A Summary of Fatal Accidents Due to Flyrock and Lack of Blast Area Security in Surface Mining, 1989 to 1999

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ABSTRACT

This paper summarizes flyrock and blast area security fatalities from 1989 to 1999 and examines the causative factors. Coal and nonmetal mining used about 43 billion pounds of explosives and blasting agents between1989 to 1999. A majority of this consumption was used at surface mines. Accident data indicates that flyrock and lack of blast area security were the primary causes of blasting related injuries in surface mining. Fatal injuries due to lack of blast area security were attributed to: failure to clear blast area; failure to follow instructions; inadequate guarding; inadequate blasting shelter; and unsafe location.

Seven fatalities due to flyrock and lack of blast area security were reported in surface coal mines and six in nonmetal mines. Out of these, two fatalities (one each in coal and nonmetal mines) occurred outside the mine property. In the coal mining sector, two fatalities were attributed to flyrock, and five to lack of blast area security. In the nonmetal mining sector, three fatalities were attributed to flyrock, and three to lack of blast area security.

Preventive measures include: ensuring that all personnel have evacuated the blast area during shot firing; using adequate blasting shelters for employees whose presence is required in the blast area; controlling and monitoring all entrances to the blast area; ensuring that the blast is properly designed, drilled, and loaded; and emphasizing education and training to enhance skill levels for implementation of engineering control techniques.

ABBREVIATIONS

ADL	average days lost
ANFO	ammonium nitrate/fuel oil
ATV	all-terrain vehicle
CFR	Code of Federal Regulations
ft	foot (feet)
IME	Institute of Makers of Explosives
in	inch(es)
lb	pound(s)
ms	millisecond(s)
MSHA	Mine Safety and Health Administration, Department of Labor
OSM	Office of Surface Mining, Department of Interior

INTRODUCTION

Explosive and blasting agents are used in mining, quarrying, construction, and other activities where rock fragmentation is an essential part of the project. Coal and nonmetal mining used about 43 billion pounds of explosives and blasting agents between 1989 and 1999. About 4.7 billion pounds of explosives were used in the United States during 1999. Out of this, coal and nonmetal mining consumed about 3.7 billion pounds [Kramer 2000]. Even though blasting presents numerous hazards it is an essential component of excavating rock. Mechanical excavators can be successfully used in removing topsoil, clay and to some extent glacial till [U.S. Army Corps of Engineers 1983]. But blasting is a viable inexpensive alternative for excavating hard rock.

Manufacturers and users are consistently trying to enhance blasting safety. The mining industry has improved its safety record during the past five years [Rehak et al. 2001]. Lack of blast area security, flyrock, premature detonation, misfire, and disposal were major causes of blasting-related injuries in surface mines during the last twenty years. Flyrock and lack of blast area security accounted for 68% of the injuries [Verakis and Lobb 2001].

An examination of fatal occupational injury data reveals that mining is one of the most hazardous occupations in the United States. The average annual rate of fatal injuries (number of fatal injuries per 100,000 workers) in the mining industry (30.3) exceeds that of other industries, such as agriculture, forestry, and fishing (20.1), construction (15.3), transportation and public utilities (13.4), public administration (5.8), manufacturing (4.0), wholesale trade (3.3), retail trade (2.8), services (1.7), and finance, insurance, and real estate (1.1) [NIOSH 2000]. In addition, the average number of days lost (ADL) per incident in the mining industry exceeds the ADL of all other industries [NIOSH 2000]. In the mining industry, the ADL of an explosive incident (550 days) exceeds that of all other classes (46 days) of incidents [NIOSH 1998].

Blasting generally has two purposes: rock fragmentation and displacement of the broken rock. The movement of the blasted rock depends on the shot-design parameters, geological conditions, and mining constraints. In some mining practices, it is desirable to throw or cast as much rock as possible to the spoil heap. This technology, known as cast blasting, has been adopted to reduce the cost of mucking, loading, and transportation of the blasted rock to the spoil heap. Successful application of cast blasting has reduced costs for many mine operators to uncover mineral deposits.

