Finnish legislation.

J. Notes Field Trips

1. Kankberg

Ari Juhainen (sprängarbas/Shift Boss)

- Ari is sprängarbas and superintendent.
- Blasting is carried out along SOP's. SOP's are developed at Bolidens central office. Standardized for all tunneling operations.

Chargers

- Separated explosives storage. Access with a personal code. Suppliers of explosives cannot enter the storage area without someone from Boliden.
- Charging is almost always done alone, sometimes with one person working from the platform and one from the ground. Always a radio is taken along, sees other people during lunch.
- Inspections of the quality of charging are not carried out by the sprängarbas.

2. Aitik

Torbjörn

- Rock types are similar throughout the mine, therefore no need for separate charge weights etc.
- For each blasting round a new blasting plan is drawn up, primarily based on the geometry of the rock to be blasted. The drilling plan is developed by the mine planning department.
- Around 2 benches per year are excavated.
- Maximum distance between drillholes is 7.1 meters for blasting to be effective.
- Keys for the explosives storage are in the custody of the chargers. These are physical keys.
- Spring weather can be a challenge, with melting water causing more unstable slopes and different conditions.
- Stemming is carried out by a contractor.
- Problem existed with the boosters in autumn 2016.
- In general, very few misfires; 14 misfires out of 17,800 drillholes during 2016
- Special exception with regards to rock surface cleaning requirement. Because it is recorded where drillholes where located on each level, drilling can be planned such that new holes will always be located on a different coordinate. Also, there will be a few months between the blasting of a new block. Therefore, the mining authority has granted an exception to the general rule that a rock surface always needs to be cleaned before the next blast.

Chargers

- 2/3 chargers are sprängarbas, always at least 1 required. Blasting plan is developed by blasting engineer (Torbjörn), but sometimes chargers make calculations in the field.
- Special driver's license is required to drive the car with explosives. Explosives car has separate department for primers and for detonators.
- Explosives packaging cannot go together with regular old paper waste, has to be burned at end of each shift.
- Maximum of 50 booster charges per day, because of weight primers (health requirements).
- Emulsion charging is done completely by Forcit. Stemming is done by Boliden staff.
- If charging/blasting takes place in pit with one road sometimes tractor is taken along to ensure that one still can get out.
- Single detonator and primer are used in side holes if rocks cannot fly into the pit into the side.
- If it is dark, a headlamp is used for lighting.
- A lot of misfires occurred during autumn 2016, it was found this was caused by failure of the boosters in these conditions. Therefore, a switch in boosters.
- Operators of loading equipment is trained in spotting misfires. If these are spotted, chargers are called, they will blast the misfire if possible. If not possible it is hauled and dumped on a separate site.

3. Kevitsa

Materials that serve as sources for the study of explosives and blasting safety practices at Kevitsa are the following:

- These notes
- Notes comparing specific legislative requirements
- Provided documents such as guidelines, SOP's, safety instructions etc (insofar translatable from Finnish).
- Videos of successful and unsuccessful blasts

Arto Suokas (Mine Superintendent)

ORGANIZATIONAL SET-UP

- Orica has TLS-service, they therefore also have their own charging safety procedures.
- Arto is the Blasting Foreman. 2 D&B engineers. Drill&Blast design is carried out by Boliden.
- In the end blasting is the responsibility of Boliden, but delegated powers to Orica.
- Communications between Orica and Boliden after blasting, after e.g. misfires and overbreak/underbreak, in order to improve services.
- Chief mining engineer is in the rend responsible for safety.

TYPES OF DOCUMENTS USED

SOP's. Orica has own SOP's. Internal guidelines.

HOW SAFETY POLICIES ARE DRAFTED

Safety documents are primarily in Finnish, for workers. SOP's are developed by the superintendent/chief mining engineer, a safety officer. Best group also involves operators and specific engineers. It is important that the SOP's are easy to explain and understand.

There is an ongoing revision of SOP's and checklists, also in order to translate things to English.

ENFORCEMENT OF SAFETY STANDARDS

Mine inspector comes from Toukes (Centre for Safety, National Body) Deals with chemical, safety, blasting safety, mine administration. Also, responsible for approval of storage.

Safety department responsible for preparing inspector visits.

Permitting regarding dust, noise etc. relatively loose because remote. Ongoing mining permit of which general approval for blasting forms part. No specific permits necessary again. Orica has its own permit to use explosives.

TRAINING

People without a license can work under supervision. 3hr induction for all workers, then test, then you get ID-card and driving permit. Orica has its own trainings and rules. Mention about blasting and safety distances in each training.

Superintendent and some of Orica have senior license, rest regular ones. At least 1 senior license is necessary for each activity. Orica does all the checks on its own employees.

RISK ASSESSMENTS

Storage, blast and operations are all risk assessed before new starts. Not separate assessments for each blasting in regular cases. Always assessment with deviating circumstances (e.g. snow, ice). Then drilling only at night and charging immediately the day after. Blast asap.

Orica has its own checklists, this is in SOP's. Orica has assessment for each operating phase. These are communicated with global operations.

INCIDENT REPORTING

- Health & Safety responsible for managing and investigating incidents. In general H&S people serve as internal consultants, separate from daily operations. Analysis of LTI's, kpi's etc.
- Reactive indicators are well-analyzed, leading indicators more difficult to develop.
- Lots of small incidents like tripping and falling, also during charging activities and with drillers. No issues with blasting however, except for misfires.

- No LTI's known following blasting activities (except for the mentioned tripping issues perhaps).
- Concerns with misfires; there was an increase of misfires since last year. This was primarily due to contour drilling, also issues with misfires in previously excavated quarries (then used for mine development works). Other cause for misfires are cut wires. Misfires one of the biggest risks.
- Incident last week: driller drilled a hole, when lifted the drill bit, a primer was lying next to the hole. Matter with contour blasting (again).
- Presumed reasons for misfires: Cold weather casing wasn't think enough in contour blasting, tie-ups, flyrock causing wire-cutting leading to cut-offs. Misfires from previous operations, cannot change that anymore. Delay hooked up/damage to tube.
- 1-4 misfires per month, decreases 2015-2016, now increase. Due to contour blasting. Blasts around 3M tons/month, 750 tons/blasthole. Therefore 1-2 misfire per million ton mined. Drilled 977376 holes, 72000 holes with 45 misfires, i.e. 1/1600.
- Procedure with misfires; loading in the particular area is halted. Person with blasting license picks up the misfire, gives coordinates, brings it to the storage area in a box with a pipe. If no one with a blasting license is in the area the area is blocked off until there is someone to pick it up. Orica blasts misfires along with regular blasts. Each misfire is treated as a deviation for reporting.
- Case of misfire in split-up. Blast cut-off? Connections of splices caused detonation in a wet-hole (pre-blast?)
- Power lines have been hit by flyrock a few times.
- Sometimes breaches of danger zone during blasting. 3 years ago, a fuel truck drove out of the pit just before blasting.
- Centuri-system is used for safety issues, like everywhere in Boliden.

EXPLOSIVE MATERIALS USED

NONEL-system is usually used, electronic detonation is trialed. No vibration problems (remote location), trialing of electronic detonation is primarily done to improve fragmentation and wall control.

TRACK & TRACE

Orica is both importer and end-user, so system functions differently with e.g. not an xml-file for the end-customer, it's easier with one user. However, track & trace system is implemented, and in the future will be fully digital. All materials are imported from other EU-countries.

STORAGE

Orica has their own licenses for the storage. Storage containers and emulsion tanks, together with all explosive materials are owned by Orica.

- Soon a new storage to deal with the track&trace requirements.
- Orica sends an invoice twice a month; this specifies exactly what explosive materials have been used and how much are in store.
- Separate container for pre-split explosives.

BLASTING PLANNING

- Never blast at the same end of the pit, always at other ends.
- Planning is done Thursday-Wednesday, this leaves room for weekend works.
- Notice is given two days before the blast.
- Group meeting each day, 15-20 minutes with a large crew (also maintenance and processing). If blasting relevant discussed, primarily for evacuation. Later more specifically with just the mine people.
-

CHARGING

- Portable lighting towers are used during wintertime. Cap lamps are used as well. Always for charging and loading areas. Boliden supplies them to Orica.
- Charged area is fenced off. No guards needed since whole mine has fence around it. Safety berm is used when next to a busy haul road. This is risk assessed.
- Guidelines of Orica are followed.
- Drill-blast cycle is usually very quick. The main limit is the detonators, should officially be used within 2-4 weeks, depending on circumstances. Emulsion stays well for 3 months.

BLASTING PRACTICE

Ground conditions sometimes cause excitement. Spring conditions are difficult.
Evacuation 30 minutes before the blast, there are guards at all the entrances.
If not possible to protect equipment, two dump trucks moved to protect against flyrock, with bucket turned upwards. Then always first assessment if it is possible to postpone the blast. 3 of such occasions in the last 2 years.

Pre-blasting check is left to Orica, to check set-up. Items external to the blast itself are checked by Blasting Foreman (Boliden). Also checks for wall control.
1. Check if equipment is in the designated location.
2. Drive around the blasting area to look for people.
3. Orica sets up a receiver and later transmitter around 10-15 minutes before the blast.
4. Guards are in place half an hour before the blast until after.

Post-blasting check is carried out together with Orica. The Blasting Foreman is responsible for the check.
1. Check for fumes
2. Check how rock breaking went.
3. Report deviations
4. Shiftboss needs to keep guards until the fumes have cleared out.

Drilling

Drilling tasks partially carried out by Boliden, partially by contractors (for overburden). Drilling is usually carried out near charging locations. In the future contractor may be phased out for loading/hauling and drilling tasks (5 year contract awarded by First Quantum). Drillers receive training to spot misfires.

- Safety distance between drilling and charging (2 lines/10m). If drillers have to go back in charging field to fix a hole/new hole, always still 5m distance and always under Orica supervision.

- 3-4 rows at the edge of the blast are left free when drilling nearby to avoid issues with flyrock. Drilling is then done after blasting.

- Using collar pipes immediately afterwards helped a lot. With weak rock sometimes still problems however. In general, luckily good rock quality.

Loading & Hauling

- Training for loading/hauling people: They get training on the job, Orica gives a presentation on spotting misfires every two years. Before people start working they have an induction of several hours including items on blasting and misfires and a mine tour.

- Cleaning is carried out after loading when toes left (special blasting), before production drilling starts again.

Crushing

Oversize in crushers is not a problem currently. Small equipment is used in such cases to break rock. Hydraulic rockbreaker is used for oversize in the open pit.

Special Blasting

Special blasting, of toes, boulders etc., is carried out by another contractor, because Orica is expensive. For this, electric detonators are used, since they are much quicker to work with and check resistance. They have mats on top. Sometimes powerlines and equipment nearby, therefore mats are used. Power lines do not cause problems with electrical interference. For oversize blasts NONEL is used.

Other contractors

Contractors are always responsible for their own people. In the past some “cheap cowboys”, but they have improved well. Actually contractors have better safety record than own Boliden staff. Same safety reporting standards, but recorded separately from own staffs. Hartikainen (big contractor) has even own safety manager.

Ongoing Improvements

No major differences compared to working under First Quantum (until 2016). Still, ongoing gradual improvements. Orica has been there from the start and also communicates with other Orica operations.

Contact with Other Boliden Mines

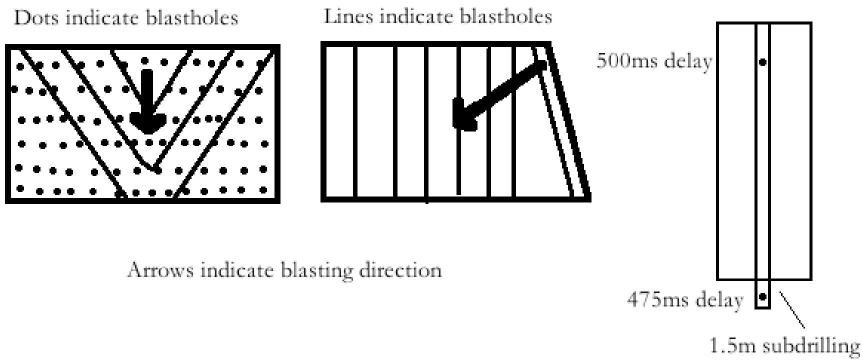
There is a working group in Boliden for transferal of blasting practices. Discussions with Aitik and technical office.

- Some geologists and hard rock engineers stay in touch with Kylylahti.
- Safety department is in touch with Bolidens office.
- No benchmarking with underground mines so far, but could be useful for the future.

Tony Vaarala (Blasting Engineer)

Design Paramaters

- Pattern sizes
- Waste: 4.6m, square pattern, Ore: 3.3*3.9m
- It is tried to have bigger spacing to improve drillers and chargers capacity



- Currently only different pattern size for ore/waste, otherwise no geological differences based on rock types.
- Problem with slow stemming works, increase in pattern size would also make it easier to work therefore.
- Stemming:
- 6.5 m if inclined blast holes
- 3.5m stemming for regular holes
- 4.5 stemming for last holes, and a bigger diameter
- Emulsion around 450 kg, 250-280 for overburden.
- 165mm and 225mm drill bits used.
- Wall control/fragmentation main priority blasting engineer.

Misfires

No drilling closer than 1 meter from previous drillings to avoid hitting misfires. Avoiding misfires sometimes difficult during winter. Important to ensure that initiation of detonators goes far enough before the wires are broken.

Danger Zone

For machines, it can be checked whether minimal distances can be less due to proper blast design.

Safety distances: 300 m for machines, 500 meters for people. Machines are kept outside the throw direction if possible.

Design&Blast Processs

- Surpac is used for drill&blast planning. Blast master is made outlining different blasting fields. The mine planner specifies the amount of rock to be blasted.
- Exact drill designs are not specified immediately, usually only around 1-2 weeks in advance, when it is also planned when a particular field will be blasted.
- Orica software also used for some blast designs aspects.

- Feedback from Orica after the blast, including in the form of an excel file specifying the exact quantities of emulsion used. Broken holes have also been marked.

Thomas Tervetuoala (Charger for Orica)

Blasting Techniques

- Different emulsion densities, near the pre-splitter thicker emulsions used.
- 3.5-meter stemming, 4.5 meter near the pre-split in order not to break the wall.
- Delays are connected to each detonator near the hole with NONEL immediately.
- Usually around 300-400 holes per day are primed, loaded and stemmed.
- Sometimes working with IKON-detonators, as trial. Work is more complicated.
- Cardboard pipes are used to avoid hole collapses, this has worked pretty well in avoiding misfires.

Licenses

Everyone has a C-license and a blasting license, except for trainees and summer workers.

Equipment used

Shovel for stemming; three different loading trucks for emulsions. Several hiluxes for personal transport.

Shifts

7x12 hour shifts (8 on Sunday), 7 days off. Usually 6 people per shift, currently 8 because summer workers are trained. During the summer holiday weeks 4 permanent workers+2 summer workers. Only day shifts, whereas drillers work 24/7. Around one blasting fielded charged per day.

Emulsion Storage

Two permanent and one temporary storages, of around 1100 tons each.

Storage

- Explosion-sensitive materials are separate in a fenced off open area, with containers for each separate type of explosive materials. The detonators are stored on one site of the storage field, the primers on the other. Distances based on Finnish legislation.
- Every charger has a key to Orica containers on the general storage site.
- Sub-contractors have their own storage containers within the storage facility.
- When explosives are taken out from the storage this is reported. Bookkeeping is done on paper forms; in the future new storage will be built to facilitate electronic track & trace systems.
- The storage is checked monthly, in order to see that the materials stored match the records.

