Safe and Efficient Blasting in Quarries

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Flyrock Problem

Damage to life, equipment and buildings can be severe if flyrock becomes a problem. With good blasting practice and well supervised charging of blastholes, the chances of excessive flyrock are negligible.

Flyrock occurs where explosion energy is vented violently into the atmosphere and propels rocks in front of it. Flyrock can occur in either primary or secondary blasting.

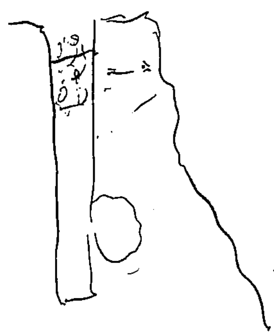
In primary blasting, flyrock occurs where the burden or stemming length is too small or where blastholes are initiated out of sequence. Drilling inaccuracies or incorrect blasthole angles may cause the burdens to be larger or smaller than those planned. If the burden is too large, poor breakage results and ground vibrations are higher. If the burden is too small, noise, airblast and flyrock can occur. It is important, therefore, to ensure that the blasthole is correctly positioned. The extra time taken in correctly positioning and aligning the drill will prevent such problems.

Flyrock also occurs where the stemming column is too short. As a rule of thumb, the stemming length should be not less than two-thirds the burden distance. If it is possible to use a longer stemming column, this is preferable. However, care must be taken to ensure that the stemming column is not too long as oversize collar rock may result.

Where loose-poured ANFO (or another bulk blasting agent) is used in the upper part of the blasthole, care must be taken that the blasthole is not accidentally overcharged. The explosive column rise should be monitored during the charging operations.

The probability of flyrock is increased where blastholes are initiated out of sequence and a charge is forced to crater upwards. This possibility can be eliminated by carefully checking the initiation sequence before firing.

Flyrock can result from secondary blasting by popping. This nuisance will occur if the charge is too heavy or if the blasthole is incorrectly positioned. The blasthole should be directed into the centre of the boulder. Deviations in the blasthole may cause the charge to be placed too close to one of the surfaces of the rock. Once the blasthole reaches slightly past the centre of the rock, a charge not greater than about 60 g/m^3 of rock should be used. This charge should result in the rock being cracked open into manageable sized lumps without flyrock problems.

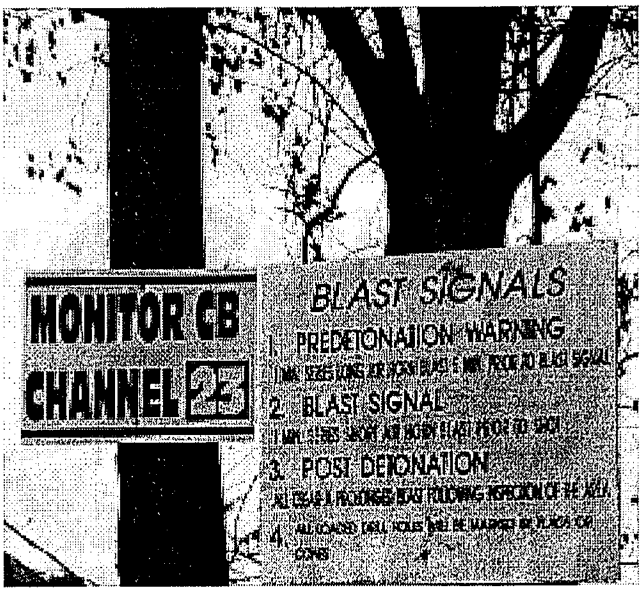


Securing the Blast Site to Prevent Blasting Related Injuries

Blasting Safety - Revisiting Site Security

By T. S. Bajpayee, Harry C. Verakis, and Thomas E. Lobb

This article examines the factors related to injuries due to inadequate blasting shelters and blast area security, and identifies mitigation techniques. The key concepts are: (a) accurate determination of the bounds of the blast area, (b) clearing employees from the blast area, (c) effective access control, (d) use of adequate blasting shelters, (e) efficient communications, and (f) training. Fundamentals are reviewed with an emphasis on analyzing task elements and identifying root causes for selected blasting accidents. Mitigating techniques are presented along with discussions and examples.