Blasted rock is not expected to travel beyond the limits of the blast area. All employees should be moved to a safe location away from the blast area when firing shots. If anyone, such as the blaster, is required to stay in the blast area, blasting shelters should be used for protection against flying debris. All entrances to the blast area should be securely guarded or barricaded to prevent inadvertent entry of employees, visitors, and neighbors. The blaster in charge is responsible for determining the bounds of the blast area and for complying with safety laws. Langefors and Kishlstrom [1963], Roth [1979], and Persson et al. [1994] have postulated concepts and developed theories to compute flyrock range. A blaster may use such concepts, in conjunction with past experience, to determine the size of a blast area. The U.S. Code of Federal Regulations (CFR), Title 30, Part 57.6000, defines ‘Blast Area’ as the area in which concussion (shock wave), flying material, or gases from an explosion may cause injury to persons. The CFR has also defined blast site as the area where explosive material is handled during loading, including the perimeter formed by the loaded boreholes and 50 feet (15.2 meters) in all directions from loaded holes. A minimum distance of 30 feet (19.1 meters) may replace the 50-foot (15.2-meter) requirement if the perimeter of loaded holes is demarcated with a barrier.

IME has defined flyrock as the rock(s) propelled from the blast area by the force of an explosion [IME 1997]. A flyrock related injury is sustained when a blast propels rock beyond the blast area and it injures someone. The primary factors for flyrock are:

- insufficient burden,
- improper blasthole layout, loading, and powder factor
- anomaly in the geology and rock structure,
- insufficient stemming, and
- inadequate delay time (hole to hole or row to row).

An injury due to lack of blast area security occurs when an unauthorized person is in the blast area when the shot is detonated or when a person fails to use an adequate blasting shelter. The main causes for injuries due to lack of blast area security were:

- failure to evacuate the blast area by employees and visitors,
- failure to understand the instructions of the blaster or supervisor,
- inadequate guarding of the access roads leading to the blast area,
- taking shelter at an unsafe location, and
- failure to use a blasting shelter.

Use of portable blasting shelters has often been advocated. The typical shelter is cylindrical in shape and constructed of steel which is able to withstand the potential impact from flyrock. The top of the structure is dome-shaped and the base is flat. It is mounted on wheels for ease of towing from one blast job to another. The blaster goes inside the shelter and closes the door prior to firing the shot.

Industry specific explosive usage and fatalities:

Between 1989 and 1999, approximately 35.7 billion pounds of explosives were used in surface coal mines and 7.3 billion pounds in nonmetal mines and quarries. Seven fatalities due to flyrock and lack of blast area security were reported in surface coal mines and six in surface, nonmetal mines.

CASE STUDIES

Reporting requirements for injuries, illness, and workplace exposures are stipulated in the Federal Coal Mine Health and Safety Act of 1969 and the Federal Mine Safety and Health Amendments Act of 1977. The OSM is responsible for investigation of the off-mine impacts to the public in surface coal mines. Two fatalities occurred off the mine site. The MSHA's accident investigation reports were used to gather information on most of the cases listed below.

1. Coal Mine, Perry County, KY: On January 26, 1989, a 49-year-old miner (House Coal Hauler) was covered under blasted sandstone in a surface coal mine [MSHA 1989a]. The victim was about 15 ft from the toe of a 43-ft highwall and loading house coal on his truck when the shot was fired.

On the day of this incident, the victim went to load coal on his truck adjacent to a highwall where preparations were going on to blast the sandstone overburden. The drill holes were 6-3/4 in diameter by 43 ft deep. Blast holes were loaded with ANFO and electric detonators were used to initiate the blast. The horn of a pickup truck, situated 468 ft from the victim, was used for the blast warning. Apparently, the blaster and his helper could not see the victim and the entire pit area from the firing station. Upon firing the shot, the victim and his truck were covered by 8 to 10 ft of broken rock.

Causes/prevention: This incident exemplifies inadequate blast area security and access control. During MSHA's investigation, a witness stated that the miner left the blast area when asked. The MSHA investigation indicated that the miner went back to load coal. The blaster did not have a clear view of the blast area from the firing station. His vision was obstructed by a pile of broken material and consequently he could not see the victim near the highwall. Such incidents could be prevented by adopting effective blast area security protocol, proper communication, a last-minute visual inspection of the blast area, and miner training.

2. Nonmetal Mine, Johnson County, IL: On July 18, 1989, a plant foreman was fatally injured when flyrock struck the roof of his 1987 Chevrolet C-20, 3/4-ton pickup truck [MSHA 1989b]. The impact caused the roof to bend downward and strike the foreman's head.

Twenty-five holes in five rows, on a 10- by 16-ft pattern, in sandstone overburden, were loaded with 6,550 lb of ANFO. Blast holes were 50-ft deep and 5-in diameter. The top 10 ft was stemmed with crushed stone.