Maintenance/Cleaning

All maintenance/cleaning of charging equipment is undertaken by Orica people, on site, at their own facility, where also the breakroom and emulsion storage is located.

4. Tara

Materials that serve as sources for the study of explosives and blasting safety practices at Tara Mine are the following:

- These notes
- Notes comparing specific legislative requirements
- Provided documents such as guidelines, SOP's, safety instructions etc.

Dessie Rogers (Health & Safety Officer)

ORGANIZATIONAL SET-UP

Miner-Shift Boss-Head of Section-Mine Manager

TYPES OF DOCUMENTS USED

- Statements; drafted by a safety officer, reviewed by safety manager, signed by the general manager. Legal requirement.
- More detailed SOP's and safety guidelines. In any case always a scope, purpose and definition included in the document.
- It is necessary that documents are simple and easy to understand for all people involved.
- Shift bosses not only need to know the relevant safety documents drafted by Boliden, but also the underlying legal documents (such as the 1972 Mines (Explosives) Regulations and 1965 Mines & Quarries Act).

HOW SAFETY POLICIES ARE DRAFTED

- Generally, three people involved, always three-stage process (Draft-Review-Approval). People involved e.g. head of section, safety officer and shift boss, but can have different compositions.
- External watchdog for changing legal requirements; when requirements change new rules & procedures will always be developed.
- In some cases, regulations are copied from Sweden. Skeptical about wide application however, due to mine-specific environment and requirements.
- No external review of procedures. Development is separate from Sweden.

MANAGEMENT SYSTEM

Centuri-system used to manage all rules & procedures, risk assessments etc. Accessible to all Boliden people involved.

ENFORCEMENT OF SAFETY STANDARDS

- Shift bosses visit activities at least twice a shift.
- Heads of section may go down as well.
- Mine Inspector visits twice a year, specifically interested in explosives.
- Department of Justice specifically checks explosive standards once a year.

INCIDENT REPORTING

- AIRS (Accident Investigation Reporting System) is used to report incidents. No significant accidents related to blasting or explosives recorded (i.e. no personal injury, no trespassing, no damage to equipment), except for misfires. Why would this go well?
- Underground mine, so trespassing practically impossible, and very effective evacuation possible.
- Very strict rules on storage and handing over explosives (powderman/magazine vs reserve station system does not exist in this way in Sweden)

EXPLOSIVE MATERIALS USED

- NONEL-cables, Emulsions based on oxidisers/gaser agents used. 1 detonator and primer per hole.
- Kimiit-"rockets" used for overhead charging
- Electronic IKON-detonation system used for raises in production stopes; this is done in order to improve blasting reliability and precision, since these raises are critical for further mine production.
- For special smaller chargers, sometimes powder cords used
- Large cartridges used misfires, large boulders in production blasting and in the crusher. In the crusher, sometimes just detonator sufficient as well.

Ordering Explosives

Explosives are ordered using Maximo. Track & Trace system has been implemented since April 2015. With delivery SP-file of all files delivered. Both complete boxes, sub-packaging and individual items are registered.

When brought to the mine site, the explosives transport is accompanied by the police. Only after formal transfer to the powdermen and when the explosives are brought into the mine from surface they leave the materials in the custody of Tara. Surveillance cameras on critical sites checking transfers.

Emulsion transports don't need police surveillance etc. Are also stored on surface. Responsibility of Orica.

Storage

- Difference between magazine and reserve station: magazine is the long-term storage, only accessible by powdermen. Reserve station stores a maximum of two day loads of explosives, shotfirers can also collect the explosive materials from the powder men from this station, but normally the powdermen are responsible to bring the explosives to the blasting site, where they can be handed over formally.
- The magazine can only be accessed with permission from G4S (security) in Dublin.
- Access to magazines and storages have copper bars that can be held to decharge static electricity. Temperature and moisture levels are regulated.
- Not aware of the Stores for Explosives Order 2007, might be because this is about the design of new storages. Tara's storages where built 38 and around 15 years ago respectively.
- Emulsion storage on the surface, maintained by Orica. Trucks bring in materials, are weighed when entering and exiting to determine the amount delivered. After that powdermen are responsible to bring tanks on trailers underground with a tractor.
- Underground emulsion storage is newer, it is not a problem that it is close to a haul road because the agents are insensitive.

Scheme of Transit

Scheme of Transit is the "Bible" when it comes to handling and moving explosives into the mine. Note on the procedure of leaving unfinished charges in emergency cases; "barricade" is nothing more than hanging up a chain; apart from that just get out of there asap.

Central terms:

- Transfer: Magazine to reserve station
- Hand-over: From reserve station (via powderman) to the shotfirer.
- Logs of transfer/handover: Have to be stored for 10 years. In some quarries this just a picture of the explosives used, in Tara done by the track&trace system.

Blasting Practice

- Two 10,5 shifts per day; blasting at 6:50 and 19:10, 1.5 hours for the blast and ventilation.
- Chargers usually charge several development headings per shift.
- Production charging may take several shifts, although usually finished in one. In total, usually 4 production chargers active.
- Some development works by contractors; they have their own shotfirers. They can also place orders with the powder men for explosives.
- Production blasting all carried out by Boliden.
- Development drill holes 5m depth, with ø 45mm; production stopes up to 20m depth, with ø 65mm
- Chargers generally work in pairs; apart from that always communication equipment with them.
- Electronic detonators used for production raises to be sure of exact programmable delays. Orica does the programming once a week.

- Shift boss keeps the blasting machine; people usually present at blast are a shotfirer for Tara, a shotfirer for the contractor, the shifts and in case of ICON-blasting someone of Orica. The shotfirer is responsible for all pre-blasting checks.

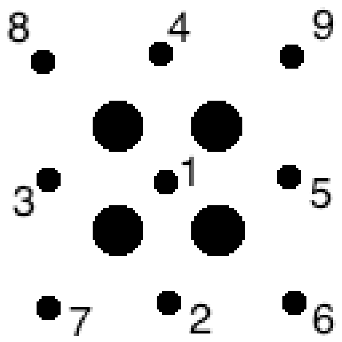


FIGURE 45: FIRST CUT DEVELOPMENT DRIFT

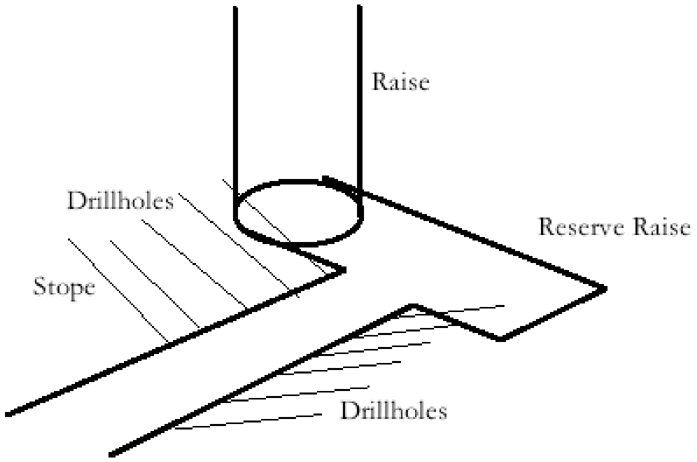


FIGURE 44: STOPE EXTRACTION METHOD

Figure 44 shows the way in which stopes are extracted; first a drift is made through the stope; then a raise is blasted upwards. Because this raise is difficult to blast and of crucial importance ICON-detonators are used to blast. The stope can then be blasted, with blasting sequence starting from the raise and driving backwards. There is room for a back-up raise on the other side of the drift, in case the first raise would not go well.

Nicola (Blasting Engineer)

- Mine planners develop drilling plans of stopes. Blasting plans worked out by blasting engineer.
- For development drill/blasting plan always the same.
- Drill core analysis is delivered to blasting engineer; also blast plans are brought back after blast to check. Usually no big differences in charges based on geology, primarily based on stope dimensions.
- Ground vibration reductions priority; most common reason for complaints.

Thomas (Powderman)/Observations

By day 3 powdermen per shift, at night 1. Responsibilities:

- Transfer of explosives from suppliers on surface to Tara, bringing these explosives into the magazine.
- Bring the oldest items in the magazine to the reserve station if needed there.
- Package explosives; standard package for development blasts, custom complete packages for production stopes. These custom packages are based on the blasting plans provided by the blasting engineer.
- Significant incident in Lisheen Mine (another lead-zinc mine in Ireland) several years ago; miner was unrolling copper wire in one hand, held a detonator in the other hand. Due to a release of static electricity detonator exploded, hand was blown off. For that reason, detonators that require a much higher current are now used in Tara.
- Major troubles with central track & trace system of Boliden. Therefore, own system is used now, but this system is also not flawless. Errors with processing scans, sometimes causing delays in explosive deliveries. IT should improve.
- Doors to the reserve station can be kept open when there are people there.
- All cars carrying explosives have red lights on them.
- Primers are prepackaged in the same room as the detonators.

Franky (Charger)/Observations

- Production drift is charged row by row.
- Lower holes are blocked to prevent inflow.
- No marked off area during lunch break.

- Working sequence: Clean-prime-push in detonator/primer-insert emulsion hose, pushes detonator/primer in.
- Stick used is made of wood.
- Connection of detonators is done at the end of the shift.
- Pump on the truck monitors how deep the hose is in the hole, and what amount of emulsion has been pumped in. The system follows the blasting plan.

Orica

- Responsibilities of Orica at Tara: Supplying emulsions, training chargers to use emulsion pumps, cleaning and maintenance of equipment. Pumps on Tara trucks are still owned by Orica.
- Not involved in blast design or selection of detonators/primers.
- Included in incident reporting systems.
- If different safety standards Tara Mine/Orica; highest standard prevails. Generally, safety standards related to working with emulsions are drafted by Orica.
- Risks associated with emulsions: Equipment/materials catching fire underground, which causes toxic fumes.
- Stones in the pump can cause a hotspot-confined mixes in the pump might cause an explosion (very small chance though); therefore, training on this topic, keep the hoses clean.
- Mixing with other materials that may lead to explosive substances.
- Equipment offers the opportunity to tailor the nitrate-gas component and oxidiser to specific needs for the blast; higher share of nitrate-gas component ensures more powerful blasts.
- From previous experiences, ICON-detonators are very effective in ensuring safe and reliable blasting; system is not sharp before this is requested; virtually no misfires since failures can be detected immediately; perfect quality of blasting, thereby better fragmentation and reduced vibrations. Expensive though (€30/det instead of €6/det).
- Why do surface mines let emulsion contractors charge holes themselves (see Kevitsa, Aitik), and underground miners not? Probably more economical to let emulsion trucks just drive into the mine directly, not possible with underground mines.

K. Misfire Reporting Sheet

6 **Tara Mines Misfire Reporting Sheet:**

09/04/2014

NEW BOLIDEN

Tara Mines Misfire Reporting Sheet

To be completed in the event of any misfire:

Location of Blast:

Blast Type : Production ☐ Development ☐

Number of Holes : ________________

Length of Holes (metres) : ________________

Did the explosive? Remain in the hole ☐ or was it ejected ☐

Indicate Position ofMisfire in relation to the development blast

0	0	0	0	0	0	0
0	**0**	**0**	0	0	0	0
0	**0**	**0**	**0**	**0**	**0**	**0**
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

If it was a production blast draw a sketch of misfire(s) location:

Name of shiftboss who discovered the Misfire (PRINT):____________ **Signed:** ________________________

Duty Captain (PRINT): ________________________ **Signed:** ________________________________

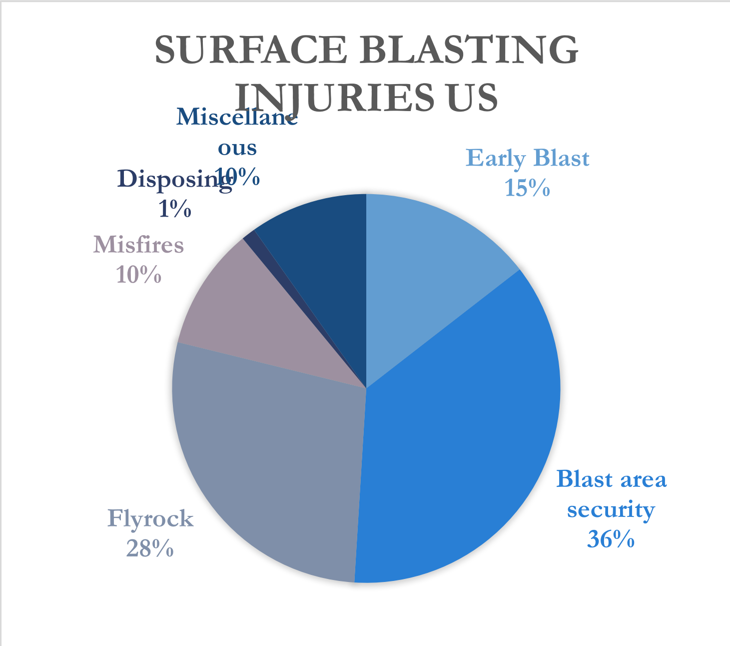
L. Tables with Australian and US Data

TABLE 48: QUEENSLAND BLASTING INCIDENT DATA

Share blasting incidents	2005	2006	2007	2008	2009	Total	Percentage
Misfire	46	43	156	190	223	658	91%
Flyrock	11	2	11	13	1	38	5%
Uncontrolled shockwave	1	0	0	0	0	1	0%
Premature blast	1	1	1	3	2	8	1%
Fumes	0	0	1	2	15	18	2%
Air overpressure/vibration	1	0	0	0	1	2	0%

TABLE 49: US DATA

Injuries	Underground	Surface
1978	4	23
1979	3	12
1980	3	18
1981	3	11
1982	1	8
1983	1	5
1984	5	21
1985	1	4
1986	1	8
1987	9	14
1988	1	9
1989	1	14
1990	1	15
1991	7	11
1992	7	7
1993	3	7
1994	3	12
1995	4	8
1996	6	7
1997	9	7
1998	3	9
1999	2	3
2000	3	5
2001	2	3
2002	3	5
2003	1	3
2004	0	7
2005	1	2
2006	2	5
2007	0	0
2008	0	0
2009	0	0
2010	1	0
2011	1	0
2012	0	0
2013	2	2
2014	0	0
2015	0	0
2016	0	1



