# Using Major Hazard Risk Assessment to Appraise and Manage Escapeway Instability Issues: A Case Study

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## ABSTRACT

A Major Hazard Risk Assessment (MHRA) was developed in Australia after a series of mine disasters in the 1990's. A MHRA is used to help prevent major hazards, i.e. fire, explosion, wind-blast, outbursts, spontaneous combustion, roof instability and chemical and hazardous substances, from injuring miners. A MHRA is a structured process that identifies the characteristics of major hazards, assesses and ranks the risk they present, and evaluates engineering and administrative controls to mitigate them. These controls typically consists of a broad spectrum of prevention, monitoring, first response, and emergency response techniques and helps to move an operation from a reactive to a proactive approach towards safety.

This paper documents a MHRA performed at an underground mine where strata instabilities and fire hazards may threaten the condition of its escapeways. The objective of this MHRA is to 1) identify what hazards could affect the egress through the mine's escapeways, 2) determine what unwanted events pose the greatest threat for the mine, and 3) recommend a plan to prevent or recover from the potential disruption of egress through the escapeway. The plan provides information on the key existing controls that should be monitored and audited, and makes recommendation of new potential controls to further reduce related risks. By documenting the use of MHRA to this specific ground control issue, this paper provides a framework for others to judge the merits of this approach and to help design and perform these activities.

## INTRODUCTION

Recent mining disasters have focused attention on the need to improve how major hazards, the kind that are associated with multiple fatalities in underground mines, are assessed and managed. The Australia minerals industry began their movement towards risk-based management systems in the mid-1990's, shortly after the Moura coal mine explosion in 1994 fatally injured 11 miners (Hopkins, 2000). As a result, industry began using risk analysis methods to mitigate certain key hazards. Later, the various regulatory bodies in Australia began to mandate safety management plans for principal hazards. In New South Wales, the Chief Inspector of Coal Mines (NSWDPI, 1997) published a risk management handbook that offers a process to anticipate and prevent circumstances which may result in occupational injury or death. Queensland followed (QDME, 1998 and QMC, 1999) with it own standard. These regulations require mines to perform Major Hazard Risk Assessments (MHRAs) on a regular basis to address the possibility of unwanted events like spontaneous combustion, gas outbursts, explosions, air blasts, inundations and roof falls. The Australian underground mining industry now is realizing some of the lowest fatality injury rates in the world, even lower than that of the U.S. (table 1). The National Institute for Occupational Safety and Health (NIOSH) has undertaken a pilot project to evaluate MHRA potential for US mines through a series of case studies across several mining sectors. The purpose is to validate the use of this technique and to identify obstacles to its successful implementation in the U.S. mining industry. This case study examines the roof instability hazard and provides an example as to how MHRA could help to mitigate risk.

Table 1. Average fatality rates for underground mining in U.S. and Australia from 2004 to 2006 based on the number of fatal injuries per 1 million hours worked.

| | Commodity | Avg. fatality rate |
|---|---|---|
| U.S. | Coal | 0.25 |
| | Metal/nonmetal | 0.14 |
| Australia | Coal | 0.04 |
| | Metalliferous | 0.07 |

The general conditions found at the study site are shown in figure 1. The part of the mine that comprises the study area was mined over 40 years ago using the room-and-pillar technique. Large rooms were driven 45 ft (13.7 m) wide and 30 ft (9.1 m) high perpendicular to a highwall in an adjacent quarry and off-set cross-cuts of the same size were mined typically on 90 ft (27.4 m) centers. The parallel Primary and Alternate Escapeways run southeast from Portals No.1 and 2 to inby portions of the mine. In January 1994, a roof collapse occurred in an area adjacent to the Alternate Escapeway about 250 ft (76.2 m) from Portal No.2. Between January 1994 and December 2006, other roof falls have occurred to the southwest of the Alternate Escapeway, resulting in a large restricted area shown in figure 1. Management has responded to this roof instability hazard through best-practice controls, including roof monitoring, supplemental standing support and tensioned cable bolts in the Alternate Escapeway adjacent to the restricted area.