The victim was in a pickup truck near the entrance to an access road to the blast site. Upon firing the shot, a sandstone rock weighing 8.5 lb and measuring 8- by 5- by 3-1/2-in, traveled 1,050 ft and hit the roof of the cab.

Causes/prevention: In this flyrock incident, the MSHA investigation report did not indicate which factors caused this unusual flyrock. There was no evidence of misaligned boreholes, presence of voids or fissures in the limestone rock, or overloading of explosive charge. It is difficult to go back and reconstruct the circumstances leading to this incident.

3. Coal Mine, Webster County, WV: On August 29, 1989, a drill operator sustained minor injuries and a 41-year-old dozer operator was fatally injured by flyrock in a surface coal mine [MSHA 1989c].

A total of 144 holes, 7-7/8-in diameter and 19-ft deep, were loaded with emulsion explosive. Each hole contained about 221 lb of explosive charge. The blasting crew notified the foreman of an impending blast and the foreman cleared all employees from the pit area. The foreman was guarding the access road to the pit. About two minutes before the blast, the foreman left his post and went to the mine office for a brief visit. No barricade or notice of blasting was posted at this access road. In the mean time, the drill operator and the dozer operator, unaware of the imminent blasting, entered the pit area in a pickup truck. Since the blaster's vision was obstructed by a large mound of dirt, he could not see the pickup truck entering the pit area. Upon firing the shot, the dozer operator was fatally injured and the drill operator sustained minor injuries.

Causes/prevention: This incident exemplifies inadequate blast area security and access control. The MSHA investigation report indicated that the foreman acted inappropriately by leaving his post immediately prior to blasting. He should have put up barricades or posted a notice of the impending blasting. This incident emphasizes the significance of securing and guarding all entrances. Such incidents can be prevented by adopting effective blast area security protocol, proper communication, and miner training.

4. Nonmetal Mine, Caldwell County, KY: On July 5, 1990, a blaster was fatally injured by flyrock. Flyrock measuring 9- by 7- by 5-in and weighing about 14 lb, traveled over a 200-ft highwall and struck the victim [MSHA 1990a]. The victim suffered a massive head injury.

On the day of this incident, blasters were assigned to blast a toe round and a bench round. The toe round was scheduled to be shot first. The toe round consisted of 23 holes ranging in depth from 3 to 5 ft. The holes were charged with a 2-1/2-in diameter packaged explosive product. One hundred and seventy-six pounds of explosive, averaging 7.6 lb per hole, were used. The victim was standing on the top of a 200-ft highwall about 505 ft from the blastholes. The highwall could not shield him from flyrock.

Causes/prevention: The MSHA investigation report indicated the importance of using blasting shelters to protect employees in the blast area. Explosive energy takes the path of the least resistance and blasting of small diameter slanted toe holes requires special consideration. Trajectories of flyrock from toe blasting are often unpredictable. Apparently, the blaster with 15 years of experience could not perceive that flyrock could strike him on top of the highwall. Such incidents can be prevented by using blasting shelters.

5. Nonmetal Mine, Livingston County, IL: On July 11, 1990, flyrock from a limestone quarry traveled about 930 ft and fatally injured a resident who was mowing grass on his property [MSHA 1990b]. Limestone was mined from a single bench by drilling and blasting.

On the day of this incident, thirty-six holes in three rows, twelve holes per row, were loaded with 2,556 lb of ANFO. The holes were 4-3/4-in diameter and 21-1/2-ft deep. The spacing and burden were 13-1/2 and 9 ft respectively. The upper 5 ft of each hole was stemmed with drill cuttings and crushed stone. One of the holes near the center of the front row used an additional 18 to 25 lb of ANFO. The blaster did not consider this unusual. A 70-ft high pile of rock and dirt was between the blast site and the victim's property.

Causes/prevention: This flyrock incident underscores the danger of overloading boreholes, particularly in the front row. The MSHA investigation report indicated that overloading a hole could have propelled flyrock further than usual. In a limestone formation, free-flowing powder may easily find its way into voids, crevices, or wide open cracks. Such situations could create problems in the front row. A blaster should check the rise of the explosive column while loading a borehole to prevent powder from filling a void, resulting in an overloaded hole. If a void is encountered, it should be filled with inert decking material. Crushed stone is generally recommended as a suitable stemming material. Drill cuttings and dust are usually very poor stemming material, particularly if the borehole has water present [Schneider 1997]. A stemming length of 5 ft, consisting of drill cuttings, for a 21-1/2 ft-deep borehole at a 9- by 13-1/2-ft pattern merits further consideration. Recommended preventive measures include avoiding overloading of boreholes.