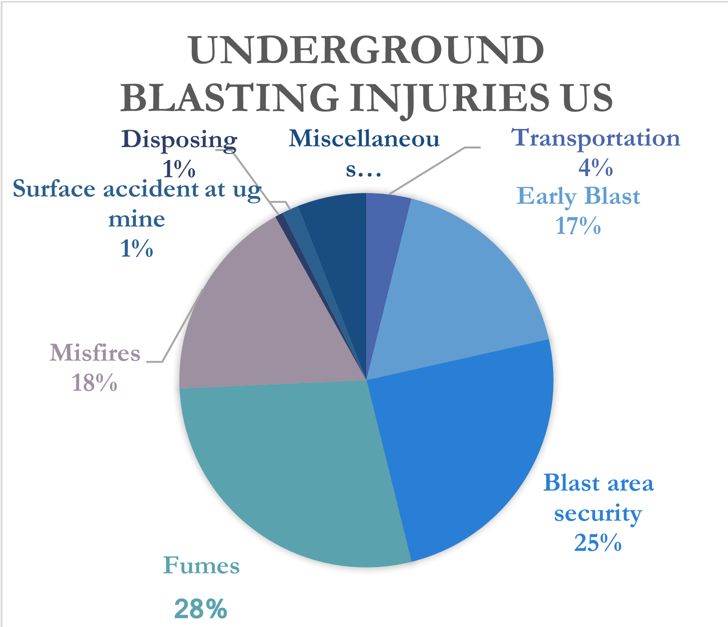


FIGURE 46: PIE-CHARTS BLASTING INJURIES CAUSES US

M. Tables with Statistical Data Boliden

TABLE 50: YELLOW AND RED INCIDENTS PER SWEDISH MINE

	Aitik	%	Garpen berg	%	Maur liden	%	Boliden Area (excl Maurliden)	%
Responsible Persons	2	0,84%						
Documentation	1	0,42%						
Packaging	1	0,42%						
Storage	10	4,22%	6	16,67%	1	4,55%	8	21,05%
Transportation	5	2,11%	4	11,11%			2	5,26%
Drilling	8	3,38%	2	5,56%	2	9,09%	2	5,26%
Charging	12	5,06%	3	8,33%			3	7,89%
Charging Equipment							5	13,16%
Blasting	40	16,88%	6	16,67%	2	9,09%	2	5,26%
Blasting/Evacuation Procedure	104	43,88%	4	11,11%			1	2,63%
Explosives Left			2	5,56%			6	15,79%
Post-blasting	11	4,64%	3	8,33%			2	5,26%
Misfire	27	11,39%	4	11,11%	4	18,18%		
Crushing	1	0,42%	1	2,78%			4	10,53%
Loading	15	6,33%	1	2,78%	13	59,09%	3	7,89%

Note: Only underground Swedish mines and Tara have been included in the above data

TABLE 51: INCIDENTS FOR ALL MINES

Category	"Red" cases 84
Responsible Persons	2
Documentation	0
Packaging	0
Storage	3
Transportation	6
Drilling	2
Charging	3
Charging Equipment	0
Blasting	15
Blasting/Evacuation Procedure	26
Explosives Left	8
Post-blasting	4
Misfire	9
Crushing	0
Loading	6

N. Sample Database Incident Reporting

Ärendenummer	Beslutad korrigerande åtgärd	Beskriv händelsen och dess omfattning	Föreslagen åtgärd med syfte att det inte ska hända igen	Datum och klockslag för	Område/Avdelning so	Avvikelsetyp -	Riskbedömnings
H100003	Utred om det är dolor eller sprängämne som har läckt ut från borrhål samt beställ inmätning av koordinater på dem ifall det finns kvar boostrar I närheten av dem. och markeras I caes	Gruvmätare hittade två misstänkta dolor nere på söder. Meddelade till laddpersonal som kontrollerade dem. Det rör sig om emulsionsrester som ligger kvar en bit upp I väggen. De sitter så till att man inte kan komma åt dem på grund av rasrisk och kontrollera om det rör sig om odetonerade hål eller bara sprängämnes rester. de är hur som helst att betrakta som dolor.		17/04/2015 14:00	G52 Gruva	Risk/Oordning	Klass: 1 GRÖN
H100616	Utred orsaken till dolorna.,	Under skrotning och rensning av vägg på Sa2_60 nivå har ett flertal dolor påträffats. Dessa har spärrats av och får skjutas om vid nästa sprängning i salmijärvi. I ett par stycken har det funnits kvar tändarkablar och dessa har konstaterats att de har tänts upp men borrhålen har inte	Tyvärr förekommer det ibland dolor i sprängda bergmassor.	10/05/2015 08:30	G52 Gruva	Risk/Oordning	Klass: 1 GRÖN
H102501	Märk upp och kommunicera ut.	Dola upptäcktes på lastad truck 75 på väg från 1152. A-led kontaktades som pratade med laddarna. Truck föraren fick tippa lasset på anvisad plats. Därefter tog laddarna hand om den. Det visade sig vara gammalt sprängämne från omtag 5.		08/07/2015 08:00	G52 Gruva	Tillbud	Klass: 2 GUL
H107260	Be BDX/entreprenören förtydliga hur man introducerar ny personal. Be BDX/entreprenören gå ut med information om blå färgmarkeringars betydelse till personal	Stannade och pratade med personal I skutknackare som knackade I klack med dolor. Ställde frågan om de visste vad de blå färgmarkeringarna på klacken betyder, men det visste man inte. Stor risk att knacka på sprängämne.	Be BDX/entreprenören förtydliga hur man introducerar ny personal. Be BDX/entreprenören gå ut med information om blå färgmarkeringars betydelse till personal	02/12/2015 08:00	G52 Gruva	Risk/Oordning	Klass: 3 RÖD
H118692	Inget	Bil 866 kör förbi spängpost vid dola sprängning innan klartecken fåtts av laddarna att sprängningen är klar, dolan var sprängd när bilen passerade men klartecknet från laddarna		05/11/2016 14:00	G52 Gruva	Risk/Oordning	Klass: 1 GRÖN
H21436	Hantera dolor enligt rutin i berganvisningar. Dolor skall oskadliggöras eller märkas ut tydligt. Borrning får ej utföras innan dola är	Vid laddning av justerings stross K6 upptäcktes en dola i väggen bara några decimeter ifrån ett nyborrat hål. Tändarslangen hängde helt synligt ,borrhålet var fullt av sprängämne, .	Följ skydds föreskrifter angående dolor	30/04/2007 17:45	G2K	Tillbud	Klass: 3 RÖD
H27556	Se bifogad fil	På grund av sk"ryckare" uteblev detonation på bottensprängkapsel och dola var ett faktum. Dolan omhändertogs med att nytt Snaplinerblock kopplades på signalledare till bottensprängkapseln,detonation genomfördes med gott resultat.Efterbesiktning av salvan och information till närmaste berörd personal på skanska gjordes via telefon.Sprängarbasen påtalade att ingen utlastning av berget får ske förrän sprängarbasen är åter på plats enligt överenskommelse med anledning av sprängarbasens övervakning av utlastning med	Ytterligare kontroll av uppkopplningen av salva innan detonation.	07/12/2007 12:15	G67 Proj.ledn. Bygg	Tillbud	Klass: 3 RÖD
H31222		Grävmaskinisten observerade noneltrådar som kom upp ur bergborrhål vid en förhöjning av sprängbotten.Då det kunde mistänkas vara dolor tillkallades omedelbart sprängarbasen. Denne kunde konstatera att detonationen passerat genom alla nonelsangarna och att eventuellt kvarvarande sprängmedel fanns skyddat nere under solid bergyta. Påföljande arbetsdag blåstes hålet och inget sprängmedel hittades. Förhöjningen i sprängbotten borrades med nya hål och sprängdes bort. Omkodat av Michael Sandberg till risk/oordning.	Inga åtgärder har vidtagits eftersom inget oförutsett inträffat. sprängmedelet hade av allt att dömma detonerat men på grund av de jordslag som fans i berget gick sprängkraften delvis förlorad och delar av bergbotten stog därför kvar efter första sprängnngen. Efter omsprängning var sprängbotten utjämnad och schaktningen återupptogs i full omfattning.	16/01/2008 09:00	HR och Hållbarhet	Risk/Oordning	Klass: 3 RÖD
H34353	Placering av poster där postplats-skyltar ej används anges med A, B, C etc för att undvika missförstånd	Vid sprängning av dola 23/6 14:00 placerade sig en post fel. Vid denna dola-sprängning hade en särskild karta med posteringsplater utfärdats men post 5 (enl kartan) placerde sig vid postplats 5. Någon fara uppstod dock inte då den post som var placerad på intilliggande väg hade sådan uppsikt så inpassering till farligt område kunde ej ske utan att det uppmärksammats	Placering av poster där postplats-skyltar ej används anges med A, B, C etc för att undvika missförstånd	23/06/2008 14:00	G52 Gruva	Tillbud	Klass: 2 GUL
H35274	En god besiktning av förman/ borrare före borrning. Borraren ska med förman planera kommande borrning, justering av gavel eller dyl. Bör diskuteras på nästa berggruppsmöte.	Tar över en påbörjad salva, taket o några takhjälpare är borrade fortsätter med v-bom ner på v-vägg börjar sedan gå uppåt med vägghjälparna, har 2 hål kvar, ett skut släpper Geologi.Bergartskontakt Malm Dolomit V o Baksida skut, ovansida påverkad av tidigare bergtryck/sprängning/geologiska strukturer	Planspräningning av gavel,	15/08/2008 07:30	G9N9 Gruvan	Tillbud	Klass: 2 GUL
H57602	Jag har inga bra uppslag som kan hindra det från att inträffa igen.	Påkörning sprängsten i ramp nedanför o-hall med sevicebil 20768. Trafik i rampen dvs låg fart samt halvljus. Uppmärksammade ej dold sprängsten inbäddad i snö.		20/10/2010 20:10	G52 Gruva	Tillbud	Klass: 2 GUL
H63376	Information till alla lastare omg. ang. hantering av dola. (dokumenteras) HMS regel finns.	Vid lastning i salva Sa2_0_3 med 1151 hittade man sprängmedel i salvan (dola) och man kunde ej rutinerna för dola. Då tog man upp sprängmedlet till gruvkontoret och lade den på bron utanför dörren.	Utbildning och information regelbundet om hantering av dolor för arbetsledare,vikarb.ledare samt lastare.	15/07/2011 17:10	G52 Gruva	Tillbud	Klass: 3 RÖD
H69980	Åtgärder enligt ovanstående.	Vid gavelskrotning skrotade Hendriksson längst ner på höger sida det låg en del berg på sulan och spettet var inne i den berghögen under skrotningsarbetet. Plötsligt detonerade något under spettet (kan ha varit en tändare och en liten mängd sprängämne) Hendriksson hörde en smäll samt såg ett ljussken samt att det kändes röklukt. Hendriksson stoppade skrotningen och gjorde en bedömning av situationen. En hydraulslang skadades troligen vid detonationen och den byttes ut. Efter kontroll av gavel - sula fortsatte skrotningen tills den var klar. Rensning före borrning utfördes och ytterligare kontroll gjordes men inga dolor eller sprängämne kunde	Alla normala rutiner i salvcykeln har följts i detta fall. Händelsen får betraktas som mycket ovanlig. Vad vi ska informera om är skärpt uppmärksamhet om vi hittar kvarblivet sprängämne och odetonerade tändare i salvor då får åtgärder vidtas utifrån detta. Vidare ska vi informera om vikten att det är ordentligt utlastat före skrotning så att det inte ligger mycket löst berg framme vid gavel vilket försvårar gavelskrotningen längst ner.	02/05/2012 06:30	G2K	Tillbud	Klass: 2 GUL
H78644	Flytta varningslampa för luckor till en mer synlig plats i kupèn	Vid körning från sprängmagasin 7/4 öppnades sidolucka varvid denna tog i grindstolpe och demolerades.	Flytta varningslampa för luckor till en mer synlig plats i kupèn	07/04/2013 15:00	G52 Gruva	Tillbud	Klass: 1 GRÖN

O. Suspected Causes of Incidents in Underground Mines

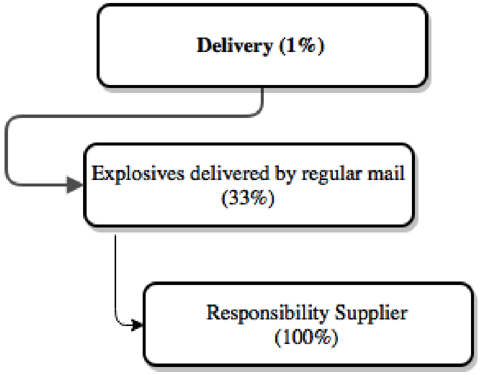


FIGURE 48: DELIVERY INCIDENT CAUSES

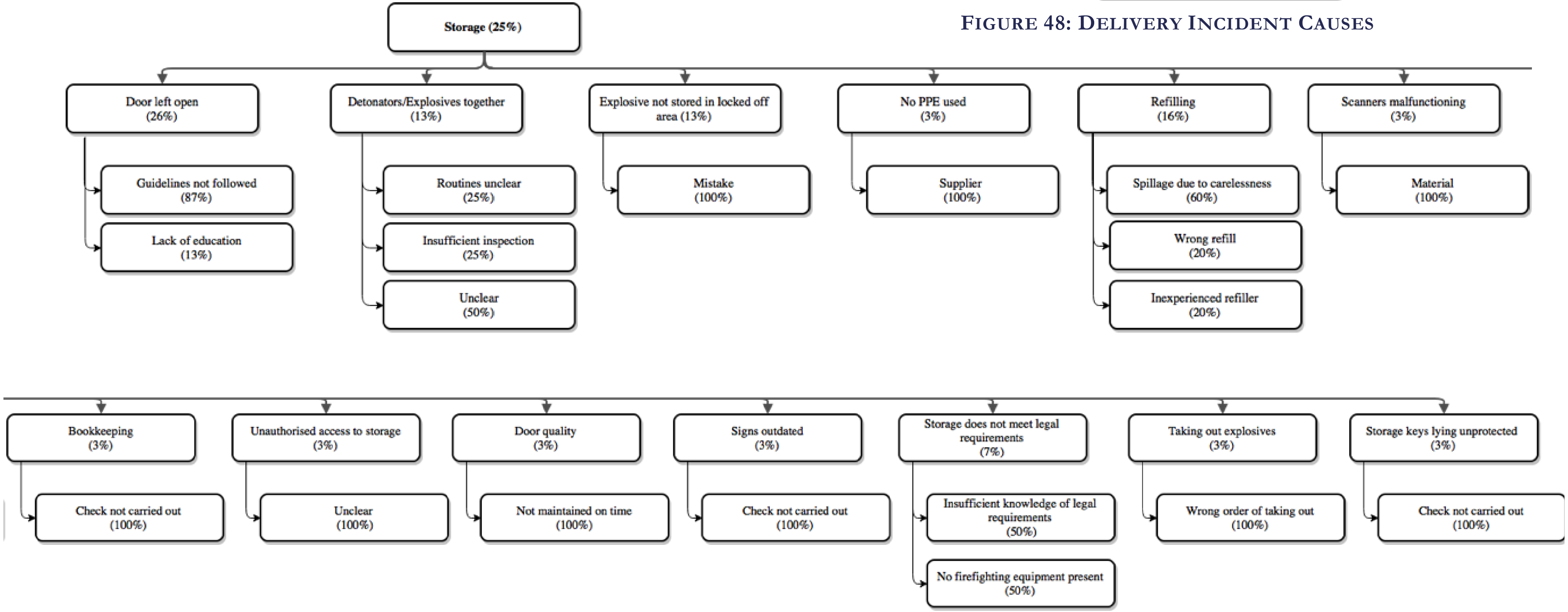
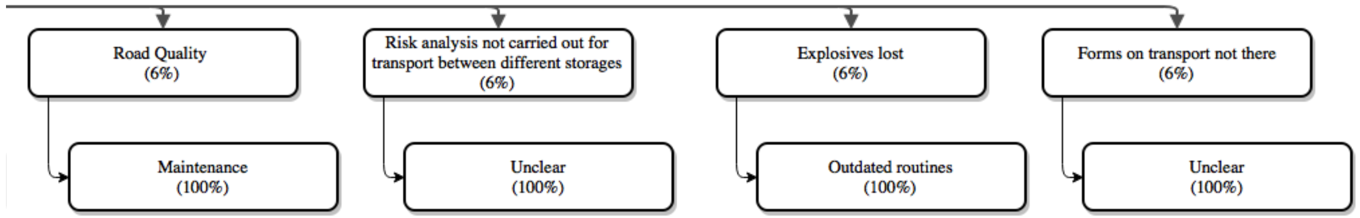


