Mine Safety Technology and Training Commission

December 5, 2006

Mr. James F. Roberts
Chairman, Board of Directors
National Mining Association
101 Constitution Avenue, NW
Suite 500 East
Washington, D.C. 20001

Dear Mr. Roberts:

On behalf of the members of the Mine Safety Technology and Training Commission, I am pleased to provide the enclosed commission report, *Improving Mine Safety Technology and Training: Establishing U.S. Global Leadership.*

Since its creation in March 2006 by the National Mining Association (NMA) as an independent study commission, the commission has drawn upon the knowledge and experience of mine health and safety professionals from academia, government, industry and labor; those having special expertise in communications technology, emergency and disaster response and recovery; and mine rescue experts. Further, the report has benefited from a review by a group of recognized mine safety experts. The commission thanks the NMA and its members for supporting the creation of an independent study commission and the work that produced this report. And we applaud the industry's willingness to embark upon this important effort.

As the industry entered 2006, it was poised to continue a record of continuous improvement in mine safety. That record was tragically interrupted by fatalities that have rocked the industry and caused NMA and its members to recommit to returning the U.S. coal industry to a global mine safety leadership role with a goal of achieving zero fatalities and zero serious injuries in the U.S. underground coal mining industry. Our report outlines a way to achieve this goal. Specifically, it details a comprehensive approach to increase significantly the odds of survival for miners in emergency situations and to create a culture of prevention to address significant hazards that lead to injuries.

At the heart of our approach is a call for a new paradigm for ensuring mine safety: One that focuses on systematic and comprehensive risk management as the foundation from which all life-safety efforts emanate.

Additionally, the report recommends:

- Better technology in communications, mine rescue training, and escape and protection of miners;
- More frequent and realistic training focusing on key principles;
- A broadened and more professional emergency response and mine rescue capability; and
- Development of a culture that supports safe production at the business core.

In support of these overriding recommendations, which the commission members made unanimously, are 75 specific recommendations to the industry, including interim steps that can be taken until new technologies, where appropriate, are developed and approved for the underground coal mining environment.

To reach our recommendations, the commission looked at existing research and best practice training examples. We administered a "training for preparedness" opinion survey and examined the requirements of the Mine Improvement and New Emergency Response (MINER) Act, signed by the president in June, and the Mine Safety and Health Administration's (MSHA) Emergency Temporary Standards, which MSHA issued in March, along with the existing regulatory framework. We also utilized information from published literature, technical reports and the expertise of individual commission members, and we utilized lessons learned by NASA and the Navy nuclear submarine fleet.

Finally, we analyzed underground coal mining emergency incidents involving fires or explosions over a 25-year period, looking at common weaknesses and persistent problems, pinpointing unaddressed gaps and synthesizing insights gained from them. All of this has led to a comprehensive look at underground coal mining safety; how it has improved, what remains to be done and how to fulfill our promise to return each miner home safely everyday.

Today's underground coal industry is fast-changing. Miners work in an increasingly sophisticated and complex environment where the jobs of management, miners, contractors, emergency responders, mine safety inspectors and other mining professionals demand a full range of critical skills. Recent tragedies in underground coal mining present a serious challenge that demands new insights. Accordingly, the prevention of mine emergencies and accidents of all types require comprehensive approaches, based on the new insights, to reflect the reality of modern mining.

The commission has attempted to highlight some of these insights and to provide a framework for the industry as it pursues its mine safety objectives.

Sincerely,

R. Larry Grayson

R. Larry Grayson
Chair, Mine Safety Technology and Training Commission

Enclosure

cc: Kraig R. Naasz
President & CEO
National Mining Association

Improving Mine Safety Technology and Training: Establishing U.S. Global Leadership

Mine Safety Technology and Training Commission

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Acknowledgements

The commission extends its thanks and sincere appreciation to the MSHA and industry safety professionals who participated in the Training Survey. Your input is valued and your opinions are held in high regard. Special thanks go to Allen Dupree (MSHA), Pat Brady (MSHA), Ray McKinney (MSHA), Bruce Watzman (NMA), Jack Holt (CONSOL Energy), Nick Johnson (Arch Coal, Inc.), Bob Peters (NIOSH), Mike Brnich (NIOSH), and Kathleen Kowalski-Trakofler (NIOSH). Their input, cooperation, and support made the Training for Preparedness chapter possible.

The commission appreciates the participation of the mine rescue experts from across the country-east and west, coal and metal/nonmetal-including team trainers, captains, and members from Arch Coal, BHP, Bowie Resources, CONSOL Energy, the Deserado mine, Eastern Associated Coal, Energy West Mining, Massey Energy, Peabody Energy, and the Waste Isolation Pilot Project. Special thanks go to Link Derrick and Dianna Ponikva-Scott of Twentymile mine and Elizabeth Chamberlain of CONSOL Energy for their assistance and insight.

Before publication, the commission sought a thorough review of report content by multi-constituent, recognized mine safety experts, seeking their comments on whether the final draft report had missed any key points in the study related to the following questions:

1. What critical areas must be addressed to change the culture of mine safety in the U.S. to focus on prevention and pursue a systematic, risk assessment-based approach?
2. What fundamental changes in policy, processes, and practices must occur to achieve zero fatalities in the underground coal mining industry?
3. What level of training is needed to ensure that the culture, processes, and practices pursued will prepare miners, mine management, emergency responders, and mine safety professionals in all constituencies to meet the zero-fatality goal?
4. What needs to be done to drive technological solutions for persistent mine safety problems and to ensure timely implementation?

The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. In particular, the commission wishes to thank the following individuals for their review of this report:

Christopher J. Bise, West Virginia University
Robert Ferriter, Colorado School of Mines
Jim Joy, University of Queensland
Joseph A. Lamonica, Mine Health & Safety Consultant
Dave D. Lauriski, Safety Solutions International, LLC
Joseph A. Main, Mine Health & Safety Consultant
John N. Murphy, University of Pittsburgh
William York-Feirn, Colorado Department of Natural Resources

Although the reviewers listed above provided many constructive comments, they were not asked to endorse the findings and recommendations, nor did they see the final draft of the report, after review, prior to its official release. Responsibility for the final content of this report rests entirely with the authoring commission.

Finally, the commission acknowledges and appreciates the efforts of Congress in addressing important issues related to mine safety through the MINER Act. Also appreciated is the passing of an Emergency Supplemental Appropriation to enhance the adaptation of existing technologies in other sectors for application in underground coal mines.

Preface

During the period 1993-1999, no underground coal miners died from fires and explosions in the U.S. Further, a record low number of fatalities occurred in the coal industry in 2005, and the industry was poised to continue to make significant improvements. But in January 2006 and since, three mine tragedies rocked the industry, and coal industry fatalities have risen to 37 through July of 2006 as compared to 22 in all of 2005. As did many constituencies and Congress, the National Mining Association (NMA) called for closer, independent scrutiny of the causes behind the fatalities and how the causes could be addressed and the fatalities prevented. NMA established a multi-partite commission to independently study the causes of events and fundamental issues that must be addressed in order to move the U.S. coal industry back into a global mine-safety leadership role.

Since its creation in March 2006, The Mine Safety Technology and Training Commission has studied the relevant events and issues, while thinking broadly and innovatively about what should be done to achieve the objective of zero fatalities and zero serious injuries in the U.S. underground coal industry. Driven by forward thinking and a passion for the safety of miners who perform high-risk jobs, the commission has made 71 recommendations on how to achieve the overriding goals. ***The report that follows rings a clarion call for a new paradigm for ensuring safety in underground coal mines, one that focuses on systematic and comprehensive risk management as the foundation from which all life-safety efforts emanate.*** The process would underpin virtually all aspects of mine performance and systems analysis, and points to adoption of specific measures to mitigate identified risks. Additionally, the report recommends: 1) better technology in communications, mine rescue, training, escape and protection of miners; 2) more frequent and realistic training focusing on key principles; 3) a broadened and more professional emergency response and mine rescue capability; and 4) development of a culture that supports safe production at the business core.

It has been my pleasure to work with a very talented, inquisitive and constructive group of professionals that cuts across all the key areas of the study. Some are seasoned mine veterans in the coal and non-coal sectors, while others are specialists in mine emergency response and mine rescue. Still others focus on the development of new professionals for the industry, and some focus on mine safety and health research. The commission was also privileged to have the thoughts and insights from professionals outside the industry, versed in critical scrutiny of other tragedies, the latest technology beyond the mining industry, and ready to share their sharpened insights. I offer the commissioners my deepest appreciation for their tireless effort during the study and for their willingness to help make underground coal mines safer for our nation's dedicated miners.

R. Larry Grayson
Chairman

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Executive Summary

Mine safety in the U.S. has dramatically improved overall since the Mine Safety and Health Act of 1977, and fatalities, specifically, have dropped significantly over the past two decades. Recent tragedies have challenged that record of achievement, however, causing concern among all constituencies of the underground coal industry and reminding us that such an excellent record of improvement can be compromised quickly.