Introduction

Domestic consumption of explosives during 2003 was approximately 5.05 billion pounds and about 89% (4.5 billion pounds) was used by the mining industry [USGS, 2004]. Blasting is a great tool in fragmenting and loosening rock and other materials for easier handling and removal by mining equipment. However, blasting creates serious concerns for the mine operators and miners in terms of blast area security.

One thousand one hundred and thirty-one blasting-related injuries were reported by the mining industry during the period 1978-2003 [Verakis & Lobb, 2003 with updated data]. Blast area security accounted for 50.1% of these injuries followed by premature blast (11.4%), flyrock (10.8%), misfires (9.9%), and fumes (8.5%). **Figure 1** shows the distribution of blasting-related injuries during 1978-2003.

During 1978-2003, blast area security accounted for 41% of all blasting related injuries reported by surface mines. The corresponding figure for underground mines was 56%. The data indicates that injuries from inadequate blast area security are more prevalent in underground blasting.

Verakis & Lobb [2003 with updated data] analyzed more recent data (1994-2003) to assess any changes in the role of blast area security. During this period, blast area security accounted for nearly 41.6% of all blasting-related injuries in surface and underground mines. **Figure 1** shows the distribution of blasting-related injuries during 1994-2003. Injuries due to inadequate blast area security continue to be a major safety concern.

The injuries discussed in this article, primarily result from failure to identify and clear the blast area, inadequate guarding, failure to communicate or follow instruc-

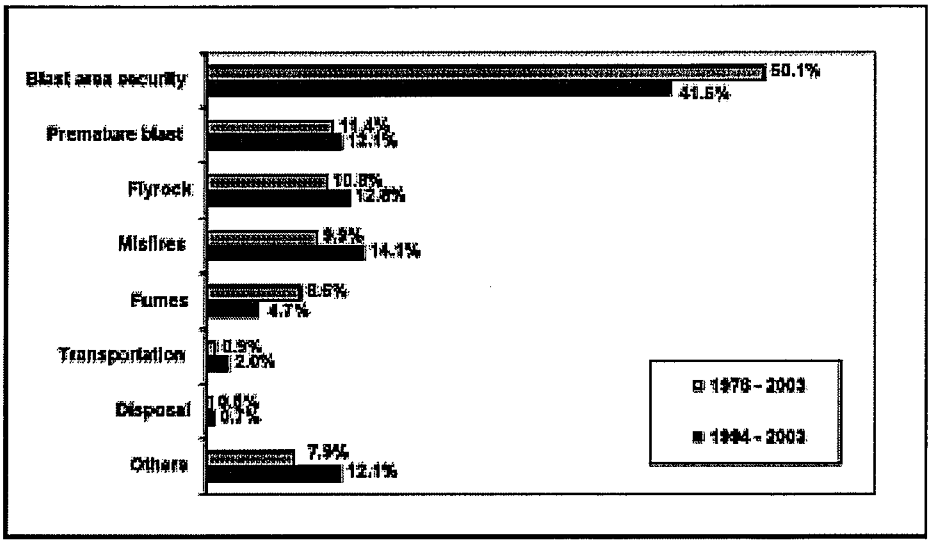


Figure 1. Distribution of blasting-related injuries in the mining industry.

tions, and inadequate or improper cover. Compliance to an effective blast area security protocol plays a key role in preventing injuries to miners, visitors, neighbors, and trespassers.

Blast Area

One of the greatest challenges, which a blaster faces in mining and construction blasting, is to accurately determine the bounds of the blast area. This is particularly true in geologically disturbed rock. A blaster's decision in estimating the bounds of the blast area is greatly influenced by the engineering design of the blast, geology of the blast, regulatory requirements, and company policy. Schneider [1995] stated that a blaster must make an estimate of the maximum possible distance flyrock could travel from a shot. Furthermore, a blaster should not assume that a shot being fired will behave like other shots previously fired at the same operation.

For surface and underground metal-nonmetal mines, Title 30 Code of Federal Regulations (30 CFR) § 56.2 and § 57.2 defines blast area as the area near blasting operations in which concussion or flying material may cause injury. The following factors shall be considered to determine the blast area:

- Geology or material to be blasted,
- Blast pattern,
- Burden, depth, diameter, and angle of the holes,
- Blasting experience of the mine,
- Delay systems, powder factor, and pounds per delay,
- Type and amount of explosive material, and
- Type and amount of stemming.