FIGURE 47: STORAGE INCIDENT CAUSES



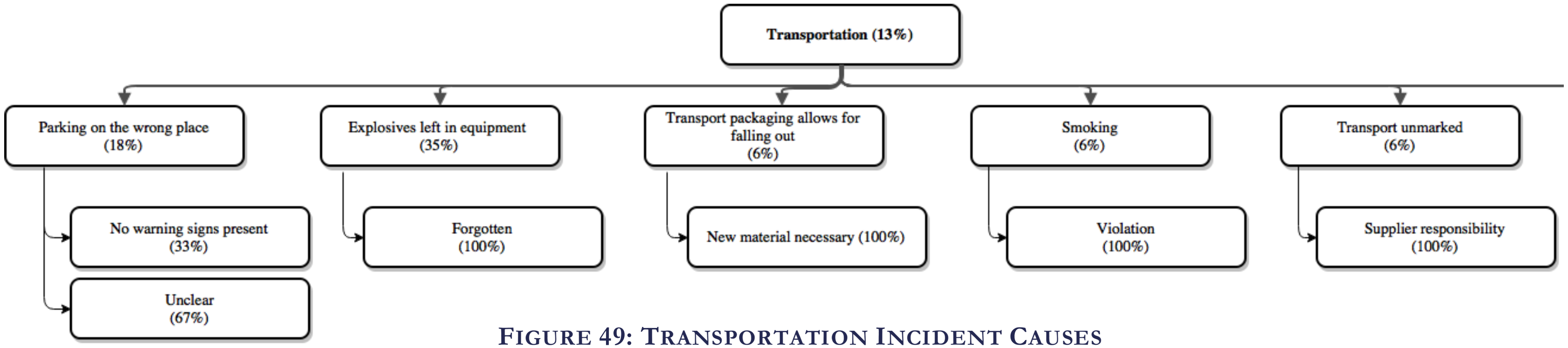


FIGURE 49: TRANSPORTATION INCIDENT CAUSES

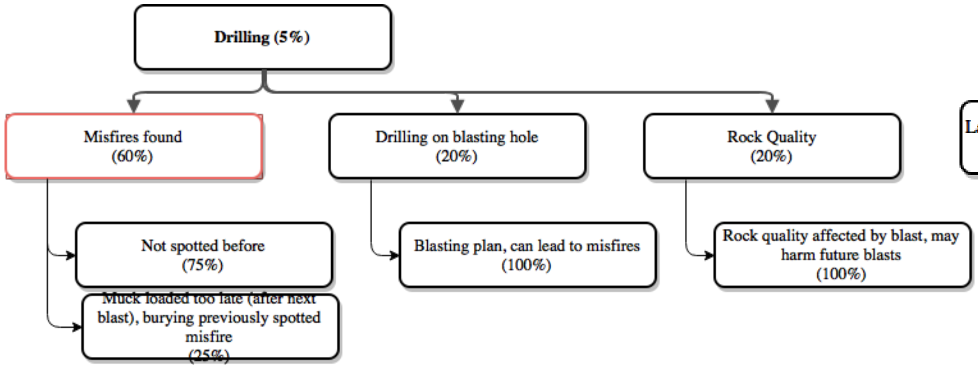


FIGURE 51: DRILLING INCIDENT CAUSES

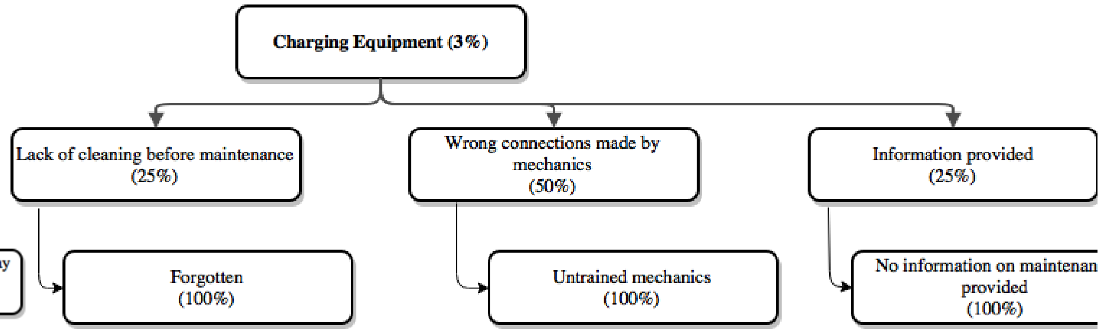


FIGURE 50: CHARGINGEQUIPMENT INCIDENT CAUSES

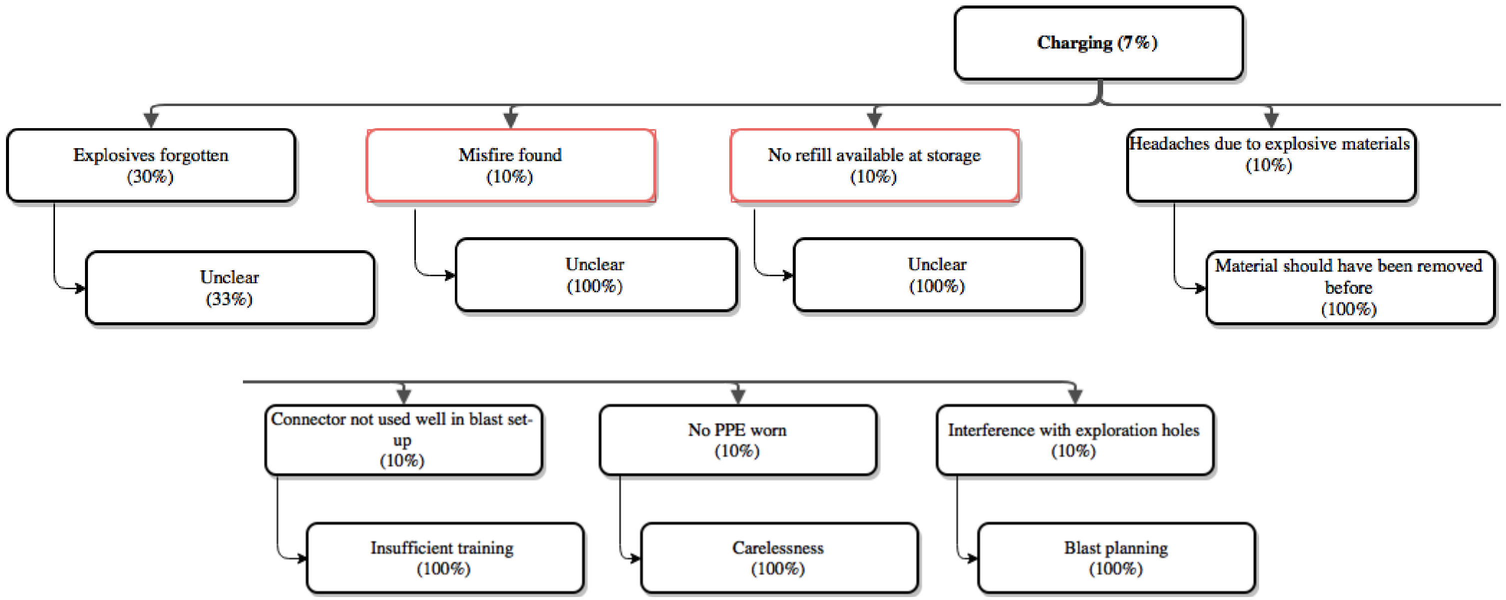


FIGURE 52: CHARGING INCIDENT CAUSES

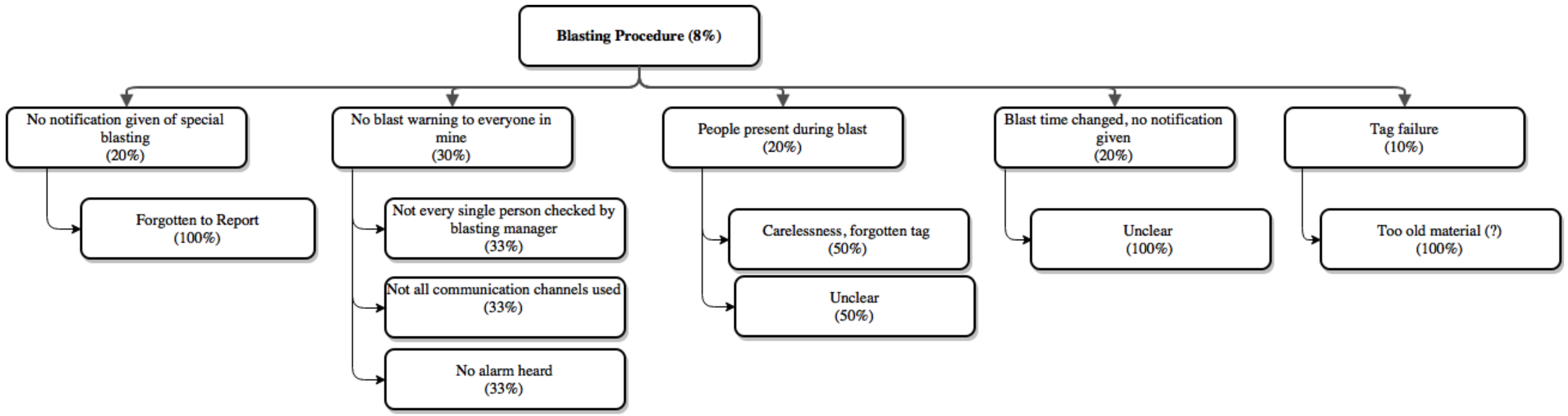


FIGURE 53: BLASTING PROCEDURE INCIDENT CAUSES

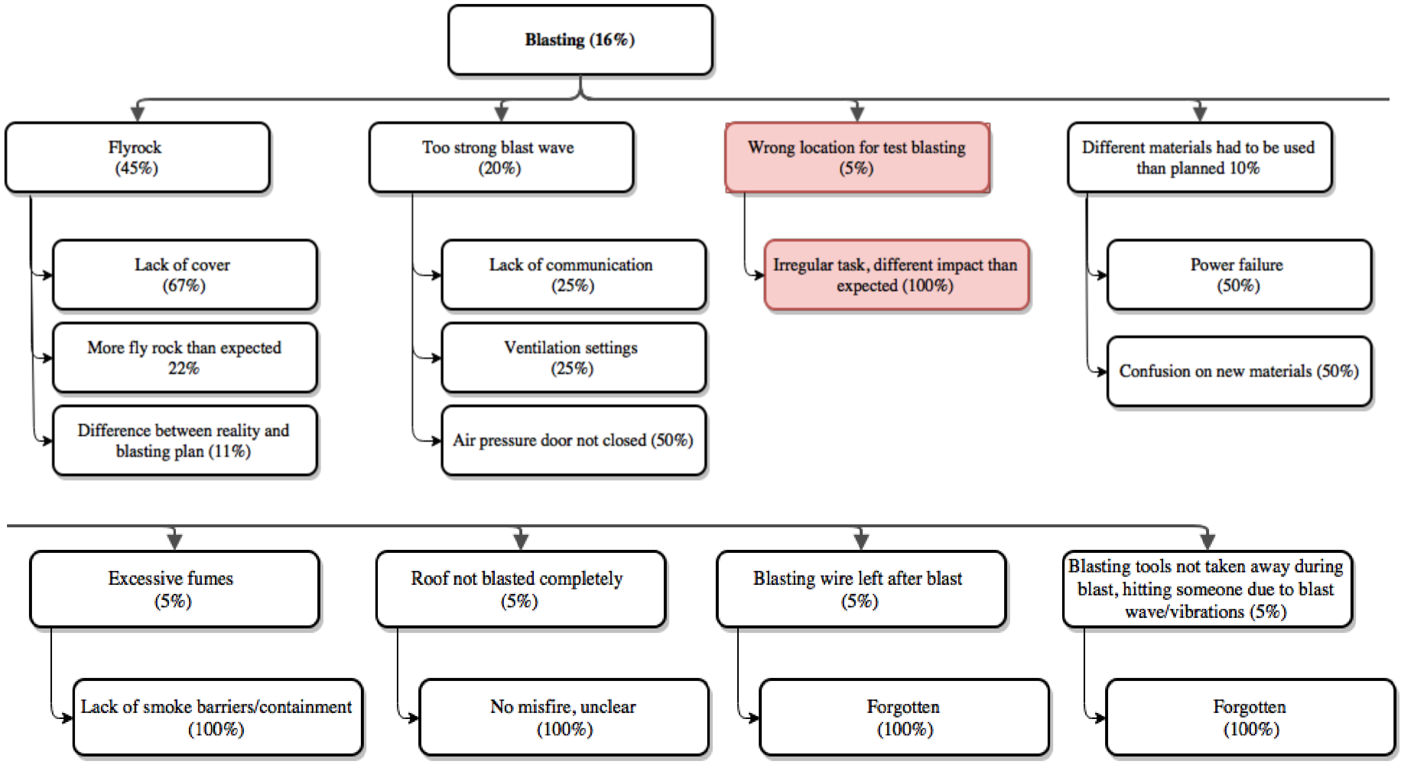


FIGURE 54: BLASTING INCIDENT CAUSES

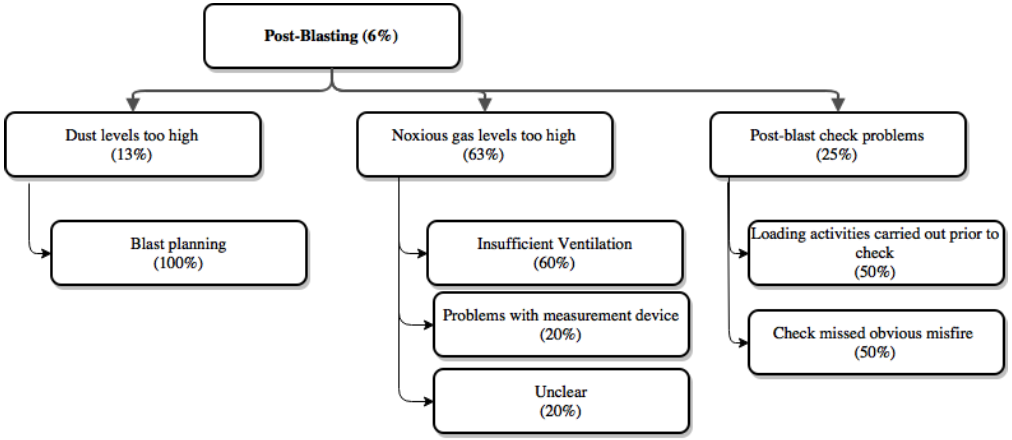


FIGURE 55: POST-BLASTING INCIDENT CAUSES

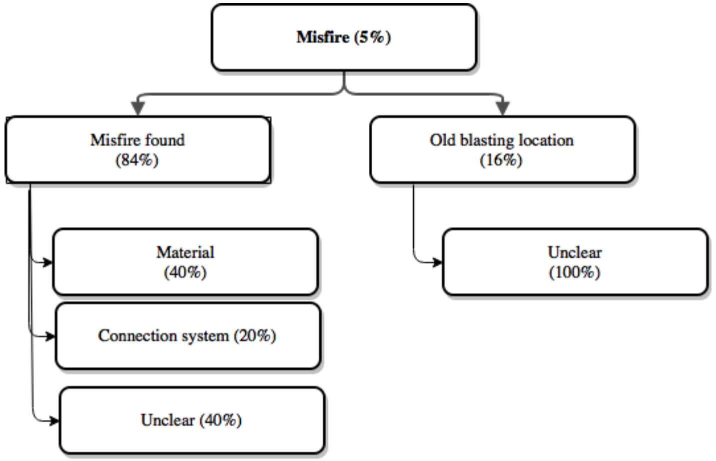


FIGURE 56: MISFIRE INCIDENT CAUSES

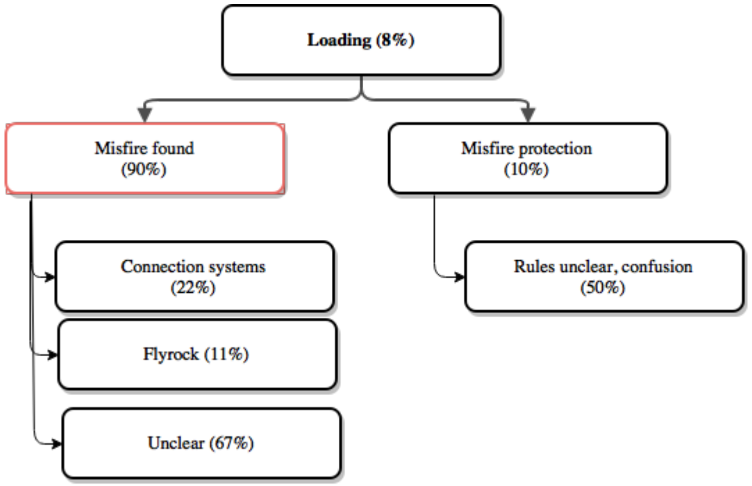


FIGURE 57: LOADING INCIDENT CAUSES

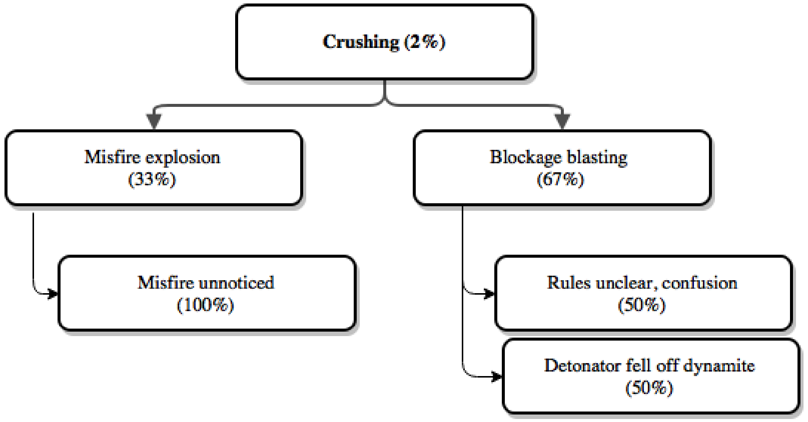