The commission believes that strong measures need to be adopted now by all constituencies of the industry to move the safety performance level in the U.S. to a leadership position globally. The commission has outlined the details of a risk assessment-based approach toward prevention, which should increase significantly the odds of survival for miners in emergency situations, and also provides a guideline for pursuing zero accidents from all sources. In the report details are also included in the areas of communications technology, emergency response and mine rescue procedures, training for preparedness, escape and protection strategies, along with 75 recommendations for achieving the overarching goals of zero fatalities and zero lost-time accidents.

In this report, the commission has specified what the needs and gaps are concerning mine safety, what constitutes a risk management-based culture of prevention, and what should be pursued as basic safety requirements or options. It is not the role of the commission to specify the means for achieving them, since various means for achieving the recommended changes exist, and the options should be debated in a broad mine safety process or processes. The commission envisions that all major stakeholders should be involved in any process seeking to actuate various recommendations, including Congress and MSHA as well as representatives of miners and mine operators. Implementation options for specific recommendations range from voluntary, joint development of Industry Safety Standards embodying Best Practices; legislation with follow-up regulation (Congress); regulation alone (MSHA and/or states); and peer pressure-based Best Practice evolution. The commission is hopeful that the details of the recommendations will be embraced by all industry stakeholders.

RISK MANAGEMENT

In proposing risk-related recommendations, the commission is calling attention to major hazards which have recently led to catastrophic events and the important role that government, industry, and workers all play in dealing with them. Thus as a minimum each mine should systematically identify its risks for an explosion, fire, or inundation. Some mines will have virtually no risk of one, but perhaps a higher risk of another. Regardless, once the risks are identified throughout the mine, or events have occurred, then each must be reduced or eliminated, if possible, and if not, they must be controlled to the point that risks are as low as reasonably achievable, which is the aim of good risk management. The purpose of the risk analysis is to identify the type, root cause(s), and extent of the risk. A variety of qualitative and quantitative tools/processes may be used, and those only matter to the extent that the risks and root cause(s) are defined. The purpose of the risk management effort is to reduce the risk through a variety of site-specific means. In some cases the risk may be reduced or eliminated through engineering, and in other cases engineering or administrative controls may be effective. Most often some risk will remain, and then training or the establishment of protocols or plans to address it, which essentially address behavior, would be developed. Frequently, a combination of actions is required to reduce the risk. Again the specific processes applied to reduce the risk are less important than the outcome, i.e. the extent to which the risk being managed lessens the likelihood of worker injury if an explosion, fire, or inundation occurs. **Accordingly, the commission recommends that a comprehensive approach, founded on the establishment of a culture of prevention, be used to focus employees on the prevention of all accidents and injuries. Further, the commission recommends that every mine should employ a sound risk-analysis process, should conduct a risk analysis, and should develop a management plan to address the significant hazards identified by the analysis; simple regulatory compliance alone may not be sufficient to mitigate significant risks. The commission recognizes that not all mines have a familiarity with risk management, and therefore recommends that NIOSH develop a series of case studies that mines could use as templates, and that it conduct workshops and seminars to diffuse this approach to safety throughout the industry.**

Ultimately in the broader sense, government and industry focus their risk-management efforts on reducing the major risks as well as substandard performances, where accountability is also an important ingredient. In this respect, mine and industry safety professionals are encouraged to seek certification as a best practice, which is aimed at elevating professionalism.

COMMUNICATIONS TECHNOLOGY

The most basic requirement of a post-tragedy communication system is to provide a communication link between the underground miners and surface personnel, after a fire, explosion, or inundation. A two-way system would be immensely more useful than a one-way system, since escaping or trapped miners could relay valuable information outside. Moreover, a voice rather than text system is likely to prove much more useable in emergency conditions.

The emergency communication system should be hardened[1] to make the system more fault-tolerant and be part of a mine's routine system, rather than an entirely separate system, to better ensure that it will properly function when an emergency occurs. The urgent timetable under which these systems must be deployed in underground coal mines means that a phased-in and evolutionary approach will be required. Clearly, each mine will find it necessary to employ different mixes of technologies to meet the needs for emergency communication for its site-specific conditions and infrastructure. Finally, it is unrealistic to expect a system to operate in all parts of the mine. Nonetheless, it is

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[1] A "hardened" system will more likely provide communication after an explosion, fire, or water inundation, and may be achieved though mechanical reinforcement of system components, for example, as well as through changes to the network such as providing redundancy, among other steps.

imperative that the system provide the desired functionality in and around active panels and in escape ways.

The commission recommends that mines utilize hardened mine pager phones or leaky feeder systems, as an interim measure, to meet the immediate need for post-incident emergency voice communications. Further, guidelines will have to be prepared to address network architectures, the mechanical strengthening of components, altered installation practices, and modifications to the hard-wired network. The preparation of these guidelines or *best practice* documents will require substantial engineering design and testing, but is doable over twelve to eighteen months. **The commission recommends that the development of these guidelines be completed as soon as possible.** Employing hardened pager systems in escape ways and active panels, for example, is achievable with current technology, and would represent an important step forward. Hardening of leaky feeder systems may require modest system design changes, but even these should be addressable within a year or so. These systems could continue to serve as backup emergency communication systems as more advanced technologies come online. There may also be an opportunity to incorporate these hardened systems into *safe havens* or *refuge rooms*.

While hardened systems can meet an important need for emergency communications in coming years, they really only represent an interim solution until more advanced technologies are successfully demonstrated and commercially available. **The commission recommends that a hybrid communication system be developed to allow reliable wireless communication enhanced by the leaky feeder backbone or other metallic infrastructure, such as wire-core life lines, haulage track, and pipes, and that such a system be deployed in mines as soon as possible.** By further refining and adapting technologies developed for military applications, it may be possible to bring such a system to commercialization within the next three years.

Improvements to the communication systems used by mine rescue teams are needed. A particular type of technology system tested under the Emergency Communications Partnership shows particular promise for mine rescue applications with nodes that utilize the IEEE 802.11b WiFi networking standard at 2.4 GHz. The nodes are portable and can be battery powered. Several nodes combine to create an ad-hoc mesh network. The network can be deployed as a stand-alone wireless network as the rescue team advances into the mine. Good quality voice and data communications can then be established through the network. This system is currently applied by first responders in non-mining applications, such as police and firefighters, and in these applications it has been found to be durable and to provide reliable communications. The current product needs to be re-designed to meet intrinsic safety requirements. **The commission recommends that work be done to adapt this "breadcrumb" technology for use by mine rescue teams.**

The implementation of an electronic miner tracking system will depend heavily on the existence of a communications system's ability to transmit the tracking data outside of the mine in a post-tragedy environment. Thus the applied research and engineering developments recommended in this section are a prerequisite to a successful tracking system. Assuming that effective wireless communication systems begin to come on-line during the net three years, the details of implementing the tracking in the vast expanses of an underground coal mine must be addressed. It is likely that a radio-frequency-identification (RFID) tagging system will be adapted for use. While the use of such a system in a normal production environment is straightforward, it is not for a post-fire/explosion setting. **The commission recommends that work be conducted to develop an RFID-based tracking system that will function with the emergency communication systems that are under development, such as software-defined radio, and that the system be demonstrated as soon as the emergency communication systems are developed.**

Communications for underground mining is unregulated – a Federal Communications Commission does not exist for underground mines to allocate frequency bands, power levels, and to take other measures to ensure the interoperability of devices or that devices do not interfere with each other. There are already examples of interference, and if these routine and emergency communication and tracking systems are to operate harmoniously with mine-monitoring systems, remote-controlled machinery, and so forth, standards must be developed. **The commission recommends that NIOSH lead the development of standards for wireless communications in underground mines.**

The above recommendations are based primarily on the need to bring emergency communications and tracking technologies on-line as soon as possible. To this end, the commission acknowledges and appreciates the efforts of Congress in passing support through an Emergency Supplemental Appropriation for moving technology from other industries into underground coal mines. At the same time the commission recognizes that several different technologies, in various stages of maturity, are in process, and it recognizes that these must be moved forward to ensure that emergency communications and tracking will fully meet all of the needs of the mining community. This must be a continuous process of improving technology and integrating it into the mines. **Accordingly, the commission recommends that alternative and promising emergency communications and tracking systems be developed and commercialized for the long term enhancement of mine safety.**

EMERGENCY RESPONSE AND MINE RESCUE PROCEDURES

The primary purposes of mine rescue teams are to rescue survivors and recover fatalities in the event of an accident. In pursuit of these goals, teams can be called to provide a variety of functions, including exploration, removing or isolating ignition sources, building ventilation structures, setting roof support, and implementing ventilation plans. In addition, teams often have skilled first-aid providers (often certified Emergency Medical Technicians) and firefighters, who may need to perform their associated duties. The conditions under which teams operate are unstable, dangerous and unpredictable. The exigencies are extreme when lives are at stake. There are two fundamental enablers of success under these circumstances: the skill of team members and their level of trust for each other, other teams and those directing them. The commission's recommendations target the following two goals: to rescue survivors and to recover a mine. Beyond the MINER Act of 2006, the provisions of which are consistent with our own conclusions, there are important efforts already under way to enhance mine rescue practices and procedures. Recommendations for improvement of the national mine rescue capability fall into several categories, as defined below.