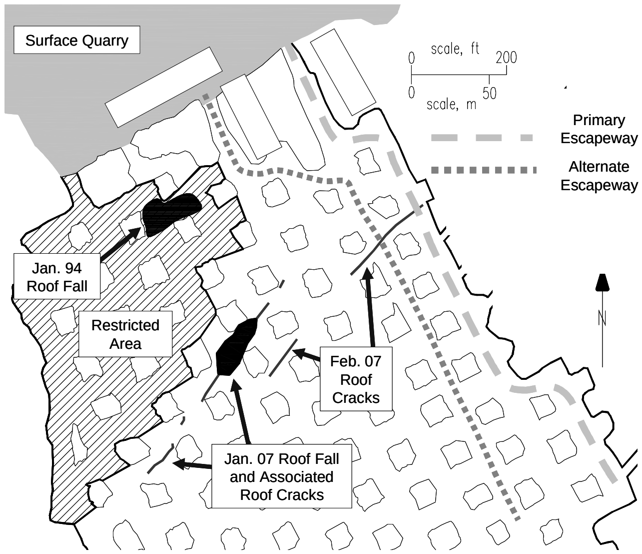


Figure 1. Escapeways, roof falls and recent roof cracks found at the mine.

Recently, roof conditions in the escapeways showed signs of deterioration. Of particular concern are the January, 2007 roof fall and the January/February, 2007 appearance of intermittent, en echelon roof cracks (figure 1). One of these roof cracks is especially troublesome because it extends across the Alternate Escapeway and into the Primary Escapeway, signaling an elevated risk.

The objective of the MHRA is to:

1. Identify hazards that could affect egress through the mine's escapeways,
2. Determine what unwanted events pose the greatest threat for the mine, and
3. Recommend a plan to prevent, or recover from, potential disruption of escapeway egress.

## INITIAL STEPS OF THE ESCAPEWAY EGRESS RISK ASSESSMENT

The initial MHRA steps consist of scoping document generation, scoping team selection and assessment framework identification.

The Scoping Document: A scoping document identifies the MHRA tasks. First, major hazards associated with egress through Primary and Alternate Escapeways during an emergency at mine should be reviewed. Consequences associated with the unwanted event are investigated and the likelihood of the event occurring should be estimated. Threats that disrupt egress through the escapeway are to be analyzed and ranked using a risk matrix technique. Finally, existing and new controls and recovery measures will be identified.

The Scoping Team: The scoping team consisted of the following persons:

Mine Representatives

Mine Manager
Mine Engineer
Rock Mechanics Engineer
Miner
Safety Officer

Facilitators (Risk Assessment Experts)

Experts (Field of Expertise)

Ground Control Engineers
Ventilation Engineer
Mining Regulation Specialist
Mine Evacuation Specialist

The Assessment Framework: The Scoping Team agreed to frame the assessment by limiting it to the Primary and Alternate Escapeways when egress was disrupted by a roof collapse or fire hazard. Normal ventilation operating conditions were considered, which means the fan at the ventilation shaft is either exhausting or blowing into the mine. During exhaust conditions both escapeways are in fresh air, while under blowing conditions the escapeways will be in return air. A time period of five years was used for considering hazards and risks.

## IDENTIFY HAZARDS THAT AFFECT EGRESS UGH THE MINE'S ESCAPEWAYS

Hazards that affect egress through the mine's escapeways are identified by first dividing the escapeway system into logical segments and then analyzing the various types of hazards.

Segments of the Escapeway System: For the purposes of this analysis, the description of a metal/nonmetal escapeway follows from the definitions cited in the Code of Federal Regulations, Part 30, Section 57.11050 (CFR, 2005). The escapeway system at the study mine are subdivided into six segments (figure 2).

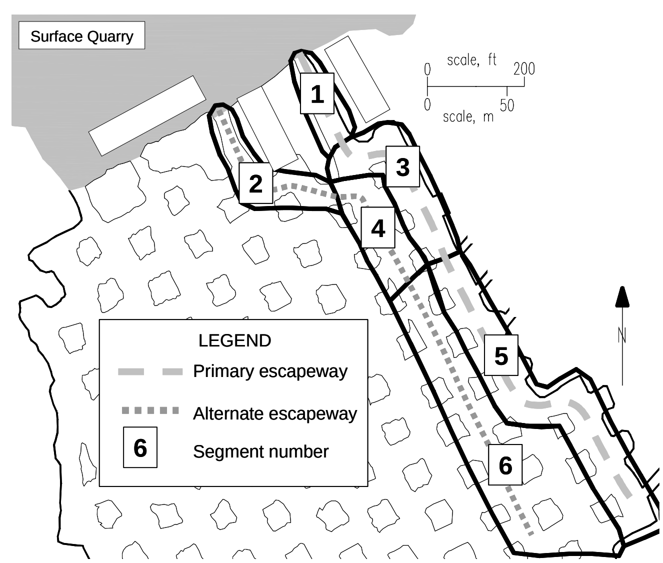


Figure 2. Six segments of the mine's escapeway system.