FIGURE 58: CRUSHING INCIDENT CAUSES

P. Suspected Causes of Incidents in Surface Mines

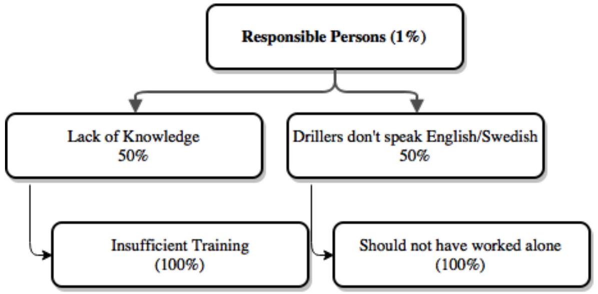


FIGURE 61: RESPONSIBLE PERSON INCIDENT CAUSES

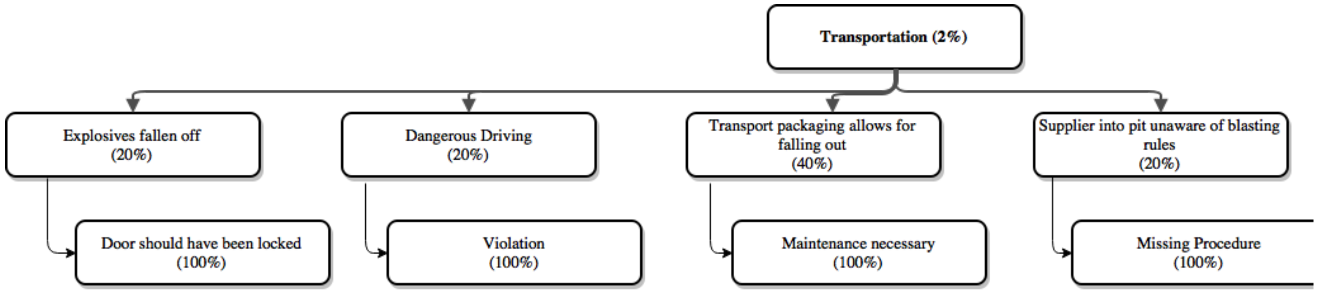


FIGURE 60: TRANSPORTATION INCIDENT CAUSES

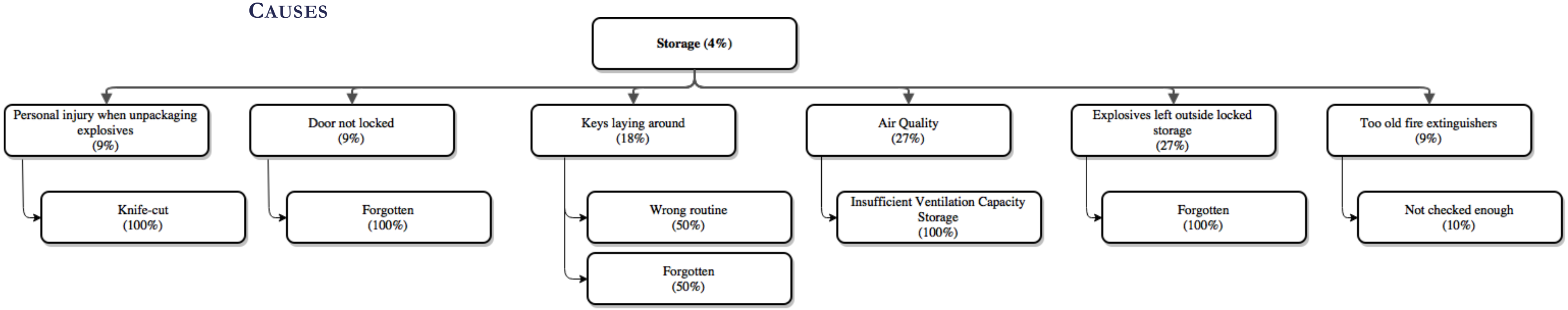


FIGURE 59: STORAGE INCIDENT CAUSES

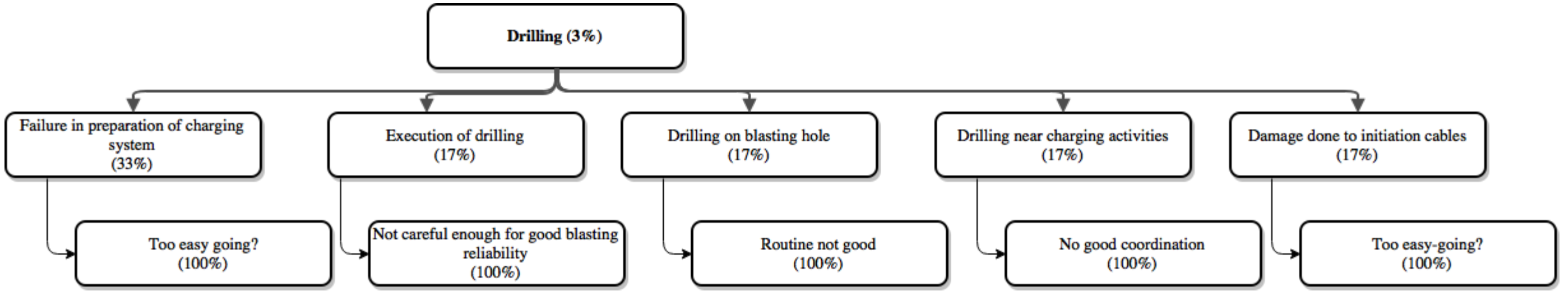


FIGURE 65: DRILLING INCIDENT CAUSES

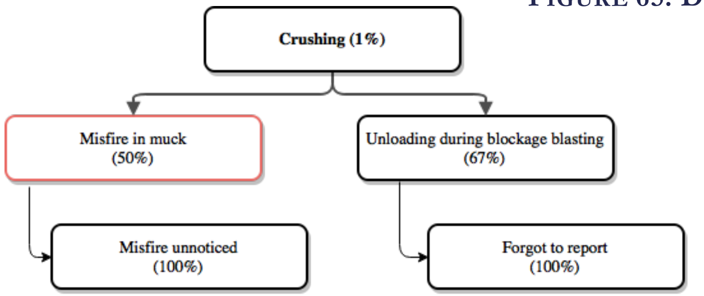


FIGURE 64: CRUSHING INCIDENT CASES

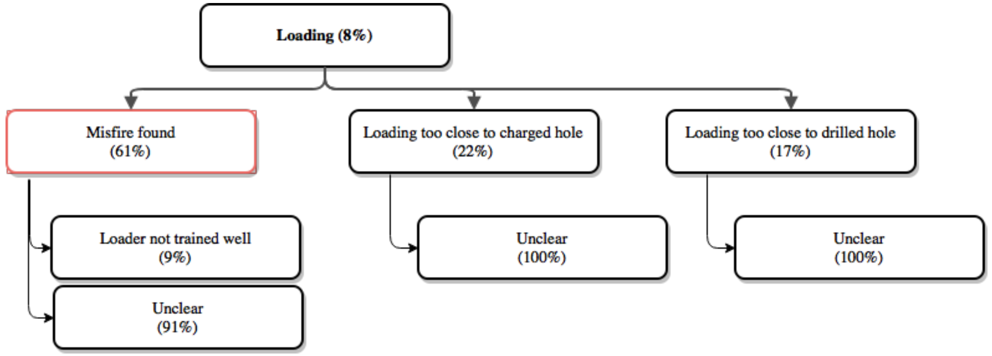


FIGURE 63: LOADING INCIDENT CAUSES

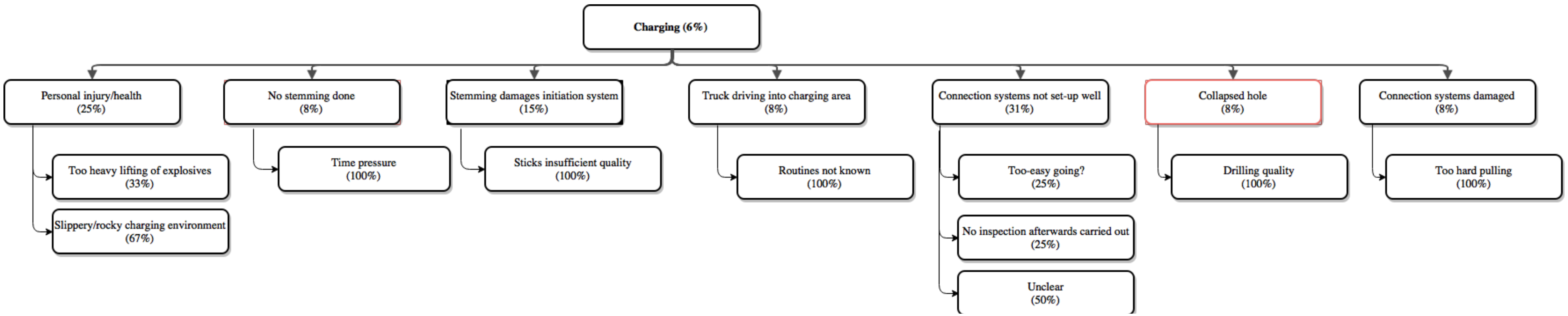


FIGURE 62: CHARGING INCIDENT CAUSES

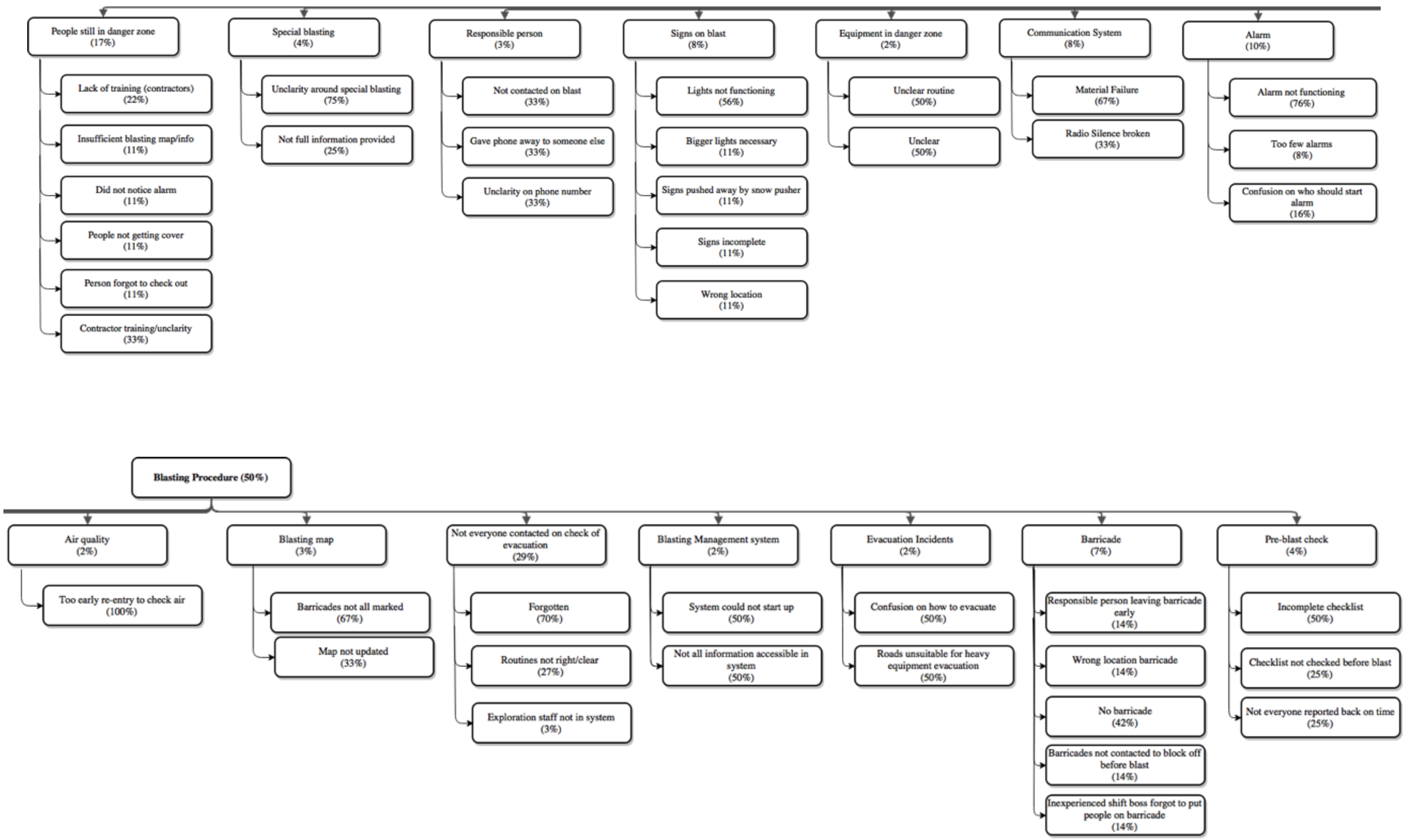


FIGURE 66: BLASTING PROCEDURE INCIDENT CAUSES

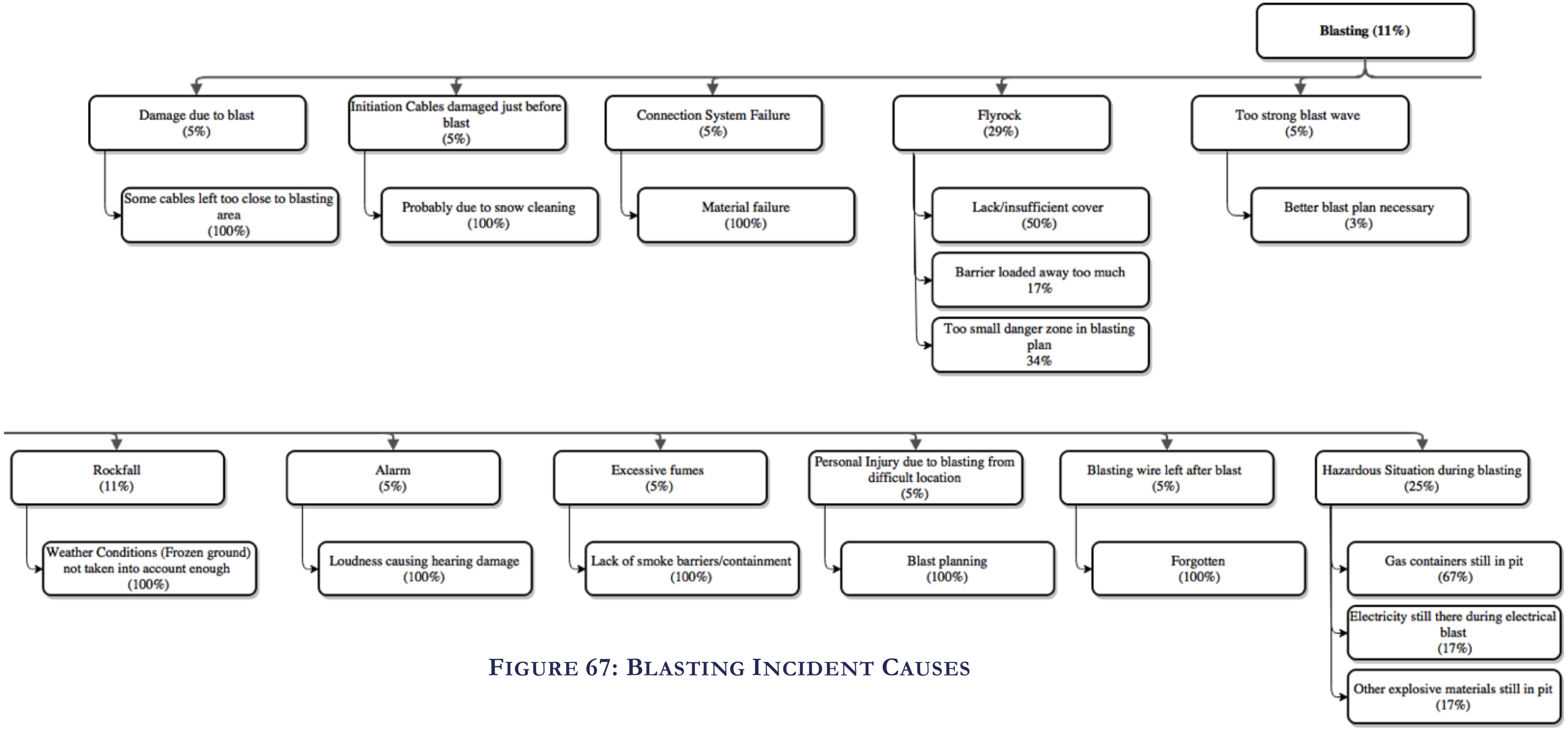


FIGURE 67: BLASTING INCIDENT CAUSES