Recommendations on Training Quality

- **The minimum amount of training required of mine rescue team members should be increased to eight hours per month.**

- **The Mine Safety and Health Administration (MSHA) should better validate mine rescue training by observing training in progress in addition to checking training logs.**

- **In conjunction with the requirement to certify teams, MSHA should conduct a systematic review of the skills required of teams. Foundational capabilities and specialized functions should be clearly identified, and the capabilities, tasks and skills required to fulfill them determined. In addition, as broader sets of skills are recognized as being relevant to team capability; training requirements, resources and contests should expand to include them.**

- **Federal and state government agencies and industry should partner to develop more joint training facilities that provide realistic environments, such as the National Institute for Occupational Safety and Health (NIOSH) Lake Lynn Laboratory experimental mine facility near Pittsburgh and at experimental mines located at academic institutions or other organizations.**

- **Every mine rescue team should be familiar with all mines to which it is committed to respond.** MSHA may have to intervene to ensure operators regularly share updated maps with the teams that service them.

- Operators must recognize that reasonable preparation for a contest – held periodically to test skills and build esprit de corps – requires about twenty hours above and beyond the commission's recommended monthly eight-hour training requirement. **Given that most teams depend on volunteers, companies should recognize individual and team success at contests with monetary and non-monetary rewards.**

- **MSHA should establish criteria for the development and use of contest problems to ensure that the time to complete a problem, which is easy to assess during a competition, should not displace other important skill-based performances as primary contest objectives. Likewise, contest problems should emphasize functions that teams will likely have to perform during an emergency.**

- **In addition to devising contest problems, MSHA should help operators and teams devise exercise plans that will help them practice all aspects of mine emergency response.**

Recommendations on Collaboration

- **MSHA, NIOSH, state agencies, industry, and the mine rescue associations should collaborate to conduct a system-wide assessment of teams' locations, availabilities, and capabilities. The findings of this assessment should be compiled as a knowledge-base that is regularly updated.**

- **After any major exercise or incident, the mine rescue teams involved should be required to write a report that described their operations, focusing especially on lessons learned, recommended practices, and required improvements. These reports should be disseminated to all mine rescue teams nationwide.**

- **The industry should support joint training between teams. MSHA should collaborate with states and operators to support joint contests. In cases where metal/non-metal, coal, and surface mines are near each other, formal agreements should be developed to assure support during incidents.**

- **MSHA should convene an annual learning conference for all mine rescue teams (metal/nonmetal, coal, underground and surface) and those who directed or coordinated responses to past emergencies to facilitate collaboration and information-sharing.**

Recommendations on Standardization

- **MSHA should establish detailed qualification, certification and substantive training requirements for mine rescue team members and all team positions and functions as part of its requirement to certify teams.**

- **Procedures should be standardized so that all teams of a particular type (surface or underground, coal or metal/non-metal) operate the same way. We recommend that this be facilitated by MSHA, but ultimately achieved through a consensus process, similar to that used by various standards-setting entities.**

- **These requirements should be supported with standard training curricula, manuals, materials that are published, regularly updated, and disseminated to all teams.**

- **A federally-sponsored national mine rescue academy should be created for the purpose of building a national community of policy and practice.**

Recommendations on Team Expertise and Sustainability

- The strongest teams include personnel drawn from a wide variety of jobs. **Teams should strive to obtain and maintain broad-based and current underground expertise. Teams should also pursue formal mechanisms for augmenting their capability with specialized expertise, such as through agreements or relationships with physicians, paramedics, or firefighters. While issues of**

training and liability of non-miners will need to be evaluated, mine operators, and especially small operators, should explore integrating local first responders into their mine emergency response organizations.

- **Teams should develop strategic workforce and succession plans to identify and plan for key personnel requirements.**

- **Mines should consider incentive programs for rescue team participation that include monetary and non-monetary rewards for performance, certification, specialized qualifications, training, contest success and other examples of commitment to the operation above and beyond basic job requirements.**

- **Key team management positions (team coordinator and trainer) should be recognized by mine management as a primary duty. In some cases, full-time mine rescue personnel may be justified.**

- **If a team is deployed to an incident at another operator's mine, then they and their employer should be held harmless, as long as mine rescue teams are acting within their training and procedures and making reasonable judgments. The scope of protection in that regard guaranteed by the MINER Act should be specified so that mine rescue teams understand it fully.**

- **Since mine rescue team volunteers are asked to take risks above and beyond those associated with normal mining work, operators that staff teams should carry extended life insurance policies for every mine rescue team member so that families are not penalized for their voluntary sacrifices.**

Recommendations on Response Time

- **Require that adequate resources are dedicated to minimize response times. Attention should be given to four key factors:**

    - **Notification. Teams should employ a formal notification process. They should keep and continuously update contact information for all team members. They should consider using paging technology.**

    - **Personnel availability. Teams should use clear accountability mechanisms so that the status of team members is known at all times. Teams should consider using duty schedules to assure that a minimum number of personnel are always available to respond immediately and can arrive at their mine within a set time period.**

    - **Transportation. Teams should have access to a dedicated vehicle and trailer to transport team members and equipment to other mines in case of an emergency.**

- **Coordination. Teams should have current points of contact at all mines for which they are formally responsible. They should establish in advance a process by which, in the event of an emergency, they can receive electronically current mine maps and an initial situation briefing so they can study them while they are en route.**

Recommendations on Team Deployment

- **The safety of the rescue team should remain the first priority. To this end, back-up teams should be available underground and outside whenever anybody is underground during an emergency (miners or another team), whether they are engaged in rescue or property recovery.**

- **In cases where miners are trapped, mine operators should exercise their authority to direct rescue teams to begin operations. They should not wait for MSHA direction to do so.**

- **Mine operators should be afforded the flexibility and discretion to relax conservative safety standards in accordance with the conditions they face. Similarly, while minimum safety standards must still be enforced, it is appropriate that they be more stringent when property recovery is the objective than when lives are at stake. Teams that are deemed certified should be permitted a greater measure of flexibility, discretion, and autonomy commensurate with their skills and qualifications to allow them to respond appropriately to the conditions they experience underground, and to use their resources as efficiently as possible.**

Recommendations on Incident Command and Decision-Making

- **Broad requirements for common command center training should be established. Command center exercises that include interactions with teams should be conducted regularly, and at least a few command center personnel should train with their mine rescue teams. MERD, MERITS or another command-center exercises should be used regularly (at least every two years) by anyone who could be involved in directing a rescue operation, including mine managers, MSHA officials and mine rescue teams.**

- **Mine managers, MSHA officials, and mine rescue teams should receive formal training in using the functionally-oriented Incident Command System (ICS) for directing responses to mine emergencies.**

- **Training should be developed for mine rescue teams and mine managers on team-based decision-making and how to communicate effectively.**

- **The linkage between teams and the command center should be strengthened. In particular, the communications and decision-making process should be formalized so that teams have a clear position in the communication "loop."**

Teams should have a clear, single point of contact in the command center who is knowledgeable about both team operations and mine management. When robust communications are in place, a future option to consider when revising command center protocols would be eventual relegation of the Fresh Air Base to a staging area.

- **The briefing/debriefing process should be systematized and should involve the entire team.**

- **A more rigorous process for developing a shared understanding of priorities and objectives should be developed and adopted universally. Joint planning meetings for each operational cycle should be conducted and should include team inputs. Teams should be able to voice ideas and concerns without fear of retribution.**

- **The industry should develop protocols for communicating with the media and other outside parties. All mines should train on these.**

- **The integrity of internal communications should be protected and information leaks should by prevented by isolating communications between the command center, fresh air base and teams.**

- **Operators and teams should improve the precision of their knowledge of the scope and authority of mine managers and MSHA, the conditions under which this knowledge may change, and the mechanisms that alter authority during an emergency.**

Recommendations on Equipment and Technology

- **Investments should be made to demonstrate, test, and field available technologies that show potential for improving team operations. Research and development efforts should target promising technologies that could enhance survivability and mine rescue capability. In particular, MSHA should work to expedite the approval and certification process for technologies that can improve life safety.**

- **Apparatus support for emergencies should be upgraded. In particular, a trained benchman should be posted at the fresh-air base to handle minor apparatus problems. Portable facilities for cleaning, benching, and drying apparatus that can provide direct support to multiple teams should be developed and deployed.**

- **Mines should consider ways to keep power on for safety support systems or establish a separate electrical circuit for the water system and compressed air going underground.**

- **In advance of improved communications technologies (discussed elsewhere in this report), current mine communications systems should be hardened, and the ability of teams to operate communications technologies should be improved.**