6. Coal Mine, Walker County, AL: On September 22, 1990, flyrock projected from a surface coal mine blast fatally injured the owner of a logging company [MSHA 1990c]. He was in the process of preparing access roads for future logging operations and was outside the mine property.

Fifty-four holes, in six rows, 9-in diameter, 40-ft deep, on a 18- by 18-ft pattern were loaded with emulsion explosive. Each hole contained about 864 lb of explosives. The stemming length was 10 ft. The pit area was cleared and the shot was fired. The blast projected flyrock about 900 ft and fatally injured the victim. Several large boulders were scattered near the accident site.

Causes/prevention: The MSHA investigation determined that a blown out shot caused the flyrock. This incident emphasizes the importance of blast design, highwall inspection, and assessment of the bounds of the blast area. A blaster should inspect the conditions of the bench and highwall and increase the blast area accordingly.

7. Nonmetal Mine, Luna County, NM: On October 12, 1990, a visitor sustained severe injuries and a 32-year-old drill/blast helper was fatally injured by flyrock in a surface silica flux mine [MSHA 1990d]. The mining company used a blasting contractor for loading and firing the shots.

The blast round consisted of 49 holes, 3-in diameter, 12-ft deep, on a 6-ft spacing. Each hole was bottom primed with a stick of 60-percent gelatin dynamite taped to detonating cord. Another stick of dynamite taped to detonating cord was placed three to four feet below the collar. Some of the holes were stemmed with two feet of drill cuttings. Several holes were completely filled with ANFO. A detonating cord trunk line was used to tie each hole without any firing delay. The trunk line was tied to a cap and fuse assembly.

The visitor and the drill/blast helper were about 150 ft from the edge of the blast. Upon firing the shot, the drill/blast helper was fatally struck on the back side of his head.

Causes/prevention: This incident underscores the importance of blasting shelters. The MSHA investigation indicated that poor blasting practices (such as, overcharging boreholes, lack of stemming, and absence of delays) were followed during this shot. The investigation report also indicated that the employees were not properly trained and the victims were too close to the blast. This incident emphasizes the significance of training to build up a team of competent employees. Preventive measures include deployment of blasting shelters, proper blast design, and training of miners. Several companies mandate using remotely operated video cameras to photograph blasting events.

8. Coal Mine, Mingo County, WV: On February 1, 1992, a blaster was fatally injured in a surface coal mine by a 1-ft 5-in by 2-ft 11-in by 8-1/12-in flyrock [MSHA 1992]. The blaster positioned himself under a Ford 9000, 2-1/2-ton truck while detonating the shot. A flyrock traveled 750 ft and fatally injured the blaster. The mining company used a blasting contractor for loading and firing the shots.

Eighty boreholes, 9-in diameter, on a 18- by 18-ft pattern were loaded with 35,414 lb of explosives. The stemming length was 10 ft. Sixty-two holes were 30-ft deep and each hole was loaded with 468 lb of bulk ANFO. Eighteen holes were 20-ft deep and each hole was loaded with 351 lb of bulk ANFO. Each hole was primed with a 1-lb cast primer and stemmed with drill cuttings. A nonelectric initiation system was used with 200-ms down-hole delay, 100-ms delay between the rows, and 17-ms delay between the adjacent holes in a row.

On the day of this incident, the blaster and helper loaded eighty holes. Upon clearing the blast area and securing access roads, the shot was fired from a distance of 1,500 ft. A misfire was noticed and after 15 minutes, the blaster returned to examine the blast site and reconnected the lead-in line in preparation for firing the remaining holes. The blaster positioned himself under a Ford truck, at a distance of 750 ft, and fired the shot. Upon firing the shot the blaster was fatally injured by flyrock.

Causes/prevention: This incident illustrates the importance of using a proper blasting shelter. The MSHA investigation report indicated that the blaster was within the limits of the blast area and did not use a proper blasting shelter. The blaster's decision to use the Ford truck as a cover caused the tragedy. This tragic incident could have been avoided by using a proper blasting shelter. The blaster could have also fired the shot from a location beyond the limits of the blast area. The space under a truck should not be used as a blasting shelter. A good rule when firing a misfire is to increase the size of the blast area due to possible cracks in burden or spacing.