The Federal Office of Surface Mining (OSM) regulations [30 CFR § 816.67 and 817.67] help to characterize the bounds of the blast area by specifying that flyrock shall not be cast from the blasting site-

- More than one-half the distance to the nearest dwelling or other occupied structure,
- Beyond the area of control required under 30 CFR § 816.66(c), or
- Beyond the permit boundary.

Similar requirements are prescribed by many coal mining states such as Colorado, Illinois, Kentucky, New Mexico, Ohio, Pennsylvania, Utah, Virginia, West Virginia, and Wyoming.

The bounds of a blast area should be adequately determined for each blast. Flyrock could travel beyond an inadequately defined blast area and cause injury. In Campbell County, TN, flyrock traveled beyond the blast area resulting in a fatal injury to a motorist traveling on interstate 75 [Shea & Clark, 1998]. The bounds of the blast area were not adequately determined for this blast. In a coal mine blast, flyrock traveled 900 feet and landed beyond the permit boundary causing a fatal injury [MSHA, 1990a]. During a construction blasting operation near Marlboro, NY, flyrock was showered on passing motorists on Route 9 W about 180 feet from the blast pit. This incident resulted in property damage and injury. There are numerous instances where the bounds of the blast area were not accurately determined, resulting in injury, or property damage. There are many cases of close calls where accidents were narrowly missed.

Blast area security in underground mines is much more complex than surface blasting. It requires a thorough understanding of ventilation, roof characteristics, and the roof control plan of the mine. The bounds of the blast area need to be adjusted accordingly. Blasting could cause ground fall in adjacent entries, and exposure to smoke, dust, or toxic fumes. All employees must be removed from such adjacent entries or other affected airways. Post-blast roof fall and exposure to fumes have caused several accidents.

Fundamental task-elements of a blast area security system

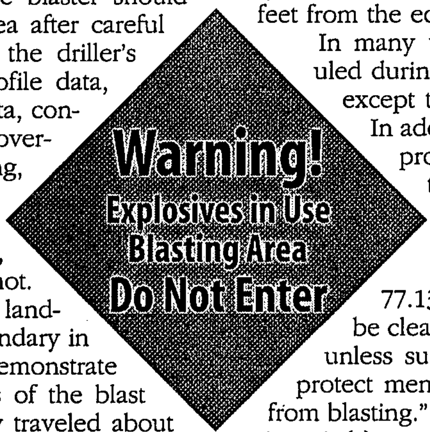
A blast area security system is the means by which a mine operator prevents injury to people or damage to equipment when a scheduled blast is detonated [Fletcher

& D'Andrea, 1987]. Most blasting accidents in surface and underground mines occur during scheduled blasting and are due to inadequate blast area security. MSHA accident data reveal that the blasting crew and blasters often suffer serious injuries due to inadequacy of the shelter used for protection from blasts.

The functional task-elements of a blast area security system are (a) estimate the flyrock zone based on shot conditions, and add a factor of safety to determine the bounds of the blast area, (b) clear all employees, contractors, and visitors from the blast area, (c) post guards at the access points to prevent unauthorized entry, (d) use adequate blasting shelters for employees whose presence is required in the blast area, and (e) maintain effective communication with guards, mine foreman, and other employees.

Determination of the bounds of the blast area

Correct assessment of the bounds of the blast area is the first step in ensuring safety. The blaster should determine the bounds of the blast area after careful consideration of information such as the driller's log, blasthole deviation data, laser-profile data, slant of the holes, blasthole loading data, condition of the highwall, presence of overhangs, back-breaks, voids, weathering, and variations in the local geology. A blaster usually understands that in a given surface or underground mine, blast area could vary from shot to shot. There are many occurrences of flyrock landing beyond the property or permit boundary in surface blasting. Such occurrences demonstrate incorrect determination of the bounds of the blast area. Flyrock from a limestone quarry traveled about 930 ft and fatally injured a resident who was mowing grass on his property [MSHA 1990b].



In underground mining situations, the mine roof conditions, ground support system, and ventilation are important factors in determining the extent of the blast area. In an underground gold mining operation in Nevada, blasting in a drift caused a roof fall in another drift situated about 25 ft below the blasted drift. When the blast occurred in the upper drift, about 40 to 50 tons of material above the anchorage zone, supported by 6-ft roof bolts, fell as a result of the blast.