- **Each mine should have, on a constant basis, arrangements for competent survey personnel and equipment to be immediately available at each mine to expeditiously identify surface locations for drill sites, and each mine should maintain arrangements for emergency drilling equipment as part of the mine emergency response plan.**

- **The equipment requirements for mine rescue teams should be periodically reviewed and updated in light of current technologies and typical missions. Once developed, new equipment should be displayed and demonstrated at national and regional training venues.**

TRAINING FOR PREPAREDNESS

Training strategies are a critical component in our effort to improve the ability of miners to survive a mine-wide emergency. As a result, the commission analyzed the emergency self-escape and aided-rescue competencies of underground miners and other mine-site positions with responsibility for responding to an emergency, e.g., supervisors, mine managers and responsible persons on the surface. The objective of this analysis was to identify and close skill/knowledge gaps with the greatest potential to improve the ability of miners to escape or to be rescued during a mine emergency. The commission identified three key skill/knowledge areas that are critical to the ability of miners to escape or be rescued during a mine-wide emergency. These areas include:

- *Knowledge of Escape/Rescue Technologies*
- *Mine-Specific Knowledge*
- *Escape/Rescue Conceptual Knowledge*

Miners must be competent in all three skill/knowledge areas to successfully escape or to be rescued during an emergency. They must be proficient in their knowledge of the mine and competent in using the available escape/rescue technologies. They must also have the ability to solve complex problems and the fortitude to make critical decisions. *In the commission's opinion, the escape/rescue training need with the greatest potential to improve the ability of miners to successfully escape during a mine-wide emergency is in the area of* ***Escape/Rescue Conceptual Knowledge.***

Review of NIOSH Research

The commission's "training for preparedness" recommendations are based on existing research, including NIOSH's considerable research into the behavioral aspects of escaping an underground mine during an emergency. In general, NIOSH found U.S. miners were less well-trained in the areas of self-escape and aided-rescue than many of their foreign counterparts. To some extent, the researchers attributed this finding to the standard (or) prevailing training methods used in the U.S. mining industry. They described these methods as over-relying on the rote learning of information and passive methods of instruction (i.e. videos and films).

One key finding identified by the NIOSH research was that *miners tend to respond to mine-wide emergencies as a group***,** as opposed to acting as individuals. The NIOSH research also identified the *quality of group leadership* as having a significant impact on the "escape group's" perception of the problem, its ability to cope with stress, the effectiveness of its problem solving, and overall group behavior in response to the problem. In addition, the NIOSH researchers found that the *quality of decision-making* was closely related to the effectiveness of an escape group's evacuation.

Best Practice Training Examples

One aspect of the commission's analysis involved an evaluation of available training materials. The commission evaluated forty-two distinct instructional programs available through the MSHA Academy Resource Library and/or NIOSH. The best available training resources for developing the conceptual skills of underground miners are the NIOSH simulated emergency exercises. These materials include, but are not limited to, the following exercises:

- *I Can't Get Enough Air*
- *Travel Through Smoke*
- *The Belt Fire*
- *Smoke on the Section*

These exercises provide the trainee with detailed, fact-specific problem-solving scenarios. They require trainees to react to complex, changing situations and to integrate their knowledge of basic mine emergency concepts.

Training for Preparedness Survey

The commission administered a "training for preparedness" opinion survey (Survey). The Survey sought the opinion of industry and MSHA safety professionals on key "training for preparedness" issues. The training issues addressed by the Survey include the following:

- The escape/rescue competency levels of miners
- Methods of evaluating competency levels
- The need to develop new/better training materials

In the commission's view, the results of the Survey confirm the findings of the NIOSH research with regard to improving the ability of miners to escape (or be rescued) during a mine disaster. The Survey's results also lend foundation to the following general recommendations in the area of "training for preparedness." **The commission recommends:**

- **The primary focus of self-escape and aided-rescue training must be on preparing miners to escape during a mine emergency.**

- **Training miners to escape (or be rescued) during a mine emergency must be based on a comprehensive emergency response plan that is risk-based and mine-specific. All mine operators must prepare for emergencies and train miners thoroughly on their emergency response/rescue plan(s).**

- **To be effective, "training for preparedness" interventions must be performance-oriented. In addition to training content, the intervention must consider non-training- related factors, such as the physical capability of miners to walk their escape ways.**

- **"Training for preparedness" must be competency-based. It must focus on the critical skills/knowledge miners need in order to successfully escape (or be rescued) during a mine emergency.**

- **"Training for preparedness" interventions should be systems-based. Interventions should be designed to address identified training needs (gaps in performance). They should also be designed according to sound instructional design concepts.**

- **In order to better identify "training for preparedness" needs, the industry needs to improve methods of evaluating miners' competencies. The performance of miners, mine managers and responsible persons on the surface should be evaluated during emergency response drills and mock-disaster exercises. In addition, actual mine-wide emergency incidents and near-miss events should be analyzed to identify "lessons learned."**

- **"Training for preparedness" programs and interventions should be reviewed and revised at least on an annual basis.**

Regulatory Training

On March 9, 2006, MSHA published an Emergency Temporary Standard (ETS) on Emergency Mine Evacuation. In addition, on June 14, 2006, President Bush signed the Mine Improvement and New Emergency Response Act (MINER Act). The MSHA ETS and the MINER Act both contain provisions requiring improved emergency response-related training for miners (and other key emergency response personnel). *In the commission's opinion, many of the key "training for preparedness" needs identified by the NIOSH research and the commission's Survey will be addressed if mine operators comply with these new training requirements*.

- **The commission recommends that the priority training needs identified below be addressed in this manner.**
  - **SCSR Training**
    - **Donning an SCSR**

        - **Transferring from one SCSR unit to another SCSR**
        - **Expectations training (breathing through an SCSR)**
        - **Location of SCSR caches**

    - **Escape ways**
        - **Location of escape ways**
        - **Walking key portions of escape ways**
        - **Location and use of life lines (and other directional devices)**
        - **Way-finding (utilizing alternate escape routes)**

    - **Ventilation**
        - **Mine ventilation systems**
        - **Ventilation leakage**
        - **Effects of carbon monoxide and other gases**

    - **Barricading**
        - **Barricading as a last resort**
        - **How to erect an effective barricade**

    - **Emergency Response Procedures**
        - **Training on mine emergency response plan**
        - **How to give/receive effective emergency warnings**
        - **Firefighting training**

While regulatory training can address many of the "training for preparedness" needs, the commission believes additional self-escape/aided-rescue training should be offered to miners. Part 48 (and other required emergency response) training requirements are not sufficient to deal with the training gaps that exist in this area. In order to adequately prepare miners for self-escape/aided-rescue, the mining industry needs to provide employees with training in addition to what is required by law. *A particular emphasis should be placed on providing additional self-escape/aided-rescue training for supervisors and other individuals with critical emergency response responsibilities*.

In addition, **the commission recommends that MSHA use its existing authority to approve training plans to improve the quality of training provided to miners.** Improved competency-based training designs are needed to improve the effectiveness of regulatory training. In addition, improved instructional designs should be applied to regulatory training to make it more interactive and interesting to miners.

Priority Training for Preparedness Needs

*In the commission's opinion, the escape/rescue training needs with the greatest potential to improve the ability of miners to successfully escape during a mine-wide emergency are in the area of **Escape/Rescue Conceptual Knowledge**.* Miners need "conceptual knowledge" of the common issues related to mine disasters. They should be able to apply this conceptual knowledge to their specific situation. Conceptual knowledge is a higher level of understanding. It is attained by exposing the learner to examples (and non-examples) of the concept they are trying to understand. Within the context of "training for preparedness," miners can better understand the concepts of self-escape and aided-rescue if they are exposed to various types of mine disaster scenarios. Training in the area of Escape/Rescue Conceptual Knowledge is only partly addressed by the MSHA ETS and the MINER Act.

- **The commission recommends that the industry, MSHA and NIOSH focus their "training for preparedness" efforts in this critical area. These efforts should concentrate on the development and delivery of training interventions in the following areas:**

    - **Emergency response decision-making training**

    - **Leadership training for supervisors**

    - **Team-building training**

    - **Simulated smoke training**

    - **Dealing with stress during:**
        - **Emergency escape**
        - **Barricading**
        - **SCSR use**

    - **Command center protocol for mine managers**

Evaluation Methods

- **The commission also recommends that the industry, MSHA and NIOSH focus on developing and/or improving methods of evaluating the self-escape and aided-rescue competencies of underground miners (and other key emergency personnel) in the following areas:**

    - **Emergency/response decision-making**
    - **Coping with a smoke-filled environment**
    - **Implementing emergency response procedures**
    - **Locating escape ways and life lines**
    - **Way-finding (identifying alternative escape routes)**

Need for New/Better Training Materials

The commission identified a significant training materials gap. There is a lack of available instructional material for intermediate-level escape/rescue training for underground miners. Self-escape and aided-rescue training resources are needed to bridge the gap between basic skills and advanced-level mine rescue/emergency response**.** The existing resources tend to underestimate the likelihood that underground miners will be involved in a real-life emergency that requires them to utilize emergency problem-solving and/or decision-making skills.