9. Coal Mine, Campbell County, TN: On June 4, 1993, a 16-year-old passenger, in a car driven by his parent on interstate 75 (I-75), was fatally injured by flyrock originating from an overburden blast in a nearby coal mine [Shea and Clark 1998]. The closest blasthole was within 75 ft of the Right of Way and 225 ft from the I-75 pavement. This blast generated a large amount of flyrock. The I-75 traffic was not monitored prior to the blast.

Twenty-eight blastholes, in four rows, on a 18- by 18-ft pattern, 7-1/4-in diameter, were loaded with ANFO. Each hole was loaded with 573 lb of explosive and stemmed with 11 ft of drill cuttings. The length of explosive column in each hole was about 32 ft. Unlike previous blasts, explosive charges were not decked during this blast.

The fatal blast was not designed according to the specifications approved in the permit document [Shea and Clark 1998]. Instead of decking the explosive charges in two columns and priming separately, the entire charge was loaded in one column. Hole diameter and blast pattern used in this blast were different from the approved plan. The stemming was insufficient and the I-75 traffic was not monitored [Shea and Clark 1998]. The blaster, apparently, was unaware of the presence of an 8-ft thick layer of clay on the top of the sandstone overburden. Loading of explosives near the collar zone in unconsolidated material was considered a contributory factor.

Causes/prevention: This flyrock incident illustrates the significance of communication between the blaster and the driller. The interstate traffic was not monitored before firing the shot. Some of the blast design parameters (such as, hole diameter, burden, spacing, and decking) were altered for this blast. The OSM investigation [Shea and Clark 1998] indicated that the causative factors were insufficient stemming, single decking of holes instead of double decking on separate delays, and a change in the geology of the overburden. Preventive measures include paying close attention to drillers' log and watching for any abrupt changes in the geology or rock structure. Blast design parameters should not be changed without a critical review of its impact. When necessary, highway traffic should be stopped.

10. Coal Mine, Greene County, IN: On April 25, 1994, a driller/loader was fatally injured by flyrock in a surface coal mine [MSHA 1994a]. He was transported to the county hospital where he was pronounced dead.

Coal was mined from a 60-in thick seam having a shale parting at the middle. One hundred and seventeen holes, 6-3/4 in diameter, 11 ft deep were drilled on a 11- by 11-ft pattern. Each hole was backfilled with about one ft of dirt and loaded with 42.75 lb of emulsion explosive. The length of stemming varied from 7-1/2 to 8 ft. The firing delay between adjacent rows was 42 ms and adjacent holes in a row was 25 ms. There were nine rows and 13 holes in a row. Some of the holes contained water.

The blasting crew notified the superintendent of an impending blast and cleared other employees from the pit area. The victim and another employee working under the direction of the blaster were about 236 ft from the blast area. Upon firing the blast, the victim was fatally injured by flyrock.

Causes/prevention: This incident emphasizes the significance of using a proper blasting shelter. The MSHA investigation revealed that the accident happened because an adequate blasting shelter was not used. The presence of water in the holes was considered a contributory factor. Preventive measures include the use of proper blasting shelters for employees whose presence is required in the blast area and hazard recognition training to increase the general awareness of all employees.

11. Nonmetal Mine, Madison County, IL: On May 23, 1994, a crane operator was fatally injured when flyrock struck him in the back [MSHA 1994b]. During the blast, the victim and the blaster were standing on a top bench 120 ft from the nearest blasthole. This limestone quarry operated in multiple benches. The quarry was about 160 ft deep and accessed by an inclined haul road across the benches. The haul road extended to the floor of the bottom bench.

Forty-one holes, 3-1/2 in diameter, 12 ft deep, were loaded with ANFO. Each hole contained a 500-ms down-hole delay. The delay between the adjacent holes was 25 ms. The bench height was 11 ft. The length of stemming was about 3 ft and crushed limestone was used for stemming. The stemmed holes were covered with blasting mats of 3- by 3-ft size. Five-gallon pails containing crushed stone were placed over the mats.

On the day of this incident, the victim helped stem the holes and place mats over the holes. Prior to detonating the shot, the victim and the blaster moved to a top bench behind the blast. Upon initiation of the blast, one of the holes threw flyrock toward the victim.

Causes/prevention: This incident accentuates the importance of using blasting shelters. The MSHA investigation indicated that failure to blast from a safe location and failure to use a blasting shelter caused this fatality. This incident could have been avoided if the crane operator was removed from the blast area. This incident underscores the need to remove all employees from the blast area and provide blasting shelters for employees whose presence is required in the blast area.