Blasting often causes redistribution of stress in pillars and roof area. The blast area should be extended beyond any suspected zones of weakness in roof strata. Often, blasting has caused roof falls in metal/nonmetal mines particularly in weak roofs. The blast area should be extended to mitigate such hazards. Roof and rib conditions need to be checked before any employee is allowed to enter the area.

Determining the bounds of a blast in an underground coal mine is an especially important task. Serious injuries and fatalities have occurred when a blast shoots through into an adjacent entry. In an underground coal mine in Floyd County, KY, three miners were injured when a face blasted into an outby crosscut [MSHA, 2003].

Removing employees from the blast area

All employees must be cleared from the blast area and removed to a safe location prior to any scheduled blasting. All equipment in the blast area should be removed or protected from flyrock damage, if possible. An accounting must be made for all employees to make sure that no one is left behind in the blast area. Arrangements should be made to ensure that no one can return back to the blast area prior to sounding an "all-clear" signal. Several accidents were caused because a blaster or a crew member was within the bounds of the blast area when the shot was fired. In a limestone mine, a blaster and a crane operator were standing on a top bench about 120 feet from the nearest blasthole. Upon firing the shot, the crane operator was fatally injured by flyrock [MSHA, 1994]. In a nonmetal mine, a visitor sustained serious injuries and a blaster-helper was fatally injured by flyrock [MSHA, 1990c]. They were within 150 feet from the edge of the blast.

In many underground mines, blasting is scheduled during a non-production shift when no one, except the blast crew, is present underground. In addition to mitigating blasting hazards, this procedure aids in providing additional time for clearing dust, smoke, and fumes from the underground workings.

For surface coal mines, 30 CFR § 77.1303 (h) requires that "All persons shall be cleared and removed from the blasting area unless suitable blasting shelters are provided to protect men endangered by concussion or flyrock from blasting." For underground coal mines, 30 CFR § 75.1325 (c) requires that "All persons shall leave the blasting area and each immediately adjacent working place where a hazard would be created by the blast, to an area that is around at least one corner from the blasting area. The qualified person shall ascertain that all persons are a safe distance from the blasting area." The onus of determining the safe distance rests on the qualified person, who in most cases is the blaster.

In brief, the message is **"Be alert and share information; know the blasting time, blast area and clearing procedure; and do not enter the blast area until an "all-clear" signal is sounded."**

Access control

To prevent unauthorized entry, guards should be posted at all access points leading to the blast area. Guards should physically remain at their duty stations until an "all-clear" signal is sounded. The guards must be attentive at all times to ensure the security of the blast. Additionally, barricades may be erected with signs in bold letters such as **"Warning! Explosives in Use, Blasting Area, Do Not Enter"** may be posted at all access points.

For surface and underground metal/nonmetal mines, 30 CFR § 56.6306 (e) (3) and 57.6306(e) (3) require that "All access routes to the blast area shall be guarded or barricaded to prevent the passage of persons or vehicles." 30 CFR § 56.6306 (a) and 57.6306(a) require that "When explosive materials or initiating systems are brought to the blast site, the blast site shall be attended; barricaded and posted with warning signs, such as "Danger," "Explosives," or "Keep Out;" or flagged against unauthorized entry."

The OSM regulations in 30 CFR § 816.66 (c) and 817.66 (c) require that "Access within the blast area shall be controlled to prevent presence of livestock or unauthorized persons during blasting and until an authorized representative of the operator has reasonably determined that - (a) No unusual hazards, such as imminent slides or undetonated charges, exist; and (b) Access to and travel within the blasting area can be safely resumed."

Several accidents were related to inadequate access-control to the blast area. A neighbor was fatally injured when he inadvertently entered the blast area through an access trail before the blast [MSHA, 1999]. Guards were not posted for access control. The access trail was in a wooded area and not visible from the firing station. This incident underscores the need for an effective access control protocol.