- **As a result, the commission recommends that industry, MSHA and NIOSH focus resources on developing new/improved training materials in the areas listed below:**

    - **Simulated smoke training**
    - **Emergency/response decision-making**
    - **Team-building**
    - **Leadership training for supervisors**
    - **SCSR expectations training**
    - **Building effective barricades**
    - **Mine rescue protocol training**

Conclusion

In closing, the commission wishes to emphasize that the "training for preparedness" performance needs identified here will not be met on their own. The workforce demographics of the U.S. mining industry are undergoing significant transformation. A significant percentage of the industry's workforce is over 50 years of age. As time goes by, more and more inexperienced miners will be entering the workforce. This fact makes it imperative that we close the skill/knowledge gaps in this critically important area, not only among the existing workforce but also with new employees. Increased emphasis must be placed on passing the knowledge of retiring exemplary workers to succeeding generations of miners as well, not only in these critical areas but in others like hazard awareness and control, which is part of every task in mining.

ESCAPE AND PROTECTION STRATEGIES

As emphasized in the report, prevention of fatalities and serious injuries through a systematic and comprehensive risk management-based planning and design process is paramount. Accordingly, t**he commission recommends that mine-specific escape and rescue plans be required for each underground coal mine, and such plans must specify measures to be taken to address specific hazards at the mine, associated with the mine's characteristics.**

Because of the high priority of escape from the mine during an emergency, the following recommendations are aimed at increasing the probability of escape:

- **Pursue improved technology for oxygen provision so that devices can be practically worn by the miner.**

- **Install life lines, preferably with a metal core, to facilitate emergency communications, or other direction-indicating devices in all designated escape ways.**

- **Make available tag lines available at strategic locations in a mine, including near the beginning of all designated escape ways.**

- **Locate required oxygen-supply device caches in substantially constructed, or protected areas between adjacent designated escape ways. This would require MSHA approval.**

- **MSHA-approved compressed air breathing apparatuses and refill stations, or other approved oxygen-supplying devices, may be substituted for SCSRs in a mine, provided devices are not mixed.**

- **Incorporate the use of strategically located ventilation or escape shafts equipped with escape hoists when feasible and consistent with a risk analysis as a strategy to reduce escape times from a mine during an emergency.**

The commission recommends the following actions to protect miners during an emergency, even if they are not able to escape:

- **Pursue research and/or development of oxygen-supply devices such that the devices provide adequate oxygen to effect escape, are capable of renewing the oxygen source without removing the face piece and are more practically wearable.**

- **Develop standards to govern specifications for a safe room for future optional implementation.** Hardened, isolated "safe rooms" could be constructed along escape ways where escaping miners may take off their SCSRs, rest, get food and water, and through borehole service, call outside for a status update (both ways). Miners could then move on to the next "safe room." **The implementation of safe rooms should be based on risk analysis.**

- **Evaluate specifications for fire-suppression systems, the flow quantity and pressure required for water lines, and other fire-protection measures for compatibility with modern technology, and any required modifications must be evaluated by means of a risk analysis.**

- **The commission recommends that the industry expand its ability to control fires, and mitigate the risk of a major fire by developing "Fire Brigades," first responders, etc. and further recommends that every underground mine adopt the Fire Brigade, first responder, etc. concept. The commission also recommends that MSHA provide support for Fire Brigades, first responders, etc. by developing relevant, effective training materials.**

- **Apply a systems approach to mine ventilation, utilizing mine personnel familiar with overall ventilation-system complexities, to analyze different possible modifications of the ventilation system for potential hazards and assure that risks are identified and addressed.**

- **Research is needed to determine whether new science-based, practically achievable specifications for stopping construction along escape ways are needed to better preserve the escape routes for use in emergencies.**

- **Establish new criteria for the approval of seal designs and installation through research. Seal design and installation must be certified, and mines must conduct a risk-based assessment of all potential hazards related to sealed areas to determine how to manage any identified risks.**

- **Develop "hardened" monitoring systems and methods for safely and effectively utilizing monitoring during emergencies.**

- **Conduct research and development to identify opportunities and practices for safety improvement through an expanded use of a mine monitoring system.**

- **Conduct research on strategies and technologies to maintain miners trapped underground and to facilitate their rescue.**

- **Employ a range of strategies and technologies that are consistent with the mine's risk analysis and management plan.**

- **Require mine operators to develop rescue management plans that look at the hazards, decisions and actions that could be taken for any given situation by miners, managers, mine rescue teams and incident management teams. Using a risk management-based process, the more likely scenarios would be assessed for hazards and interventions taken to reduce the risks.**

Although the initial goal of this study was to significantly increase the odds of miners' survival in emergency situations, the overriding issues mentioned above came to the forefront as the commission realized that much needs to be done systematically across a broad range of areas to achieve that goal. In the end, the commission is hopeful that its comprehensive recommendations, once adopted, will make a significant difference in preventing fatalities and serious injuries from occurring in the future.

Certainly other major issues are pressing the mining industry now, and no small problem is the shortage of miners and mining professionals, including those who must engineer and manage mines as well as do the research and development work. In particular concerning research and development recommendations, retirement of researchers from NIOSH is problematic. Accordingly the commission acknowledges that a major effort must be undertaken to enhance the ties between universities and Federal mine health and safety research efforts, so that students view research into developing technological solutions to address mine safety problems as an attractive career option.

With the myriad recommendations made and the driving goal of creating a risk management-based culture of prevention comes an onus for supporting change for the high-risk underground coal mining industry. Other organizations and industries with high-risk missions, such as NASA, the Navy's nuclear submarine fleet, and the nuclear power industry, require substantial facilities and recurring funding to address their safety risks well. Such should be the case for underground coal mining, particularly reflective of the most current compromises of miner safety. **Accordingly, the commission recommends that Congress study the level of funding that would be commensurate with the need to support research and development, cultivation of safety and technical professionals, addressing the serious shortage of miners and mine supervisors, and other issues for this high-risk industry.**

1
Introduction

Recent tragedies at the Sago Mine, the Aracoma Alma Mine No. 1, and Darby Mine No. 1 have caused concern among all constituencies of the underground coal industry. The prevention of further tragedies is being addressed through many venues, including the Mine Safety Technology and Training Commission. Each of the recent tragedies and others that have occurred since 2000 give lessons that must be heeded and addressed comprehensively. This report, completed before the release of the final investigation reports by MSHA, outlines the details of a comprehensive approach toward prevention, which should significantly increase the odds of survival for miners caused in emergency situations, but should also provide a guideline for pursuing zero accidents.

Mine safety in the U.S. has dramatically improved since the 1977 Mine Safety and Health Act, with the Fatal Incidence Rate for underground coal mines dropping from 0.069 (per 200,000 employee-hours worked) in 1978 to 0.036 in 2004, or a 47.8% reduction over 26 years. During the period the number of fatalities in underground coal mines dropped from a high of 112 in 1981 (a Fatal IR of 0.112) to a record low of 14 in 2004, while the number of underground coal mine employee-hours worked changed from 200.8 million in 1981 to 78.2 million in 2004 (61.1% reduction).

The corresponding figures for underground metal/nonmetal mines are a Fatal Incidence Rate of 0.135 in 1978 to 0.022 in 2004 (2 fatalities), or a 83.7% reduction over 26 years. The number of fatalities in these mines dropped from a high of 35 in 1978 to a record low of 1 in 2003, while the number of underground employee-hours worked changed from 55.0 million in 1979 to 18.2 million in 2004 (66.9% reduction).

The non-fatal days lost incidence rates (NFDL IR) for underground coal mines and underground metal/nonmetal mines were similar in 1978 at 10.87 and 10.54, respectively. In 2004 the NFDL IR was 6.24 for underground coal mines and 3.50 for underground metal/nonmetal mines. Each of these records represents a significant improvement of the lost-time injury rate, with metal/nonmetal underground mines dropping by 66.8% while the rate dropped by 42.6% for underground coal mines.

In spite of these dramatic improvements, the Sago Mine and Darby Mine No. 1 explosions have reminded the entire industry that such a record can be compromised in an instant, and the recent accumulation of fatalities in underground coal mines is a stark reminder that a record of continuous improvement can be shattered in an entire sector. A new emphasis on preventing such tragedies is now manifested.

In the aftermath of the spate of fatalities in underground coal mines in 2006, Congress and state legislatures have pursued legislation directed at drastically reducing the possibility of another mine disaster as well as improving the overall mine health and safety efforts to protect miners; however, more is needed, particularly directed at creating a culture of prevention. The U.S. coal companies with underground coal mines have also taken initiative toward the same goals, and through the National Mining Association, have established the independent Mine Safety Technology and Training Commission to study the situation and recommend interventions in technology, emergency response and mine rescue procedures, and training directed at achieving the ultimate goal of zero fatalities and zero lost-time accidents.