Hazards: A hazard is a source of potential harm with the potential to cause loss -- an uncontrolled exchange of energy (Standards Australia, 2004). The two kinds of hazards investigated in this study are fire and roof collapse. Fire hazards are identified by considering potential fuel and ignition sources. The results are summarized in Table 2. Roof instability hazards are considered only in terms of their potential to block egress through escapeways. Small roof falls that can result in injuries were therefore excluded from the analysis, since they do not block egress.

Table 2. Fire hazards consisting of potential fuel and ignition sources.

| | |
|---|---|
| Fuels | Diesel equipment – truck, front end loader, backhoe, grader, crane, scoops and other smaller pieces of diesel equipment |
| | Fuel Storage – diesel tanks and other flammable materials |
| | Electrical – Mine carts, transformers, substations and power lines |
| | Other Equipment and Storage – conveyor belt, natural gas pipe line, wood, PVC pipe, and other minor amounts of material |
| Ignition/heat sources | Overheating of diesel equipment, electrical equipment and electrical cabling |
| | Welding and cutting operations<br><br>Lightning |

A NIOSH developed tool, called the Roof Fall Risk Index (RFRI), was used to systematically identify roof fall hazards in the escapeways. The RFRI is a hazard assessment technique that maps the spatial distribution of stability conditions. The RFRI focuses on the character and intensity of defects associated with specific roof conditions (Iannacchione et al., 2006; Iannacchione, et al., 2007). Ideally, values approaching 0 represent safer roof conditions, while an RFRI approaching 100 represents a serious roof fall hazard. The RFRI values for the mine's escapeway system are shown in figure 3. Higher values indicate increasing risk of roof collapse in the absence of additional roof stabilization efforts. For example, the relative roof fall risk in Segment 1 of the Primary Escapeway is potentially lower than Section 2 because this section contains roof bolts, wire mesh and narrower entry spans.

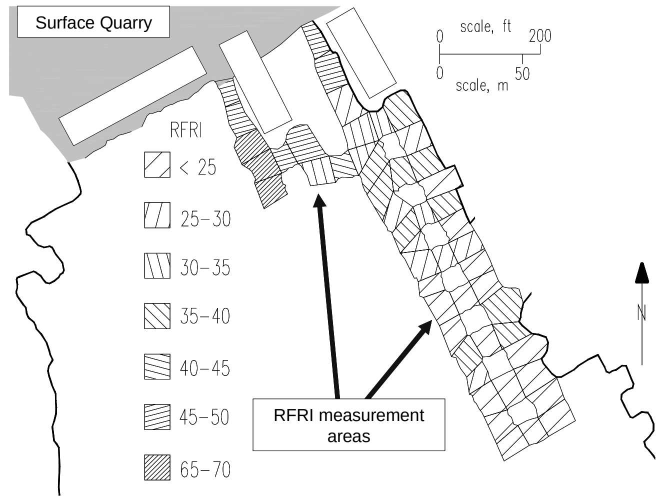


Figure 3. Roof fall risk index (RFRI) measured in the mine's escapeways.

## DETERMINE WHICH UNWANTED EVENTS POSE THE GREATEST THREAT

The hazard assessment followed a structured process which relies extensively on qualitative risk analysis methods. After the scoping team is familiar with the escapeway routes, current ground conditions, ventilation and operational requirements, the risk for a potential unwanted event in each segment are determined. The risk associated with unwanted events are rated using the Broad Brush Risk Assessment (BBRA) method which considers the likelihood and consequences of each event.

Table 3. Roof and rib hazards capable of blocking escapeway egress.

| | |
|---|---|
| Hazards | Roof falls |
| | Rib instability |
| Degree of hazards | Roof Fall Risk Index (RFRI) variations |
| | Rock reinforcement and room spans variations |

Broad Brush Risk Assessment: The scoping team identified 28 potential unwanted events based on the defined list of hazards (tables 2 and 3). Each potential unwanted event was risk-ranked using a qualitative risk analysis method (table 4). Lower numbers indicate a higher risk. The likelihood of an event was subjectively assessed by considering the probability of the event occurring in the next five years. The consequences of an event were assessed by

Table 4. A 4 by 5 risk matrix for ranking the unwanted events.