In a coal mine incident, a guard was posted to prevent entry to an access road leading to the blast area. Immediately before the blast, the guard left his post and went to the mine office for a brief visit. No barricade or notice of impending blasting was posted at this access road. In the meantime, a drill operator and a dozer operator, unaware of the impending blasting, entered the pit area in a pickup truck. Upon firing the shot, the dozer operator was fatally injured and the drill operator sustained injuries [MSHA, 1989a]. This accident could have been prevented by proper access control.

In another coal mine, a fatal accident occurred because an employee, who was cleared from the blast area, managed to return to the coal bench a few minutes before the scheduled blast. No one including the blaster noticed the employee returning to the coal bench. The victim was about 15 feet from the toe of a 43-feet highwall. Upon firing the overburden shot, the employee and his pickup truck were covered under a pile of blasted material [MSHA, 1989b]. It is important to make certain that no one can return back to the blast area until an "all-clear" signal is sounded.

Bennett's [1981] study indicated that access control and blast guarding suffer from poor procedures rather than from a lack of advanced technology. Management and employees should diligently strive to formulate and follow best site-specific procedures and policies to prevent injuries. A good access control procedure, upon implementation, can prevent injuries from blasting.

Blasting shelter

MSHA accident data indicate that blasters and helpers often suffer injuries due to lack of adequate shelter from a blast. The blaster and blasting crew are typically closer to a blast than other employees and need to use shelter that will provide complete protection from flyrock that may be projected from a blast. Flyrock from a blast can travel vertically and does not fall like gentle rain. Flyrock can also travel along a horizontal path and become a deadly projectile.

Unfortunately, there are too many instances that illustrate the use of inadequate protection from flyrock that was generated by a blast. For example, a blaster fired a charge inside a water well hole. A piece of flyrock traveled 208 feet and fatally struck the blaster on the head. The blaster was standing in the open and did not use some means of protection such as a blasting shelter.

In another incident in Pulaski County, KY, a blaster having sixteen years experience, took shelter behind a metal magazine of approximate size 4-feet high by 4-feet wide by 4-feet long and fired a charge. A piece of flyrock weighing about 15 pounds traveled 150 feet and fatally struck the blaster on the head [Schneider, 1995]. This accident could have been prevented by using an adequate blasting shelter.

Figure 2 shows a blasting shelter used at a surface limestone mine in Southwestern USA. The shelter was constructed by the mine's personnel. Another example of a blasting shelter used at a surface limestone mine in Ohio is shown in **Figure 3**. The mining company requires that this type of blasting shelter be used for protection from a blast. The blast shelter is mounted on skids for ease of transportation and is constructed of steel that is 3/8-inch thick. The use of specially designed blasting shelters can provide the protection needed to prevent a person from being struck by flyrock. In the international sphere, a more sophisticated blast shelter has been designed by two Queensland, Australian inventors [Queensland Government Mining Journal, May 2001]. The shelter, which is cylindrical and constructed of 5/8-inch thick steel, is mounted on a rubber tired trailer.

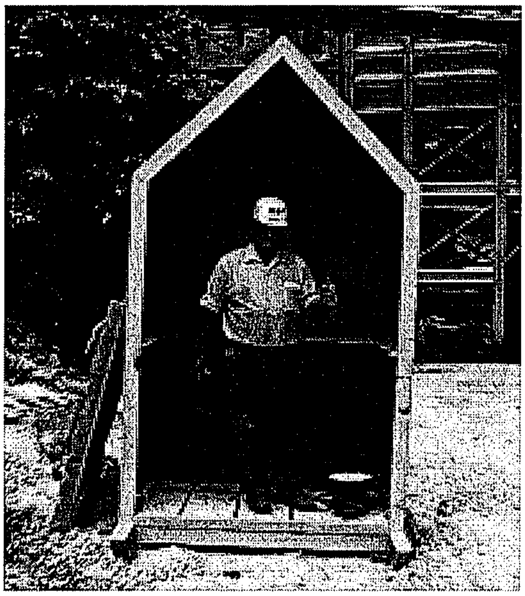


Figure 2. Blasting shelter used at a surface limestone mine in southwestern United States.