RATIONALE FOR STUDY

Notwithstanding the dramatic improvements in the safety of mines over the past 28 years, the commission foresees a time when zero fatalities and zero injuries are hallmarks of dedicated mining companies across sectors. Achieving such goals will require a systematic risk management-based approach by companies aimed at prevention, which will focus on interventions to eliminate or greatly mitigate threats of hazards through the following components:

- Setting and revising goals and objectives systematically and incorporating risk analysis to drive continuous improvement through iterative analysis for addressing targeted risks;

- Comprehensive development of skills, best work practices, and situation-based decision-making among the workforce, including emergency response and mine rescue procedures;

- As a matter of business, exceeding the minimum requirements in specific areas where hazardous conditions and situations are inadequately addressed by regulations;

- Pursuit and incorporation of new technology including communications, mine rescue, escape, and protection technology that can achieve desired risk reduction;

- Self-inspection and self-policing of periodically revised benchmark objectives, practices, and policies designed to achieve continuous improvement of safety and operating performances; and

- Forming a broad partnership of industry expertise to critically and periodically review state-of-the-art training, technologies, strategies and practices in addressing hazards and reducing risks.

Soon after its formation in March 2006 the commission developed a charter to frame its study process, address the broader safety goals, and focus on the specific need for preventing tragedies like Sago Mine, Alma Mine and Darby Mine No. 1 in the future. The commission's charter follows.

CHARTER

The tragedies at the Sago Mine and the Alma Mine have revealed vulnerabilities at some underground coal mines that must be addressed to afford miners additional protection. Over the past two decades significant developments in new information-age technology and practice have been realized, some of which could find applications in underground coal mines to improve all aspects of safety, e.g., communications, risk analysis, information analysis to support decision-making, emergency response, training, etc. The Mine Safety Technology and Training Commission will study existing and new technologies, as used in various industries, to determine which can improve the protection of underground coal miners, who work in a quickly changing industry, which may require new perspectives and approaches. Through information-gathering meetings, the commission will particularly examine the conditions under which various technologies and training procedures can significantly increase the odds of survival for miners in emergency situations. A report reflecting recommendations of specific practices and technologies and safety-related gaps that could better protect miners will be drafted by June 30, 2006, be peer-reviewed, and then published before the end of the year.

PROCESS

The commission consists of 10 members with expertise in coal mine health and safety drawn from across the major constituencies (academia, government, industry, and labor) and with some having special expertise in communications technology; crisis, emergency, and disaster response and recovery; and mine rescue. *Biographical sketches of the commission members appear in Appendix A. The commission met four times to gather and evaluate information and to prepare its consensus report – in March, April, May and July 2006 in Washington, D.C. Realizing the relevance of specific NIOSH research in several areas, subcommittees of the commission requested and met with NIOSH staff to learn more about the topics. Commission members also relied on information from published literature, technical reports, and their own expertise.*

This report presents the details of the study in the areas of communications technology, emergency response and mine rescue procedures, training for preparedness, escape and protection strategies, and recommendations for achieving the overarching goals of zero fatalities and zero lost-time accidents, along with justifications for them. The commission is hopeful that these recommendations, once adopted, will make a significant difference in preventing serious injuries and fatalities from occurring in the future.

2

Review of Mine Emergency Situations in the Past 25 Years: Identifying and Addressing the Issues and Complexities

This chapter recounts lessons learned from emergency incidents over a 25-year period, summarizes common weaknesses and persistent problems that occurred, pinpoints unaddressed gaps, and synthesizes generalizable insights gained from them. Today's underground coal industry is fast-changing, and miners work in an increasingly sophisticated and complex environment where the jobs of management, miners, contractors, emergency responders, inspectors, and other mining professionals are replete with critical skills. The recent trend in fatalities is a serious issue that requires new insights. Accordingly, the prevention of mine emergencies and accidents of all types require comprehensive approaches, based on the new insights, to reflect the reality of modern mining.

The significant progress since 1977 in reducing the Fatal IR for underground coal mines was mentioned in the introduction. But after the events in 2006 a renewed emphasis on accident prevention is now manifested. The Sago Mine, the Aracoma Alma Mine No. 1, and the Darby Mine No. 1 fatalities resulted from two explosions and a fire. To place their occurrence in perspective, the fatalities occurring in underground coal mines over the past 25 years because of fires and explosions are summarized graphically in Figure 1, which gives a proportional time line of events along the vertical axis.

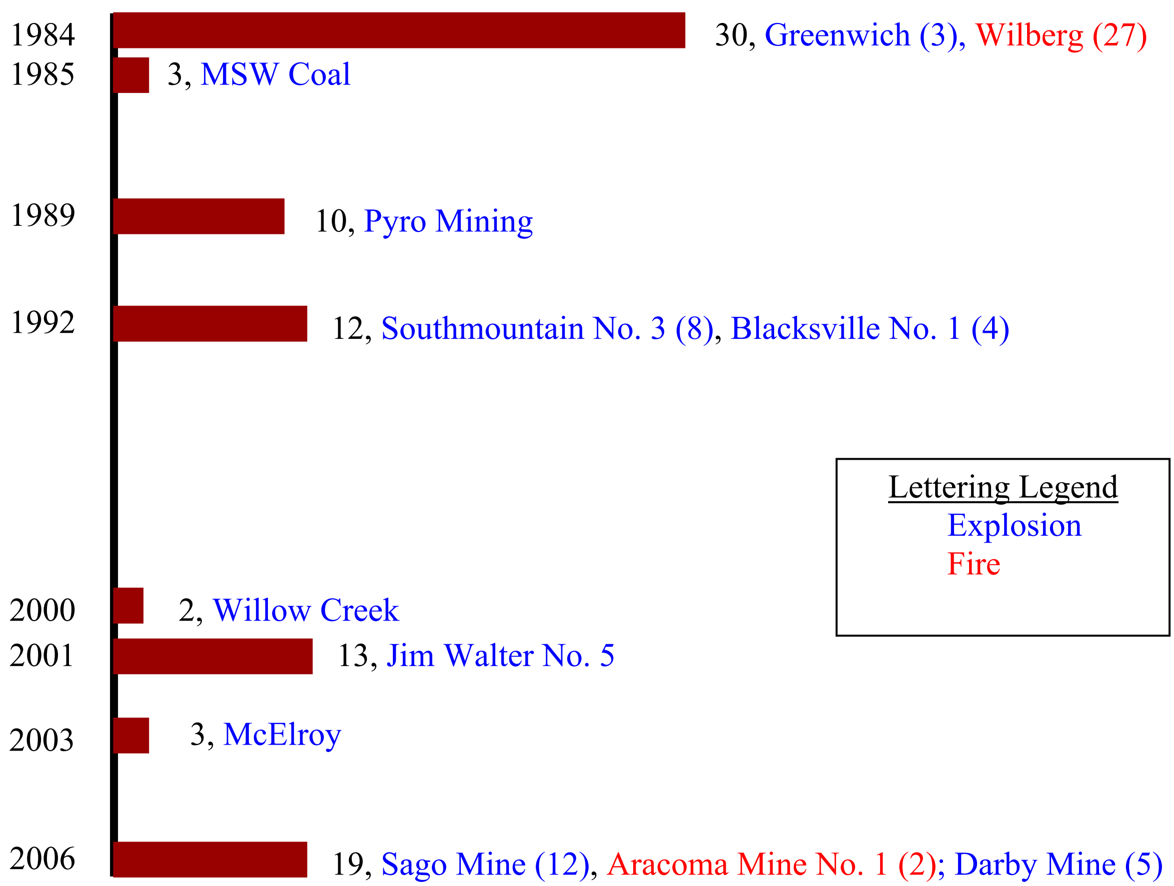
Over the past 25 years, 10 explosions claimed the lives of 63 coal miners, while two fires claimed another 29. Fifty-five of the fatalities occurred during the period 1984-1992 (9 years), or 6.11 per year on average, which was followed by a remarkable 7-year period with no incidents. From 2000 to the present, six incidents led to 37 fatalities. The six incidents over a 6-year period represent 40.2% of the total incidents that occurred over a 23-year period and translate to 6.17 per year on average. The 19 fatalities from two explosions and a fire in 2006 are the most since 1984.

It is clear that fatalities from explosions and fires were eliminated for a significant period of time (7 years) but have recently become more frequent, and they are occurring today at an undesirable and unacceptable level. Over the past decade (1996-2005), an annual average of 5.5 fires, 69.4 ignitions/explosions, and 19.7 inundations were reported to the MSHA accident database, which emphasizes that significant risk of loss exists even when major emergency events do not occur. A NIOSH analysis of reportable fires in coal mines over the period 1990-1999 gives the estimated fire risk rate and injury risk rate for both underground and surface settings (DeRosa, 2004). This information indicates clearly that elimination of the major events will require new vigilance, better preparedness, and more systematic approaches aimed at eliminating or mitigating the persistent major hazards in underground coal mines. To this end, a brief review of the situations framing the major incidents over the past 25 years will be followed by a summary of relevant weaknesses and gaps that need to be addressed to significantly increase miners' life safety.