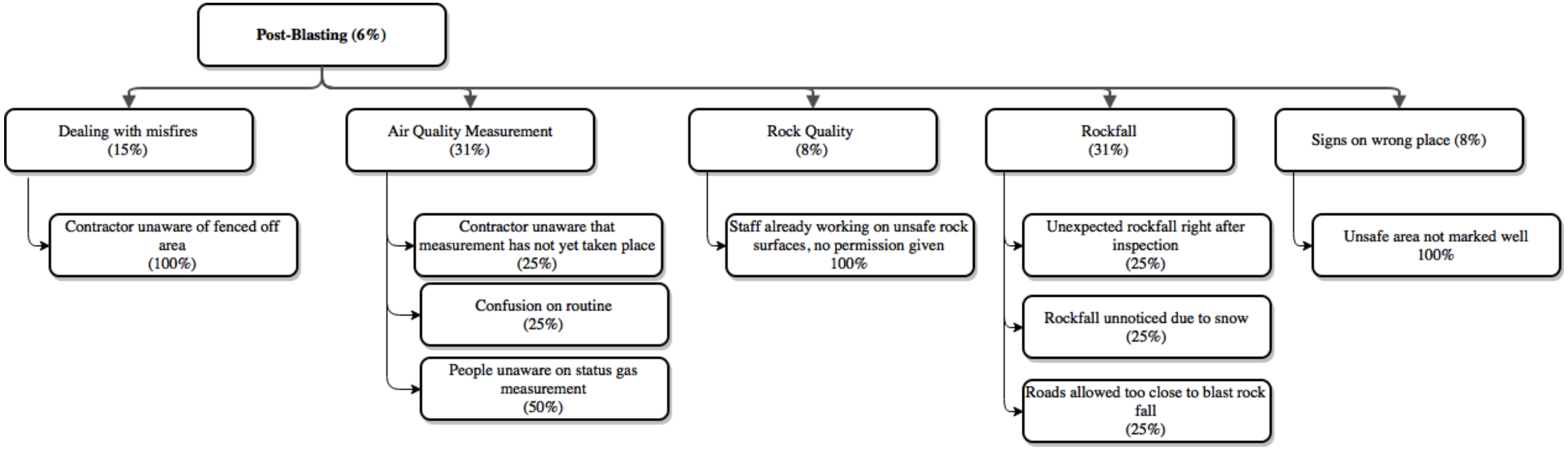


FIGURE 69: POST-BLASTING INCIDENT CAUSES

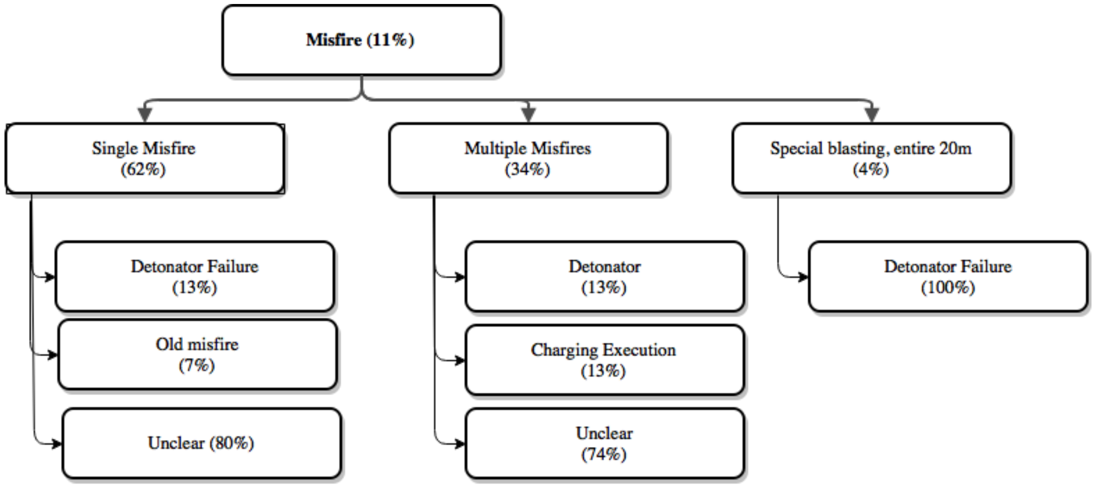


FIGURE 68: MISFIRE INCIDENT CAUSES

Q. Fault Trees

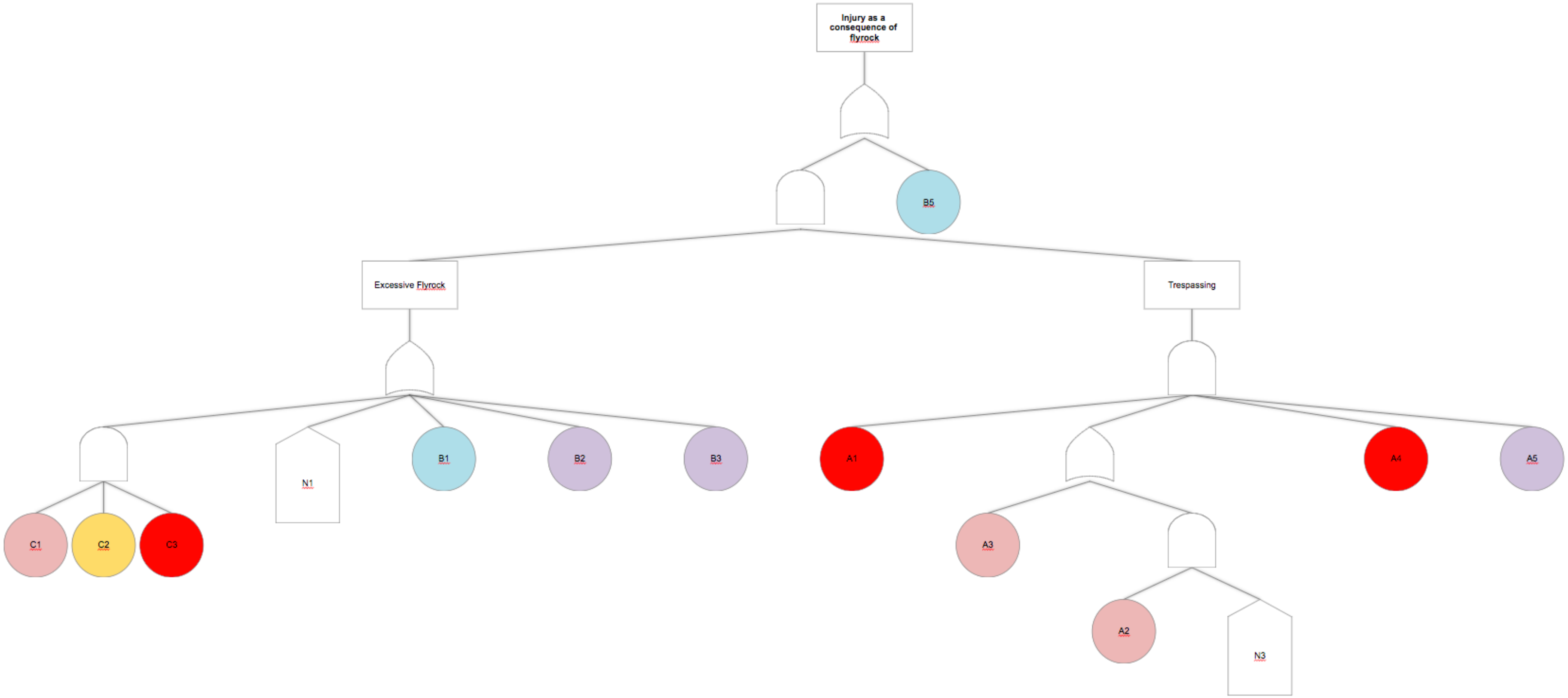


FIGURE 70: FLYROCK FAULT TREE ANALYSIS

Minimum cuts:

{B5}
{C1 C2 C3 A1 A3 A4 A5} {N1 A1 A3 A4 A5} {B1 A1 A3 A4 A5} {B2 A1 A3 A4 A5} {B3 A1 A3 A4 A5}
{C1 C2 C3 A1 A2 N3 A4 A5} {N1 A1 A2 N3 A4 A5} {B1 A1 A2 N3 A4 A5} {B2 A1 A2 N3 A4 A5} {B3 A1 A2 N3 A4 A5}

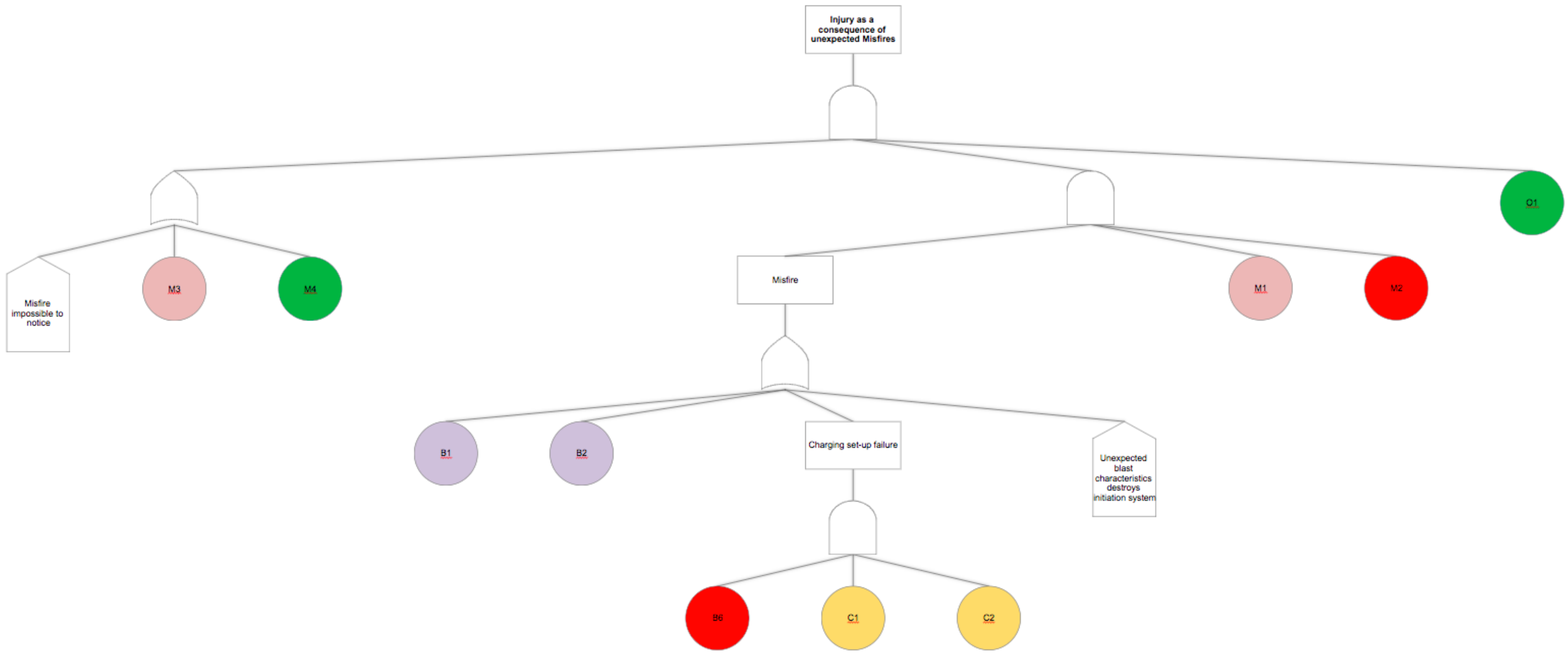


FIGURE 71: MISFIRE FAULT TREE ANALYSIS

Minimum cuts:

{N1 B1 M1 M2 O1}, {N1 B2 M1 M2 O1}, {N1 B6 C1 C2 M1 M2 O1}, {N1 N2 M1 M2 O1} {M3 B1 M1 M2 O1}, {M3 B2 M1 M2 O1}, {M3 B6 C1 C2 M1 M2 O1}, {M3 N2 M1 M2 O1} {M4 B1 M1 M2 O1}, {M4 B2 M1 M2 O1}, {M4 B6 C1 C2 M1 M2 O1}, {M4 N2 M1 M2 O1}