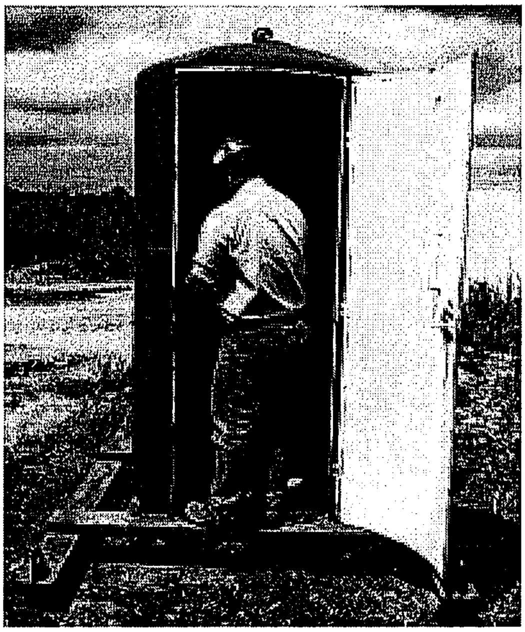


Figure 3. Blasting shelter at a surface limestone mine in Ohio.

Light buildings, pickup trucks, and other vehicles which are often used as covers, have been penetrated by flyrock [Schneider, 1996]. During a coal mine blast, a blaster positioned himself under a Ford 9000, 21/2-ton truck, and fired the shot. A piece of flyrock traveled about 750 ft and fatally injured the blaster under the truck [MSHA, 1992]. This accident could have been prevented by using an adequate blasting shelter. A safe location and sufficient cover is critical to a blaster's protection if the firing lines are not long enough to be beyond the flyrock range [Schneider, 1996]. Some blasting operations use a remote controlled firing system to permit blasters to stay out of the blast area.

In a construction blast, an employee standing behind a front-end loader was struck by flyrock. The employee suffered trauma to his neck and lacerations to his face [OSHA, 1992]. This accident could have been prevented by using an adequate blasting shelter.

The Chief Inspector of Mines in Queensland, Australia, reported that a blaster was standing behind a steel hopper while video-taping a toe shot in a metalliferous quarry. Flyrock traveled about 246 feet and seriously injured the blaster. The blaster lost his right eye, his cheek bone was shattered, and his jaw was broken. This accident could have been prevented by using a proper blasting shelter.

Effective communication

Effective communication is a key element in preventing blasting injuries. Blasting in mining operations is a complex process and requires coordination and communication between (a) driller and blaster, (b) blaster and crew members, (c) blaster and other miners, and (d) blaster and mine management, among others. Failure of effective communication may result in fatalities and serious injuries. Workers and visitors should be informed about the blasting signals, evacuation procedure, location, and timing of a scheduled blast on a daily basis. Many surface operations schedule blasting events between sunrise and sunset. In many underground operations, blasting is often scheduled when no one, except the blast crew, is present in the vicinity.

Audible signals, such as sirens, whistles, or horns mounted on a vehicle, are used in many operations to caution employees, visitors, and neighbors about a scheduled blasting event. Enough time should be provided to facilitate orderly evacuation of all personnel, whose presence is not required, from the blast area.

For surface and underground metal-nonmetal mines, 30 CFR § 56.6306 (f) (1) and 57.6306 (f) (1) require that "Ample warning shall be given to allow all persons to be evacuated." For surface coal mines, 30 CFR § 77.1303 requires that "ample warning shall be given before blasts are fired." The OSM regulation in 30 CFR 816.64 (a) requires that "The operator shall publish the blasting schedule in a newspaper of the general circulation in the locality of the blasting site at least 10 days, but not more than 30 days, before beginning of a blasting program." 30CFR 817.64 (a) requires that "The operator shall notify, in writing, residents within 1/2 mile of the blasting site and local governments of the proposed times and locations of blasting operations."

Unified approach for mitigating injuries

Brnich & Mallett [2003] advanced the concept of conducting a hazard-risk assessment for preventing mining injuries. A site-specific hazard-risk assessment based on the probability of an event and its severity is an excellent tool for the blasting community. Blasting releases a tremendous amount of energy within a very short time and is considered a hazardous operation. An analysis of site-specific risk factors will help in understanding and mitigating possible hazards. A site-specific hazard-risk matrix should be drawn up and discussed during blaster/miners job assignments, safety discussions, and training sessions.