DARBY MINE NO. 1 EXPLOSION, KENTUCKY, 2006 – 5 FATALITIES

On May 20, 2006, at about 1:00 a.m., an explosion occurred in or adjacent to a sealed area of the mine. The ignition source has not yet been reported definitively. The seals to the abandoned area were destroyed. The explosion resulted in the deaths of five miners and injury to one miner; two died from trauma and three others, despite donning their self-contained self-rescuers (SCSRs), died from carbon monoxide poisoning. The accident occurred at the start of the maintenance shift. Four of the six miners underground, including the survivor, were located in the active working section at the time of the explosion. A mine rescue team found and saved the lone survivor.

Figure 1. Underground coal mine explosion-fire fatalities – last 25 years.



ARACOMA ALMA NO. 1 MINE FIRE, WEST VIRGINIA, 2006 – 2 FATALITIES

On January 19, 2006, an underground mine fire occurred near the longwall conveyor belt drive. Twelve miners working in the development section inby the fire area began evacuating the mine and encountered heavy smoke. Two of the 12 miners were separated from the group.

Despite initial rescue efforts, the two miners could not be located, and mine rescue teams located their bodies the following day. Leakage of products of combustion occurred through holes in a ventilation stopping.

SAGO MINE EXPLOSION, WEST VIRGINIA, 2006 – 12 FATALITIES

On January 2, 2006, at about 6:30 a.m., a methane explosion occurred behind newly installed seals that disintegrated the building materials comprising the seals. The ignition source is not yet known, but lightning has been noted as a potential source. Although 17 miners escaped, thirteen miners were trapped, and communication with them was cut off. The miners barricaded themselves in a working place and used their self-contained self-rescuers to try to survive over a period of 41 hours before mine rescue teams could reach them. The barricade was constructed with ventilation curtains in an area where carbon monoxide had already accumulated. Delays were present in both reporting of the incident to MSHA and getting the mine rescue teams operational. The miners signaled by pounding on roof bolts, but seismic activity was not being monitored. Thus their specific location was not identified. A borehole was drilled into the mine a few hundred feet away from where they barricaded, and they were not found. Sadly, 12 of the 13 miners perished. The survivor reported difficulty in fully utilizing the SCSRs.

McELROY MINE EXPLOSION, WEST VIRGINIA, 2003 – 3 FATALITIES

On January 22, 2003, an explosion occurred inside the McElroy Mine, 5 South #2 Airshaft being constructed by contractor Central Cambria Drilling Company (CCD). Six miners were inside the shaft at the time of the explosion, and the explosion fatally injured three miners and seriously injured three others. Prior to the explosion, the miners were attempting to remove corrugated, galvanized steel sheeting (panning) which blocked access to the unventilated water ring being constructed. The miners first partially opened the panning with an axe, and the shift foreman placed a hand-held methane detector into the opening to test for methane. After reading 0.2% methane on his hand-held detector, the foreman directed the mechanic to cut the panning with an oxygen-acetylene torch. The mechanic ignited the torch and started to cut the panning. An explosion occurred when an explosive methane-air mixture contained inside the water ring was ignited by the torch cutting process.

JIM WALTER RESOURCES NO. 5 MINE EXPLOSIONS, ALABAMA, 2001 – 13 FATALITIES

On September 23, 2001, two separate explosions occurred at approximately 5:20 p.m. and 6:15 p.m. in 4 Section of the mine, resulting in fatal injuries to 13 miners. Nineteen other miners were working on the non-production shift, and they escaped. Prior to the first explosion, three miners were building cribs in a bad roof area near a scoop battery charging station, while another miner was nearby delivering additional materials. A roof fall occurred at an intersection near the scoop battery charging station, releasing methane and damaging a scoop battery. A methane explosion occurred soon thereafter, ignited by the arcing of the damaged battery. Four miners were injured, one seriously, and critical ventilation controls were damaged, which disrupted normal ventilation and allowed methane to accumulate in the section. Three miners left the section, while the fourth could not be moved.

Miners de-energized the electrical system for the section; however, MSHA stated that the track haulage signal block system, which extended into the section, remained energized. After some communication three miners, and later five others, entered the section to rescue the seriously injured miner. Four additional miners reached the mouth of the section.

The second explosion occurred when accumulated methane in No. 2 Entry was ignited; according to MSHA most likely because of the haulage signal block system. The explosion propagated toward the faces, and according to MSHA eventually involved coal dust in an extensive propagation, damaging a large area of the mine.

WILLOW CREEK MINE EXPLOSIONS, UTAH, 2000 – 2 FATALITIES

On July 31, 2000, a series of four explosions occurred in the mine. The first explosion of methane and other gaseous hydrocarbons was most likely ignited by a roof fall in the worked-out area of the D-3 longwall panel gob; a fire followed. Believing that a roof fall had occurred, personnel remained on the D-3 longwall section to extinguish a fire near the base of the shields on the headgate side of the longwall face. Eventually, liquid hydrocarbons became involved in the fire, and conditions worsened in the face area just prior to the second explosion. Two closely spaced explosions occurred soon thereafter. A fourth explosion occurred early on August 1, 2000. Two fatalities occurred as a result of the second and third explosions. The fire provided the ignition source for these subsequent explosions.

MSHA determined that the bleeder ventilation system did not adequately control the air passing through the worked-out area of the D-3 Panel. The system did not dilute and render harmless concentrations of methane and other gaseous hydrocarbons in the worked-out area where potential ignition sources existed.

SOUTHMOUNTAIN NO. 3 MINE EXPLOSION, VIRGINIA, 1992 – 8 FATALITIES

On December 7, 1992, an explosion occurred on the 1 Left section of the mine. Eight miners were killed, and another miner working in an outby area was injured. The bleeder system of the pillared 1 Right off 1 Left, 2 Right off 1 Left, and 1 Left sections was not examined or maintained to continuously move methane-air mixtures away from the active faces. The condition of the mine roof in the bleeder entry had deteriorated to the point where the bleeder entry had not been examined for several weeks. Methane, liberated primarily from the closely overlying Kelly [colloquially] Rider Seam, accumulated in the pillared areas and bleeder entry. Ventilation controls, both permanent and temporary, on the active working section had been removed or were not maintained. This action allowed the methane to migrate from the pillared area and bleeder entry to the No. 1 entry and in the No. 2 crosscut between Nos. 1 and 2 entries. Other factors included the dip of the coal seam, the drop of the barometric pressure before the explosion, the possibility of water accumulations, and roof falls occurring within the pillared areas and bleeder entry.

The methane was ignited on the 1 Left section in the No. 2 crosscut between Nos. 1 and 2 entries by an open flame from a butane cigarette lighter. The methane explosion resulted in sufficient forces and flames to suspend and ignite coal dust in 1 Left. The coal dust explosion continued to propagate the entire distance of the No. 1 West Main entries to the surface area of the mine.

BLACKSVILLE NO. 1 MINE EXPLOSION, WEST VIRGINIA, 1992 – 4 FATALITIES

On March 19, 1992, a methane explosion occurred in the production shaft of the mine. Contractors were installing a 16 in. casing through an opening in the cap which covered the production shaft, and a methane-air mixture was ignited by sparks produced by arc welding. A Consol manager and three M.A. Heston, Inc. employees were fatally injured. Another Heston employee and one City Neon, Inc. employee were seriously injured. During the escape of two Mole Master Services Corporation employees from the top of a nearby silo, one suffered an injury. Numerous other mine personnel and independent contractor employees were at various other surface locations at the mine.

On March 13, 1992, a cap was placed on the production shaft thereby reducing the amount of intake air entering the shaft. An opening was provided in the cap to allow for the installation of a casing to the shaft bottom for future dewatering. On March 17, 1992, actions taken during installation of the casing caused further reductions in the amount of air entering the shaft. As a result, ventilation within the shaft had been curtailed to an extent which allowed methane to accumulate beneath the cap.

WILLIAM STATION MINE EXPLOSION, KENTUCKY, 1989 – 10 FATALITIES

On September 13, 1989, an explosion occurred in the mine on Longwall Panel "O" between the 4th and 5th West Entries off the 1st Main North Entries. Ten of 14 miners in the longwall recovery area died from explosive forces. The other four miners escaped despite being exposed to high concentrations of carbon monoxide and smoke.

Changes had occurred during the mining of Longwall Panel "O" in the 4th and 5th West Entries and in the longwall bleeder system that caused a fragile balance of air flows to exist in the longwall bleeder ventilation system. This fragile balance was affected when changes were made to the ventilation controls in the 4th West Entries and the longwall recovery area. The combination of changes significantly decreased the air flow across the longwall face and reduced the air flow in the 4th West Entries. The combination of changes also permitted methane to migrate from the gob and accumulate in the No. 2 Entry of the 4th West Entries inby the No. 6 crosscut and near the longwall headgate.