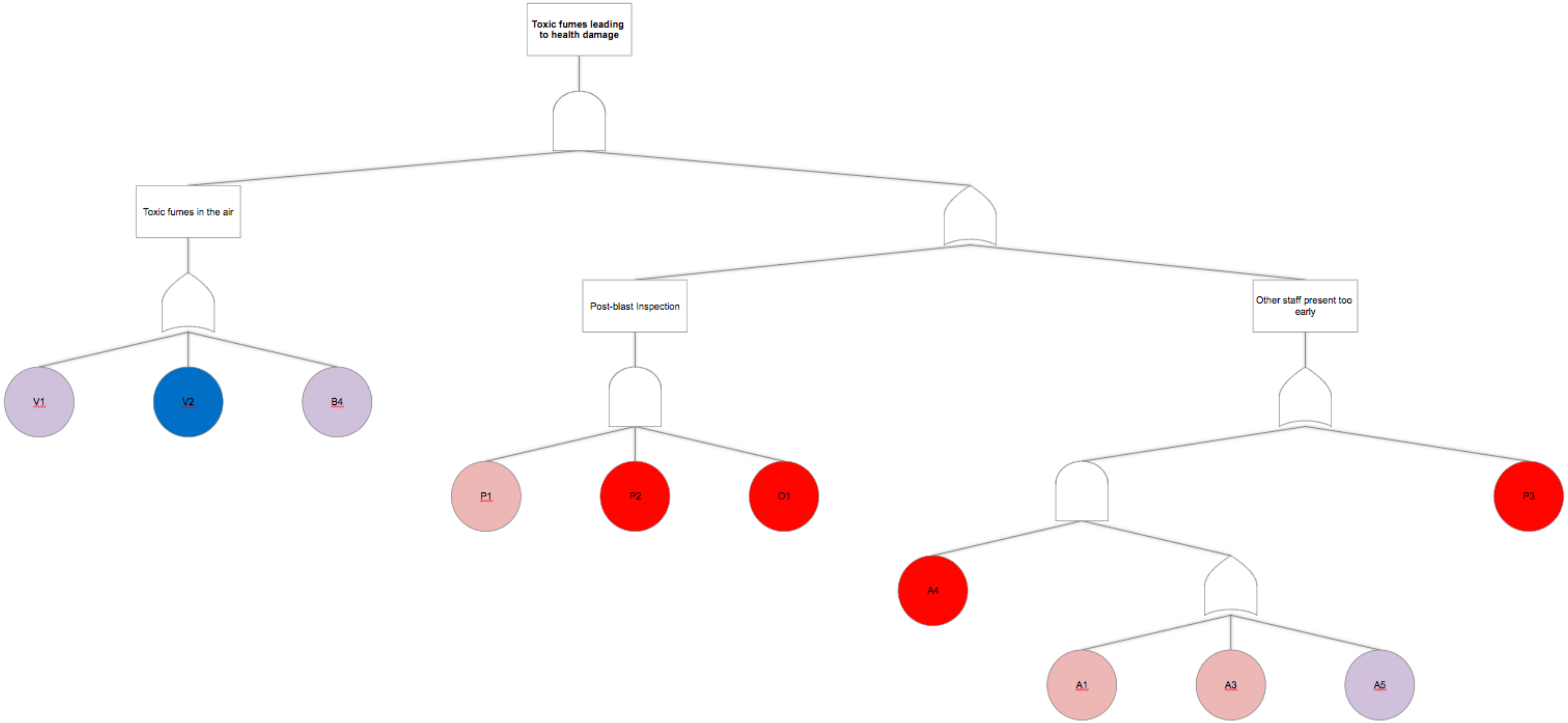


FIGURE 72: TOXIC FUMES FAULT TREE ANALYSIS

Minimum cuts:

{V1 P1 P2 O1} {V1 A4 A1} {V1 A4 A3} {V1 A4 A5} {V1 P3}
{V2 P1 P2 O1} {V2 A4 A1} {V2 A4 A3} {V2 A4 A5} {V2 P3}
{B4 P1 P2 O1} {B4 A4 A1} {B4 A4 A3} {B4 A4 A5} {B4 P3}

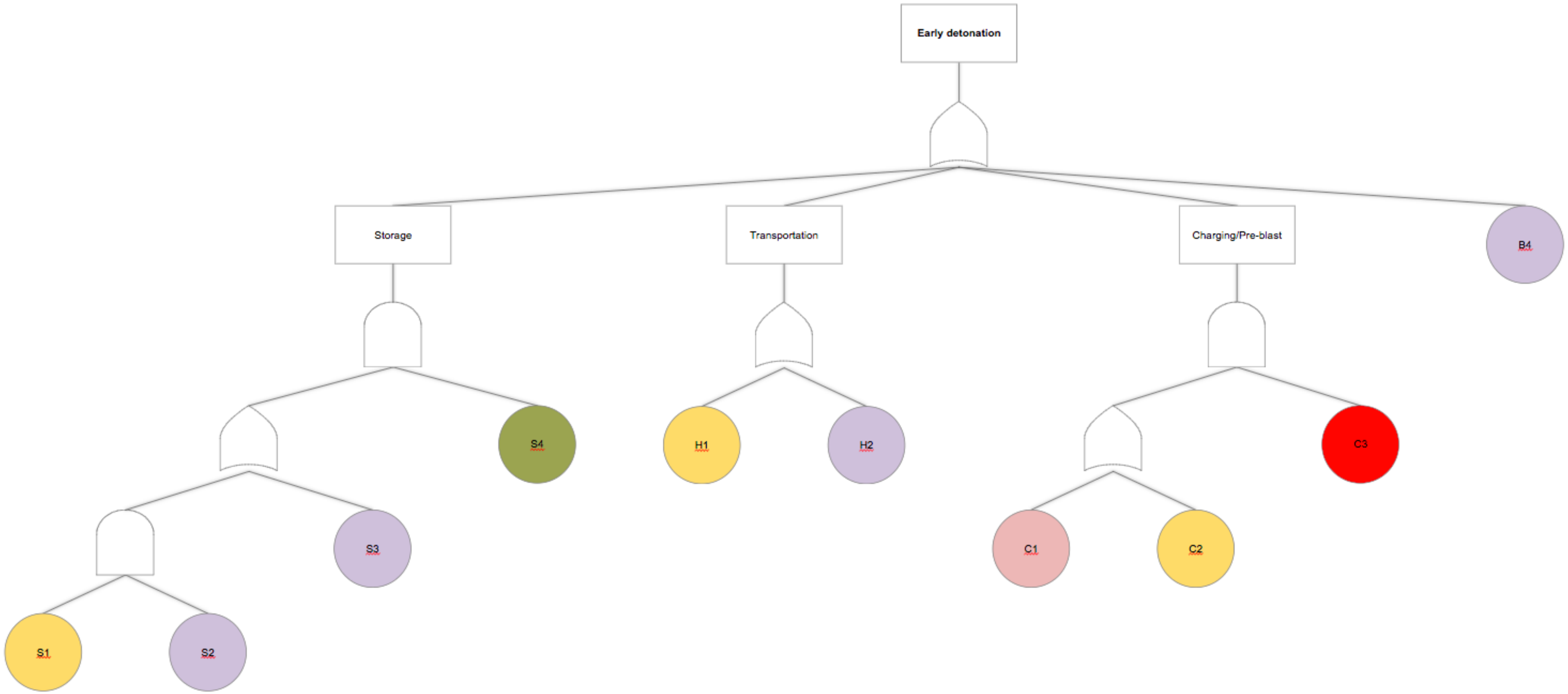


FIGURE 73: EARLY DETONATION

Minimal cuts:

{B4} {H1} {H2}
{S1 S2 S4} {S3 S4}
{C1 C3} {C2 C3}

R. Results Fault Trees

TABLE 52: RESULTING VALUES FAULT TREES

	B4	A4	O1	V1	V2	P3	A5	A3	C3	B5	H1	H2	M1	M2	N2	P1	P2	S4	A1
Fumes	4	9	3	4	4	3	3	3								3	3		3
I(I)	2	2,25	1,5	2	2	1,5	0,75	0,75								0,75	0,75		0,002929688
Misfires			12										12	12	3				
I(I)			0,75										0,75	0,75	0,75				
Flyrock		10					10	5	2	1									10
I(I)		0,625					0,625	0,3125	0,03125	1									0,625
Early Detonation	1								2		1	1						2	
I(I)	1								1		1	1						0,75	
SUM	**3**	**2,875**	**2,25**	**2**	**2**	**1,5**	**1,375**	**1,0625**	**1,03125**	**1**	**1**	**1**	**0,75**	**0,75**	**0,75**	**0,75**	**0,75**	**0,75**	**0,627929688**

	C1	C2	N1	B1	B2	M3	M4	S1	S2	S3	A2	N3	B3	B6
Fumes														
I(I)														
Misfires	3	3	4	3	3	4	4							3
I(I)	0,046875	0,046875	0,25	0,1875	0,1875	0,25	0,25							0,046875
Flyrock	2	2	2	2	2						5	5	2	
I(I)	0,03125	0,03125	0,125	0,125	0,125						0,15625	0,15625	0,125	
Early Detonation	1	1						1	1	1				
I(I)	0,5	0,5						0,25	0,25	0,25				
SUM	**0,578125**	**0,578125**	**0,375**	**0,3125**	**0,3125**	**0,25**	**0,25**	**0,25**	**0,25**	**0,25**	**0,15625**	**0,15625**	**0,125**	**0,046875**

S. Cause Statistics

TABLE 53: ELEMENT STATISTICS

Component	#	labda (/year)	Column1	Upper limit	/shift
A1: Blast area security measures implementation	5	0,5	39%	40%	5,46E-04
A2: General mine area security measures:	0	0	0%	3%	4,11E-05
A3: Awareness of blasting evacuation rules:	1	0,1	10%	11%	1,51E-04
A4: Checks on presence in wide blasting area:	2	0,2	18%	19%	2,62E-04
A5: Security systems for mine evacuation:	3	0,3	26%	27%	3,65E-04
B1: Blast design:	3	0,3	26%	27%	3,65E-04
B2: Detonator & initiation system reliability:	4	0,4	33%	34%	4,60E-04
B3: Detonator & initiation system performance:	1	0,1	10%	11%	1,51E-04
B4: Explosives & emulsion selection:	0	0	0%	3%	4,11E-05
B5: Danger zone estimation:	3	0,3	26%	27%	3,65E-04
B6: Pre-blast checks:	1	0,1	10%	11%	1,51E-04
B7: Missing cover:	6	0,6	45%	46%	6,24E-04
C1: Charging procedures:	0	0	0%	3%	4,11E-05
C2: Charging execution:	5	0,5016	39%	40%	5,47E-04
C3: Charging execution oversight	0	0	0%	3%	4,11E-05
C4: Charging equipment- wrong/insufficientexecution	3	0,3	26%	27%	3,65E-04
C5: Charging equipment- wrong information	1	0,1	10%	11%	1,51E-04
E1: Explosives outside dedicated area	11	1,1	67%	67%	9,17E-04
H1: Detonators transported together with explosives	0	0	0%	3%	4,11E-05
H2: Vehicles/road issues	3	0,3	26%	27%	3,65E-04
H3: Scanning/bookkeeping	4	0,397	33%	33%	4,57E-04
H4: Traffic violations/general irresponsible transport	7	0,7	50%	51%	6,95E-04

H5: Emulsion handling	8	0,8	55%	55%	
H6: Packaging/handling safety barriers	0	0	0%	3%	
M1: Misfire handling rules (Blasting Foremans)	0	0	0%	3%	
M2: Misfire handling execution (Blasting Foremans)	1	0,1	10%	11%	
M3: Misfire handling rules & training	1	0,1	10%	11%	
M4: Misfire handling execution for operators	1	0,1	10%	11%	
N1: Unexpected geology	1	0,1	10%	11%	
N2: Unexpected blast characteristics,	3	0,2603	23%	24%	
N3: External people moving into mine site	0	0	0%	3%	
N4: Misfire unnoticed since hidden	2	0,2	18%	19%	
O1: PPE usage	2	0,2	18%	19%	
O2: Protective gear on equipment	1	0,09	9%	10%	
P1: Post-blast inspection rules	0	0	0%	3%	
P2: Post-blast measurements/inspections execution	3	0,3	26%	27%	
P3: Post-blast return timing decision	1	0,1	10%	11%	
S1: Detonators and explosives stored separately	2	0,2145	19%	20%	
S2: Detonator storage stops external effects	0	0	0%	3%	
S3: Storage conditions	3	0,33	28%	29%	
S4: Storage inspections	0	0,026	3%	5%	
U1: Misfire unclear	14	1,4	75%	76%	
S5: Access to Storage	14	1,386	75%	75%	
V1: Ventilation capacity	5	0,5	39%	40%	
V2: Ventilation execution	3	0,3	26%	27%	
Y1: Blockage blasting rules	1	0,1	10%	11%	
Y2: Blockage blasting execution	1	0,1	10%	11%	