An Australian document [DR 04062, 2004] issued for public comment accentuates the risks of blasting and recommends that "...whenever explosives are to be used that a competent person(s) carry out a detailed risk assessment to identify all foreseeable potential hazards and take appropriate steps to eliminate or reduce the likelihood and mitigate the severity of any effects so that risks are at an acceptable level." The Australian document accentuates Brnich & Mellett's [2003] hazard-risk assessment concept.

Brulia [1993] reported that about 80-90% of all accidents are caused by human factors, and listed five salient elements which contributed to these accidents:

- Negligence - failure to observe safety rules and instructions,
- Hasty decisions - acting before thinking usually leading to hazardous shortcuts,

- Inadequate instruction - untrained or improperly trained personal,
- Overconfidence - taking chances,
- Lack of planning - insufficient understanding of a blasting situation.

Safety professionals often use a multi-faceted approach for injury prevention. This includes intervention techniques conducted through (a) training and continuing education of miners and blasters, (b) site-specific policies and procedures, and (c) engineering controls. Commitment to safety by the blaster, blasting crew, other miners, and the mine operator is the most essential ingredient for injury prevention.

Training and continuing education

Training and continuing education play a vital role in building up and enhancing the knowledge base of employees. It helps the blaster, blasting crew, and other miners to develop a higher level of awareness to identify hazards and apply proper mitigating techniques. Site-specific training relative to the bounds of the blast area, non-work zone beyond the blast area, blast guarding, access control, and clearing protocol should be made available to all new employees. A detailed discussion of hazards associated with the transport and use of explosives should also be included in the overall training program. Drillers should be trained to search for any geological anomaly and report such information to the blaster. Blasters should be trained to consider all available data to determine the bounds of the blast area for each shot. The level of training, experience, and attitude of explosive handlers is crucial to the attainment of higher blasting safety [Brulia, 1993].

The ISEE has made available several state-of-the-art training modules for mining and construction blasting. The MSHA's National Mine Health and Safety Academy also provides training and material for surface and underground blasting. Regular refresher training should be made available to all explosive handlers. OSM and many state regulations require that blasters working in surface coal mines be examined and certified.

It is important to conduct a post-blast analysis of each shot to determine if the shot performed as planned. And, if there are any deviations, the blaster should look for the reasons for such deviations. All near miss incidents should be critically examined. Training should be aimed at greatly augmenting the blaster's knowledge and confidence level. The blaster should be proactive and understand that "The challenge is defined, the solution is clear, the need is immediate, and success depends on the blaster."

Site specific policies and procedures

Mine operators should develop site-specific safety procedures consistent with company policy, local, state and federal laws. The procedure should address all activities such as equipment selection, blast planning, determining the location of blastholes, pre-blast examination of face and high wall, evaluation of driller's log, loading and priming of explosive charge, determining the bounds of the blast area and non-work zone beyond the blast area, evacuation and clearing protocol of employees, personnel accounting system, examination and guarding blast area, blasting time and signal, access control to blast area, and communication protocol.

Many mine operators have standardized their blast guarding protocol. Pre-blast planning and discussion with crew members reinforce confidence and provide an avenue for good cooperation. Such discussion and planning forums also provide an opportunity to ask questions and resolve any doubts or misconceptions.

As a matter of policy, many underground mines schedule a blasting event for the evening or night shift when no one, except the blasting crew, is present underground. Some operators have installed a remote firing system to remove the blaster from the blast area.

Engineering controls

Blasting safety can be greatly enhanced by good engineering controls and feedback mechanisms. Engineering controls should be well understood and closely followed by the blasting community. Dick et al. [1983] and Fletcher & D'Andrea [1986] advocated the use of portable blasting shelters. The shelter may be cylindrical in shape and constructed of heavy steel to withstand any possible impact from flyrock. The portable shelter may be mounted on wheels or skids for ease of moving from one blast area to another. The blaster enters the shelter and closes the door prior to firing the shot.

Commitment to safe blasting practices by the mine operator, blaster-in-charge, blasting and drilling crew and other miners and affected persons is an essential ingredient in injury prevention. Many mines have developed excellent site-specific blast guarding systems. An individual, with experience and knowledge in blasting, should oversee the entire process and advise the blasting personnel accordingly. This individual may be a blasting superintendent, blasting foreman, blasting engineer, or blaster-in-charge. This person should make sure that all relevant policies and procedures are followed, and in case of any discrepancy that corrective action is appropriately taken.