12. Coal Mine, Pike County, KY: On February 15, 1999, a 55-year-old area resident rode an all-terrain vehicle (ATV) from his residence to an access trail leading to the mine site [MSHA1999a]. He parked his ATV about 100 ft from the edge of the blast site and started walking toward the blast site. Shortly after he started walking, a blast was detonated. Later, his body was found close to the perimeter of the blast site.

Mining was conducted on privately-owned land, including land owned by the victim. The deceased often visited the mine site and some of his visits were unannounced.

A total of 212 holes, 6-3/4-in diameter, loaded with 13,010 lb of explosive, was detonated. Of these, 164 holes were 13 ft deep, and 48 holes were 23 ft deep. The blastholes were drilled on a 13- by 15-ft pattern. The blast site and the access trail leading to the blast site were examined about five minutes before the blast. Guards were not posted at the access trail, and the blaster did not have a clear view of the access trail from the firing station. A Ford F-250 pickup truck was equipped with two electro-mechanical horns, and on the day of the incident the low-pitch horn was operational. The high-pitch horn was found to be disconnected. The access trail was in a valley, and it was probably difficult for the victim to hear the signal.

Causes/prevention: This incident exemplifies inadequate blast area security and access control. The MSHA investigation report indicated that the mine operator and the blaster (an independent contractor) failed to guard the access trail leading to the blast site. The blaster did not have a clear view of the access trail from the firing station and guards were not posted. Apparently, the victim could not hear the blast warning signal or ignored the signal. Preventive measures should include blast area security and access control.

13. Nonmetal Mine, Lancaster County, PA: On December 21, 1999, a 32-year-old equipment operator was in a pickup truck guarding an access road to the blast site [MSHA1999b]. The pickup truck was about 800 ft from the blast site. Flyrock entered into the cab through the windshield and fatally struck the victim.

The mining company used a drilling contractor to drill the holes and a blasting contractor for loading and blasting. The highwall face was about 50 ft high and the depth of holes ranged between 49 and 54 ft. The blast round consisted of 22 holes drilled on a 16- by 16-ft pattern. Approximately 9,595 lb of explosives were used in this round and the length of stemming varied from 9 to 36 ft. The weight of explosive used in each blasthole was not recorded. Some of the holes were slanted up to 25° toward the highwall. This was done to compensate for irregularities in the highwall face. Drill records indicated that two blastholes were broken and contained voids. Two other blastholes were broken with one venting air out of the face.

Causes/prevention: The MSHA investigation determined that at least one of the blastholes blew-out causing a massive amount of flyrock. Excessive powder factor, voids, discontinuities, break in the rock strata, or borehole inaccuracies were contributory factors. It is difficult to assess which factor or combination of factors was primarily responsible for this flyrock. A blaster should be careful if a shot ends in a free face [Ludwiczak 1996]. This incident emphasizes several issues, such as blast design, loading of voids, burden, confinement, and record keeping. A good rule of thumb is to increase the size of the blast area when cracks are detected in the highwall face.

SUMMARY

The major causes of blasting-related injuries in surface mines are lack of blast area security, flyrock, premature blast, misfire, and disposal. Inadequate size of the blast area, flyrock, and lack of blast area security (including lack of blasting shelter) accounted for 68% of the injuries. IME has defined flyrock as the rock(s) propelled from the blast area by the force of an explosion. Fragmented rock is not expected to travel beyond the confines of the blast area. An injury due to flyrock may be sustained when it travels beyond the blast area. The main causative factors responsible for propelling flyrock beyond the blast area are insufficient burden, improper blasthole layout and loading, anomaly in the geology and rock structure, insufficient stemming, excessive powder factor, inadequate firing delays, and inadequate size of the blast area. Injuries due to lack of blast area security were primarily caused by: failure to evacuate the blast area by employees and visitors; failure to understand the instructions of the blaster or supervisor; and inadequate guarding of the access roads leading to the blast area.

RECOMMENDATIONS

- All employees should be moved to a safe location away from the blast area during shot firing. If anyone, such as the blaster, is required to stay in the blast area, blasting shelters should be used for protection from flying debris.

- All entrances to the blast area should be securely guarded or barricaded to prevent inadvertent entry of employees, visitors, and neighbors. The blaster in charge determines the bounds of the blast area.

- To promote safety surface mine blasting should be properly designed, drilled, and loaded.

- Emphasis should be placed on training and education in using suitable engineering control techniques.

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