| Consequence | Likelihood (event occurs in next 5 years) | | | | |
|---|---|---|---|---|---|
| | Certain | Very Likely | Likely | Unlikely | Very Unlikely |
| High Impact | 1 | 2 | 4 | 7 | 11 |
| Moderate impact | 3 | 5 | 8 | 12 | 16 |
| Low impact | 6 | 9 | 13 | 17 | 20 |
| No impact | 10 | 14 | 18 | 21 | 23 |

Table 5. Risk ranking of unwanted events grouped by escapeway segment.

| Escapeway Segment | Potential unwanted event | Consequence (impact) | Likelihood (next 5 years) | Risk ranking |
|---|---|---|---|---|
| 1 | Equipment fire – fan exhausting | High | Unlikely | 7 |
| | Equipment fire – fan blowing | Moderate | Unlikely | 8 |
| | Roof collapse | High | Very Unlikely | 11 |
| | Diesel storage fire – fan exhausting | High | Very Unlikely | 11 |
| | Diesel storage fire – fan blowing | Moderate | Very Unlikely | 16 |
| 2 | Roof collapse | High | Likely | 4 |
| | Equipment fire - fan exhausting | High | Very Unlikely | 11 |
| | Equipment fire – fan blowing | High | Very Unlikely | 11 |
| | Electrical Cable fire | Low | Very Unlikely | 18 |
| 3 | Equipment fire – fan exhausting | High | Unlikely | 7 |
| | Equipment fire – fan blowing | Moderate | Unlikely | 12 |
| | Charging station fire – fan exhausting | High | Likely | 4 |
| | Charging station fire – fan blowing | Moderate | Likely | 8 |
| | Transformer fire – fan exhausting | Low | Unlikely | 16 |
| | Transformer fire – fan blowing | Low | Unlikely | 16 |
| | Natural gas leak explosion | High | Very Unlikely | 11 |
| | Flammable storage cabinet catches fire | Low | Very Unlikely | 20 |
| | Roof collapse | High | Very Likely | 2 |
| 4 | Equipment fire – fan exhausting | High | Very Unlikely | 11 |
| | Equipment fire – fan blowing | High | Very Unlikely | 11 |
| | Roof collapse | Moderate | Very Likely | 5 |
| 5 | Equipment fire – fan exhausting | High | Unlikely | 7 |
| | Equipment fire – fan blowing | Moderate | Unlikely | 12 |
| | Roof collapse | Moderate | Unlikely | 12 |
| | Transformer catches fire | Low | Very Unlikely | 20 |
| 6 | Equipment fire during travel – fan exhausting | Low | Very Unlikely | 18 |
| | Equipment fire during travel – fan blowing | Low | Very Unlikely | 18 |
| | Roof collapse | Low | Unlikely | 16 |

considering its potential impact on the ability to evacuate the mine in case of an emergency. This included consideration of blockage of escapeway routes and the spread of toxic fumes or smoke. Both exhaust and blowing ventilation scenarios were considered. The inability to use either escapeway for egress from the mine during an emergency was considered to be the highest impact consequence. The results of the risk rating exercise are summarized in table 5.

## EVALUATING THE CONTROLS AND RECOVERY MEASURES FOR THE TOP UNWANTED EVENTS

The top four unwanted events identified through the BBRA are selected for further analysis.

1. Roof collapse in Primary Escapeway of Segment 3
2. Charging station fire in Primary Escapeway of Segment 3
3. Roof collapse in Alternate Escapeway of Segment 2
4. Roof collapse in Alternate Escapeway of Segment 4

The Bow Tie Analysis (BTA) is an excellent method for identifying both existing and new control and recovery measures for these highest risk events.

## The Bow Tie Analysis

The BTA was developed by Shell Oil in the 1980's as part of their Tripod package of concepts and tools for managing occupational health and safety in their business. It is important to note that the "Top Event" in the BTA is not the full event considered in the BBRA but rather a statement about the initiating event that might lead to the major consequence (figure 4).

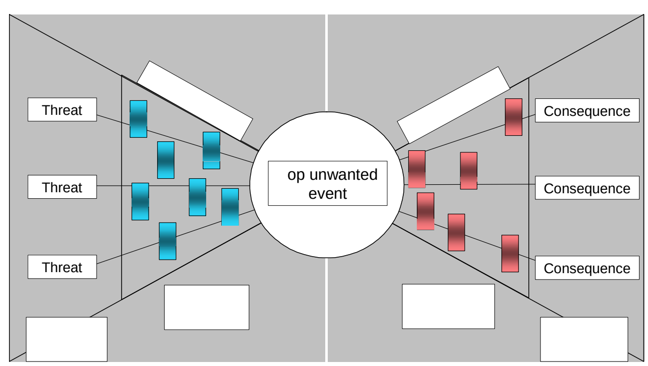


Figure 4. Bow Tie Analysis method.