T. Reliability Bowtie Models

1. Early Detonation Bowtie Reliability Model

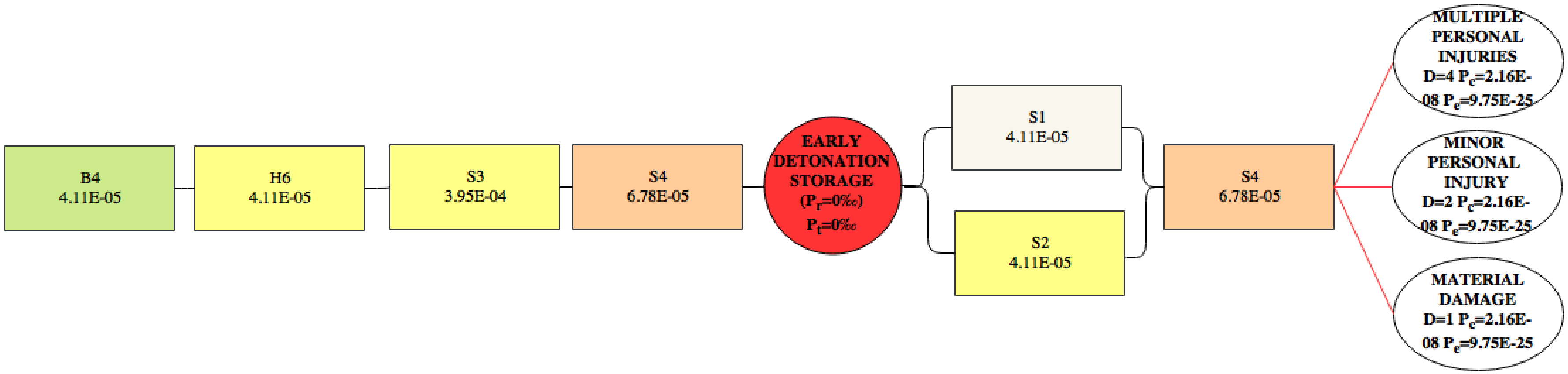


FIGURE 74: EARLY DETONATION STORAGE

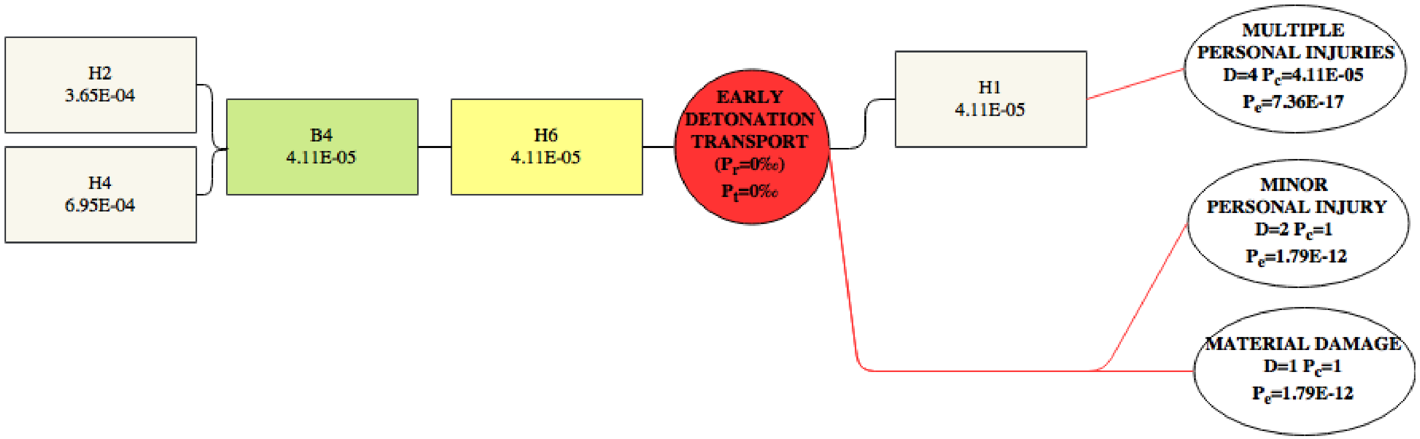


FIGURE 75: EARLY DETONATION TRANSPORT

2. Incomplete Detonation Bowtie Reliability Model

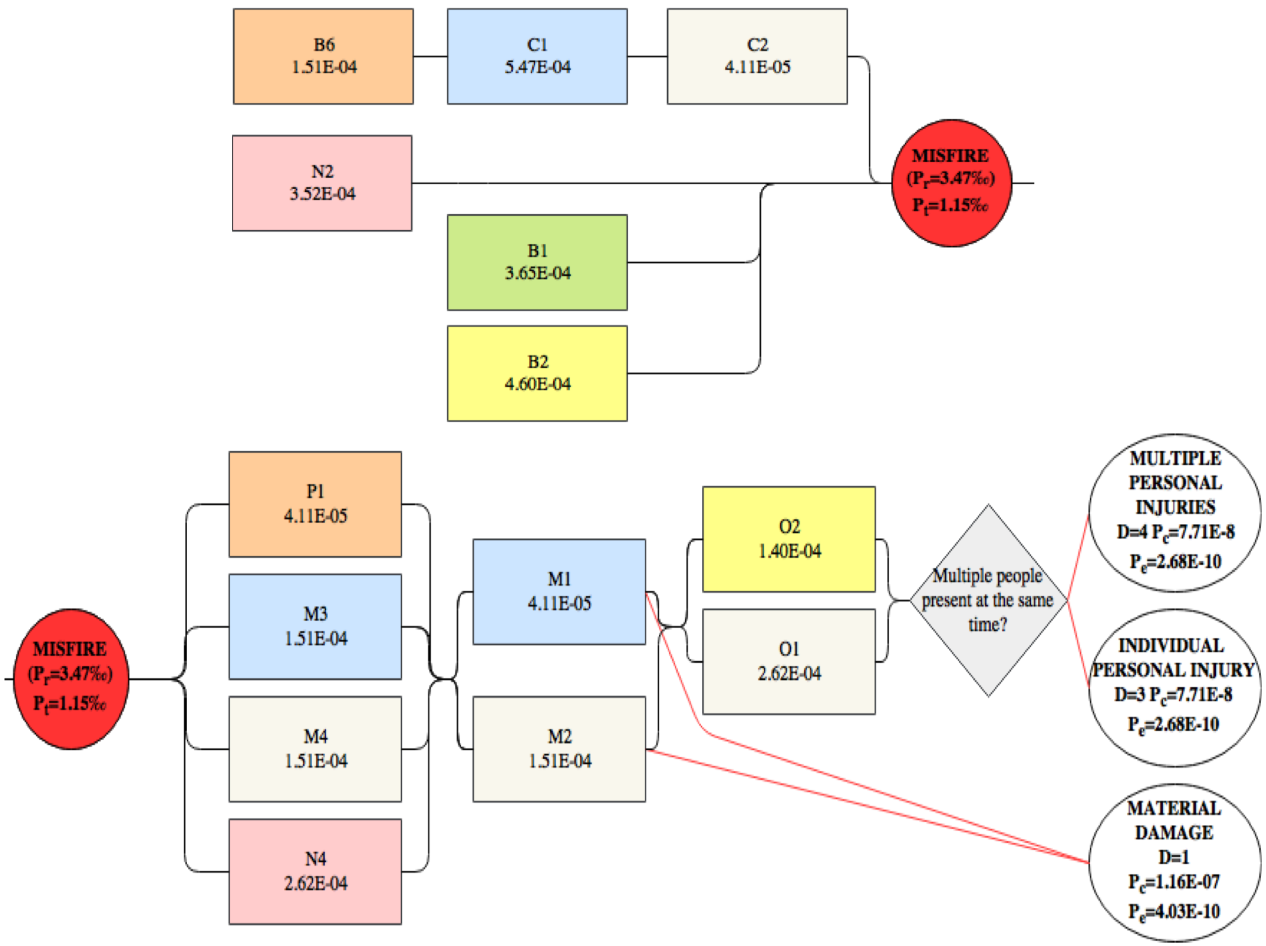


FIGURE 76: INCOMPLETE DETONATION BOWTIE RELIABILITY MODEL

3. Blast Effects Bowtie Reliability Models

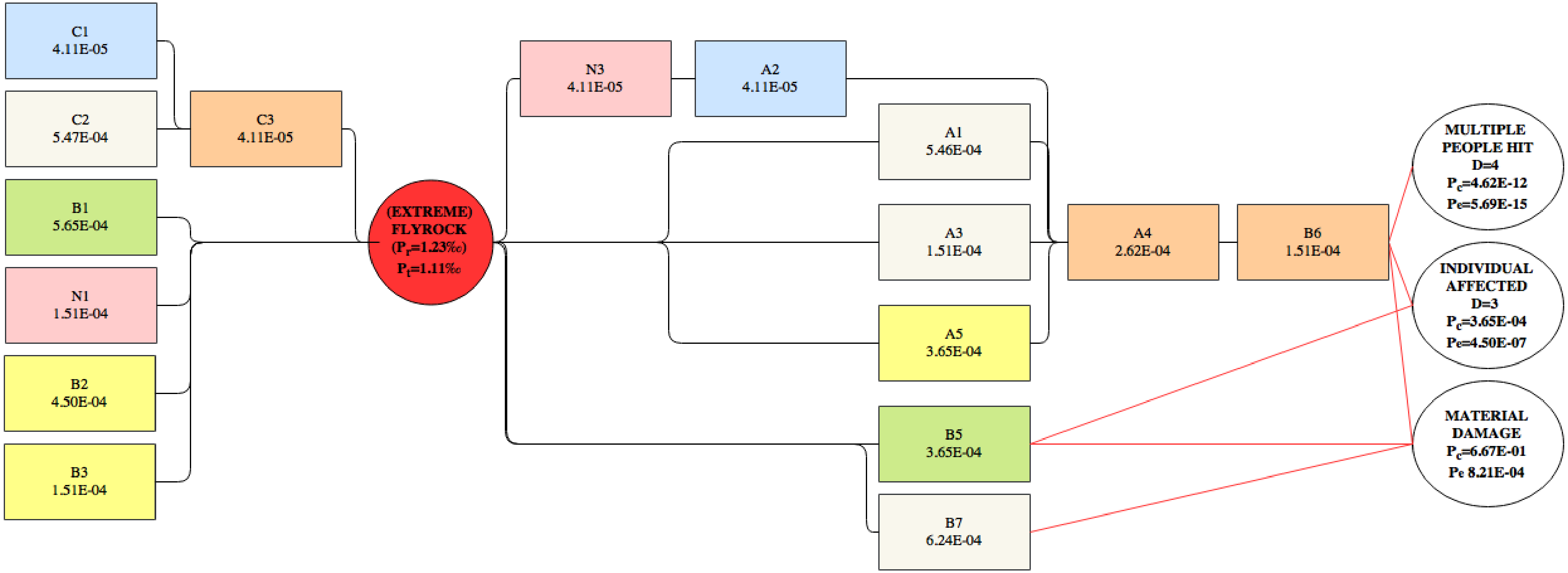


FIGURE 77: FLYROCK RELIABILITY BOWTIE MODEL

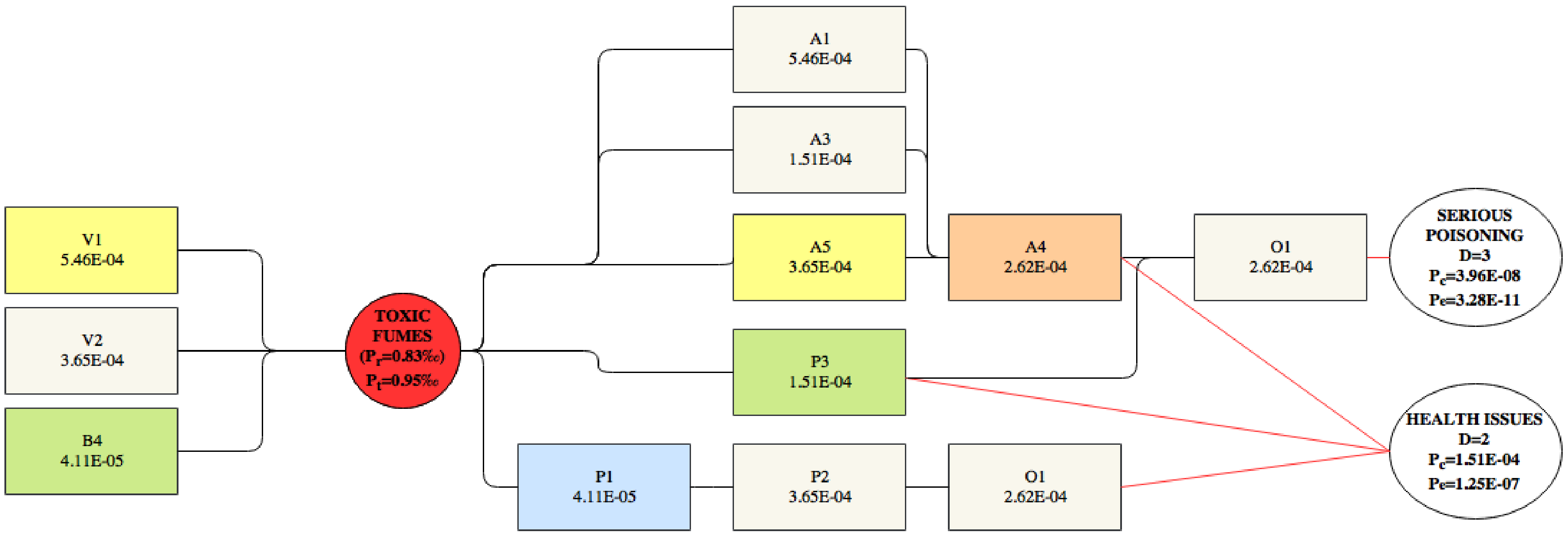


FIGURE 78: FUMES BOWTIE RELIABILITY MODEL

U. Root Cause Analyses using 5-Why Technique

Cover is Missing/Insufficient	Why?				
9 cases, 3 of which are red cases	Blasting impact not known to operators	Why?			
	No cover	Operators did not check blasting specs			
	Too small cover	No briefing to certain operators	Why?		
	Inappropriate cover	*Size blast*	Blasting routines not known	Why?	
		Timing blast	**Suspected**	Little experience with topic	Why?
				Only required at specific locations	Insufficient Practice
					Practice/repeat procedures on
Explosives Left outside dedicated area	Why?				blasting near vulnerable areas
16 cases, 8 of which are red cases	Forgotten during charging/transportatio	Why?			
	At equipment	Not taken along before lunch/end shift	Why?		
	At blast site	**suspected**	No checks/counting undertaken	Why?	
			suspected	No routine practice	Why?
				Normally tailored amount of explos	SOP's pay little attention to topic
					(see charging SOP's)
					Adapt SOP's to include standard
Door Storage left open/Keys accessible	Why?				checks of explosives going in/out
11 cases, 2 of which are red cases	Forgotten to close door				before and after charging works
	Key left in the wrong place	Why?			
		Had to switch task quickly (8 cases)	Why?		
			Unclear responsibilities	Why?	
				Multiple types of people involved	Why?
					No dedicated powdermen
					Assign powdermen
Traffic Violations	Why?				
14 cases, 6 of which are red cases	Unawareness of nature transport				
	Non-compliance cars	Why?			
	Wrong signs	Broken parts not replaced			
	Explosives can fall out of car	Signs not put on	Why?		
			No clear assignment responsibility	Why?	
			(see charging SOP's)	Different responsibilities exist	Why?
				Maintenance, chargers, storage sta	Not thought of before
					Assign powdermen responsible on
					entire transport

FIGURE 79: 5-WHY'S TECHNIQUE APPLIED TO 4 MOST CONCERNING COMPONENTS

V. GHS

TABLE 54: GHS-TABLE WITH SYMBOLS

Hazard Division	Description	Pictogram[9]	Signal Word	Hazard Statement
1.1	Ammunition that has a mass explosion hazard.		▪ **Danger**	▪ Mass explosion hazard.
1.2	Ammunition that has a projection hazard but not a mass explosion hazard.		▪ **Danger**	▪ Severe projection hazard.
1.2.1	Ammunition that has a projection hazard but not a mass explosion hazard. (More hazardous items of HD 1.2, which give large fragments over an extended range).		▪ **Danger**	▪
1.2.2	Ammunition that has a projection hazard but not a mass explosion hazard. (The less hazardous items of HD 1.2, which give smaller fragments of limited range).		▪ **Danger**	▪
1.2.3	Ammunition that exhibit at most an explosion reaction during sympathetic reaction testing and a burning reaction in bullet impact and heating tests.[10]		▪ **Danger**	▪
1.3	Ammunition that has a fire hazard and either a minor blast hazard or a minor projection hazard or both, but not a mass explosion hazard.		▪ **Danger**	▪ Fire, blast or projection hazard.
1.3.1	Ammunition that has a fire hazard and either a minor blast hazard or a minor projection hazard or both, but not a mass explosion hazard. (The more hazardous items with mass fire hazard and considerable thermal radiation).		▪ **Danger**	▪
1.3.2	Ammunition that has a fire hazard and either a minor blast hazard or a minor projection hazard or both, but not a mass explosion hazard. (The less hazardous items that burn sporadically).		▪ **Danger**	▪

Hazard Division	Description	Pictogram[9]	Signal Word	Hazard Statement
1.4	Ammunition that presents no significant hazard.		▪ **Warning**	▪ Fire or projection hazard.
1.5	Very insensitive substances, which have a mass explosion hazard.		▪ **Danger**	▪ May mass explode in fire.
1.6	Extremely insensitive articles which do not have a mass explosion hazard.		▪ *No Signal Word*	▪ *No hazard statement.*
Unstable Explosive	Any explosive in an unstable condition.	*No pictogram assigned as the transport of unstable explosive is not permitted.*	▪ **Danger**	▪ Unstable explosive.