The team discussed the nature and quality of the prevention controls as part of the BTA. Threats (also referred to as potential causes) were discussed and controls examined that could mitigate the hazard (left side of the bow-tie). Next, the consequences (also referred to as the potential outcomes) of the initiating unwanted event were identified and recovery control measures examined to reduce or minimize the loss (right side of the bow-tie). The outcomes of the bowtie analysis are presented in table 6 and summarized below:

a. Existing prevention control measures: The following are the key controls, currently in place, for the highest risks unwanted events. These existing control measures should be reinforced, monitored and audited with priority. Controls for roof collapse hazards consisted of 6 and 8 ft (1.8 and 2.4 m) grouted bolts on 5 ft (1.5 m) centers; scaling every 3 to 6 months or as needed; periodic observation of roof conditions, roof monitoring; cable bolt support with wire mesh; and breaker wall standing support between the Alternate Escapeway and the restricted area. Fire hazard controls consists of weekly battery checks.

Table 6. Controls and recovery measures for top unwanted events that impact escapeway egress.

| **Top Event ➔ Escapeway egress is partially or totally blocked** | | |
|---|---|---|
| Control measures | Threat 1 - Roof collapse in Primary Escapeway Segment 3 | Primary support – 6 and 8 ft (1.8 and 2.4 m) grouted bolts |
| | | Scale roof and ribs every 3 to 6 months, or as needed |
| | | Random observation of roof conditions |
| | | **NEW IDEAS(1):** Immediately implement a regularly scheduled roof conditions visual observation plan |
| | | **NEW IDEAS(2):** Design and install a monitoring system for roof crack and roof sag detection |
| | | **NEW IDEAS(3):** Design a method of stabilizing the roof in this area based on the information gathered from the roof monitoring program |
| | | **NEW IDEAS(4):** Consider stabilizing the adjacent Alternate Escapeway (Segment 4) to act as a buffer for securing this area |
| | Threat 2 - Charging station fire in Primary Escapeway Segment 3 | Battery water levels and terminals are checked weekly |
| | | **NEW IDEAS(5):** Place charging station outside mine |
| | Threat 3: Roof collapse in Alternate Escapeway Segment 2 | Monitoring with multipoint extensometers |
| | | Cable bolt support with steel screen |
| | | Observation of roof conditions |
| | | Breaker wall standing support |
| | | **NEW IDEAS(6):** Develop a trigger action response plan (TARP) for roof movement that will initiate additional rock reinforcement installation |
| | | **NEW IDEAS(7):** Repair/replace existing multipoint extensometers |
| | Threat 4 - Roof collapse in Alternate Escapeway Segment 4 | Scale roof and ribs every 3 to 6 months, or as needed |
| | | Random observation of roof conditions |
| | | Monitor microseismic emissions from the mine (just begun) |
| | | **NEW IDEAS(2):** *see above* |
| | | **NEW IDEAS(3):** *see above* |
| | | **NEW IDEAS(8):** Develop a policy to restrict access except in an emergency situation |
| Recovery measures | Consequence 1 – Roof collapse blocks the Primary Escapeway | **NEW IDEAS(9):** Consider installing refuge chambers in the active work areas |
| | | **NEW IDEAS(10):** Consider using the ventilation shaft as an Alternate Escape route |
| | Consequence 2 – Charging Station Fire in Primary Escapeway | Station is partially enclosed by a cinder block wall and metal roof |
| | | Scoop has fire suppression system |
| | | Fire extinguishers are present, although current policy is to evacuate rather than fight fire |
| | | Main office is contacted via radio |
| | | Use radios to communicate fire alarm to everyone underground |
| | | Sound the siren |
| | | Life lines exist in part of the Primary Escapeway |
| | | **NEW IDEAS(11):** Install backup generator for communication system |
| | | **NEW IDEAS(12):** Install fire detection/suppression systems on large diesel equipment |
| | | **NEW IDEAS(13):** All personnel and visitors to wear SCSRs (training needed) |
| | | **NEW IDEAS(14):** Close down charging station when the general public is underground |
| | | **NEW IDEAS(15):** Finish installing life line in all escapeways |
| | Consequence 3 - Roof collapse blocks the Alternate Escapeway | **NEW IDEAS(9 & 10):** *see above* |
| | Consequence 4 - Roof collapse blocks Alternate Escapeway | **NEW IDEAS(9 & 10):** *see above* |

b. Existing recovery measures: The existing recovery measures for a large roof collapse, capable of blocking the Primary or Alternate Escapeways consist of developing new escapeway routes or rehabilitating the roof fall area. If a fire occurred in the charging station area, a cinder block wall and metal roof could partially contain the fire. Fire extinguishers are present in this area, although current policy is to evacuate rather than fight the fire. Several pieces of diesel equipment have fire suppression systems. In the event of an evacuation, radio communication, directed by the mine office, would be used to communicate a fire alarm. A site wide siren is also available. Lastly, life lines exist in part of the Primary Escapeway.

c. Potential new prevention controls: Fifteen new control ideas were identified. These new controls are aimed at either the roof collapse or fire hazard. For the roof collapse hazards, new controls are divided into three groups: administrative, monitoring and engineering. An administrative control in the form of a policy could restrict personnel access to the Alternate Escapeway except in an emergency situation. A number of monitoring controls were discussed including: a regularly scheduled visual observation plan of roof conditions; installation of additional roof and crack monitors and a trigger action response plan (TARP) for monitors. New ideas for preventing roof collapse hazards include a supplemental rock reinforcement program for segment 3 of the Primary Escapeway and a stabilization design for segment 4 of the Alternate Escapeway. The new control for the fire hazard was to place the charging station outside the mine.

d. Potential new recovery measures: Several new recovery measures were identified. To mitigate the impact of a roof collapse, the existing ventilation shaft could be used as an Alternate Escapeway. Also, a rescue chamber could be installed in active work areas. New ideas to help recover from the fire hazard included using a backup generator for the communication system; installation of additional fire detection/suppression systems; elevated Personal Protective Equipment requirements; limited charging station use; and install life lines in all escapeways.

Action Plan: These new control and recovery measure ideas should be addressed through the development of an Action Plan. The Action Plan with the ideas inserted and space left for derivation of specific actions, timing and resourcing is provided in table 7.

## DISCUSSION

The attributes of this process are many. It helps to utilize the strengths of a team of experts familiar with the hazards being addressed. Risk analysis methods are used to focus the team on the highest ranked risk and to analyze these risks in a structured manner. The mine's current control and recovery measures are identified so that they can be monitored and audited. New potential control and recovery measures are produced for consideration by management. These new ideas are easily listed in the form of an action plan. The plan can then be delivered to management for prioritization and implementation.

A weakness in this approach has to do with the expectation that a specific design will be a direct outcome of the activity. Detailed designs are not easily accomplished in a MHRA exercise.

Table 7. Example of an action plan for the new ideas developed by the scoping team.

| Identified Potential New Controls | Specific Required Actions | Responsibility | Due date |
|---|---|---|---|
| 1) Immediately implement a regularly scheduled roof conditions visual observation plan | | | |
| 2) Design and install a monitoring system for roof crack and roof sag detection | | | |
| 3) Design a method of stabilizing the roof in this area based on the information gathered from the roof monitoring program | | | |
| 4) Consider stabilizing the adjacent Alternate Escapeway (Segment 4) to act as a buffer for securing this area | | | |
| 5) Place charging station outside mine | | | |
| 6) Develop a trigger action response plan (TARP) for roof movement that will initiate additional rock reinforcement installation | | | |
| 7) Repair/replace existing multipoint extensometers | | | |
| 8) Develop a policy to restrict access except in an emergency situation | | | |
| 9) Consider installing refuge chambers in the active work areas | | | |
| 10) Consider using the ventilation shaft as an Alternate Escape route | | | |
| 11) Install backup generator for communication system | | | |
| 13) Install fire detection/suppression systems on large diesel equipment | | | |
| 14) Close down charging station when the general public is underground | | | |
| 15) Finish installing life line in all escapeways | | | |

## SUMMARY

This paper provided a case study example as to how the MHRA approach, as practiced in Australia, might be used to mitigate the risk of roof instability and fire hazards in US underground mines. The major threats to escapeway egress are identified as well as an inventory of existing controls and recovery measures specific to each threat. New ideas are presented in an action plan for management consideration. All this is accomplished in a structured, group-oriented activity designed to produce a written report. MHRA promotes a more proactive approach to dealing with a mine's major hazards.

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