The removal of the stopping in the No. 1 Cut-through Entry between the 4th and 5th West Entries disrupted the separation between the 2nd Main North Entries ventilation system and the longwall bleeder system. This action caused an explosive methane-air mixture to flow toward and into the longwall recovery area where it was ignited by one of the identified five probable sources of ignition.

MSW COAL CO. NO. 2 SLOPE EXPLOSION, PENNSYLVANIA, 1985 – 3 FATALITIES

On December 11, 1985, a methane explosion occurred in the slant off the No. 9 breast of the first miner heading of the mine. The accident killed three miners and seriously injured another. A slant had been developed approximately 150 feet off the No. 9 breast of the first miner heading when pillaring was started, creating approximately a 75-ft by 75-ft void which was not connected to bleeder entries or a bleeder system to assure positive ventilation in this area. There was no natural means for bleed off to the surface. This condition permitted methane to accumulate in the area, and an explosive methane-air mixture was ignited when confined and unconfined shots were detonated in the slant.

EMERY MINING CORP. WILBERG MINE FIRE, UTAH, 1984 – 27 FATALITIES

On December 19, 1984, a mine fire occurred at an air compressor station at the mouth of the 5th Right longwall section in the mine. Of 28 miners present in the section, only one survived. The fire started at an air compressor that was operating unattended with the over-temperature safety switch intentionally by-passed, without a fire suppression system, and without being installed in a fireproof structure or area.

The fire spread rapidly in the intake airway to the belt entry, causing both of the 5th Right section escape ways to be impassable and all the section airways to be filled with thick smoke and toxic gases. Early failure of aluminum overcasts, a delayed response to the emergency, improper use of self-rescue devices, and the miners' unfamiliarity with other exits for escape purposes increased the severity of this accident.

GREENWICH COLLIERIES NO. 1 MINE EXPLOSION, PENNSYLVANIA, 1984 – 3 FATALITIES

On February 16, 1984, an explosion occurred in the D-1, D-3, and D-5 areas in the mine. Three miners in the D-3 area died from the forces of the explosion, while 11 other miners in the D-5 area survived the explosive forces. Four of the 11 miners suffered severe burns.

Prior to the explosion, water was allowed to accumulate in the D-1/D-3 longwall gob areas and bleeder entries. The water accumulation together with stoppings constructed in the two connecting entries (cut-throughs) between D-3 and D-5, blocked or severely restricted the air traveling inby the No. 6 crosscut in the D-3 entries, allowing methane to accumulate in the D-3 entries between the Nos. 11 and 14 crosscuts. The explosive methane-air mixture was ignited by electrical arcing created by the normal operation of a non-permissible, battery-powered locomotive.

COMMONALITIES OF WEAKNESSES AND GAPS AMONG EVENTS

By scrutinizing the fire and explosion events since 1984, commonalities of weaknesses and gaps among events can be discerned. Since the periods 1984-1992 and 2000-2006 were separated by a seven-year period with no events, it is likely that the situations and conditions involved in the events of the separate periods are quite different. Thus the analysis will be done separately for the two periods.

Six Events between 1984 and 1992

Inadequate ventilation in active workings and/or across bleeder systems proved to be the primary cause of five of the six events during this period. The single exception involved a rapidly spreading mine fire, while explosions occurred in all other events. Maintaining effective bleeder systems was problematic in three cases, with air flows to bleeders being disrupted by roof falls, rising water, construction or removal of ventilation controls, missing ventilation controls, and liberation of methane from a rider seam.

In multiple events, repercussions of air changes were apparently not understood, including in a contractor shaft job where the shaft was capped. In two cases, monitoring of methane was inadequate (non-existent in one). In one case, low barometric pressure coupled with upgrade migration of methane from a gob area to the active workings was an important and overlooked factor. In four cases, serious and blatant violations of regulations occurred concerning examination of bleeders, taking smoking articles in the mine, monitoring of methane levels, and blasting.

In several cases, mine management and/or miners ignored or forgot good mining practices. Specifically in the case of the mine fire, there was inadequate fire protection of the air compressor and the aluminum overcasts, and a delayed response to escape by mine personnel. In this case, the miners were also unfamiliar with any escape route other than the two designated escape ways, and many did not use self-contained self-rescuers or filter self-rescuers properly. In one event, a miner attempted to rescue two other miners and died from carbon monoxide poisoning.

Six Events between 2000 and 2006

During this period, unlike the other nine-year period, inadequate ventilation in active workings and/or across bleeder systems was a major factor in only two of the six events, and one occurred in a contractor shaft job. Only one bleeder system inadequately controlled and distributed air to a worked-out area of a longwall panel. That situation was exacerbated by splitting off another intake near the bleeders and leaving ventilation controls intact in the worked-out area.

Worked-out areas were involved in explosions in two other mines where the areas were sealed (Sago and Darby). After methane had accumulated in the worked-areas to a level at which an explosion could occur, an ignition source caused an explosion. The exact locations of the ignition source are not yet known, although it is clear that the explosion occurred inside the sealed area of the Sago Mine. In both cases, the blocks approved for construction of the seals were destroyed.

In two events, there was a delayed response to escape. Miscommunication following a first explosion allowed miners to stay in the mine and try to rescue another miner; 13 miners perished during a large second explosion. In the second case of a mine fire, miners began escape only after the fire had become a major threat, and two miners who became separated from a group of 12 perished.

Communication systems were destroyed following the events, and, thus, in two cases knowing where escaping or barricaded miners were located became a major problem. The miners perished in both instances, 2 in the Alma Mine and 11 in the Sago Mine. In two cases where miners died while using self-contained self-rescuers, the devices were not fully used (Sago Mine and Darby Mine), and miners reported difficulty in using them. This documented difficulty in use and achievement of SCSRs intended purpose is a central issue which has instigated a crisis of confidence among miners. SCSRs are only a part of the overall approach to mine safety.

PERSISTENT ISSUES AND NEW COMPLEXITIES

Worked-out areas of an underground mine continue to be a critical issue, although the primary problem of maintaining bleeder systems during the period 1984-1992 has yielded to the issue of maintaining the integrity of seals and controlling ignition sources in or around gob areas. Detecting faithfully the methane levels in and around sealed areas is an important issue as well.

Ensuring that miners do not delay their escape in an emergency is a paramount issue. Escape is the most important priority, and it needs to be triggered immediately following a significant fire or explosion.

Maintaining communications with miners who are escaping from an emergency situation or who are forced to seek a safe area in the mine for later rescue remains a significant issue. Getting communication systems in underground mines that can survive a fire or explosion is critical.

An issue has resurfaced on the effective use of self-contained self-rescuers and/or the reliability of them. Something more must be done to regain confidence in these devices, either through research and development of newer models, through more frequent reliability checks, through more effective training, through greater provision of the devices throughout a mine, or through a combination of the above.

A slow response time in reporting an explosion at Sago Mine was a significant lapse in emergency protocol. Further the long period before mobilization of a mine rescue team into the mine, coupled with indecision at various times during emergency-response activities, contributed to a protracted rescue time, eventually leading to a 41-hour period before the miners were reached.

It is clear from the historical review that miners will not be able to escape in all emergency situations, and better means of protecting them when they must stay in the mine is imperative. Robust, reliable, and sustainable ways of protecting stranded miners must be devised.

On top of these needs is superimposed an environment of complex and dynamic change for the underground coal mining industry. The best coal reserves have already been mined, and less favorable and more hazardous conditions in future mines will inevitably be encountered. The workforce is now changing rapidly, too. Older, experienced miners are retiring, and new, often smaller, mines are opening as the demand for coal increases.

ADDRESSING THE ISSUES AND COMPLEXITIES

New miners will not have experience-based skills and judgments needed to cope with rapidly changing hazardous work conditions, and this issue must be addressed through reality-based training. Even experienced miners may not have particular skills relative to mine emergencies, and thus require reality-based training on emergency response. Finally, equipment, best work practices, best management practices, and mining regulations continue to change, and they will continue to do so in the future, probably at a faster rate. Ultimately, more systematic and comprehensive ways of assessing hazards and risks, and then managing them are needed. Additionally, persistent technological gap areas will require further research and development. All of these aspects will be addressed in detail in the chapters that follow.

3
Risk-Based Design and Management

FIRST PRIORITY ON PREVENTION

If there has ever been a cycle representing achievement and challenge in the coal mining industry, it has just been experienced. To evolve from being one of the most dangerous industries, to a record year in safety performance, to three tragedies within five months presents a scenario that no one in the industry ever wants to repeat again. The mining 'family' now must take the necessary steps and precautions to ensure that incidents like these will not occur in the future.

Going forward, two points are critical. Compliance with regulations is a prerequisite but is not sufficient in all cases to achieve prevention. Compliance with all the various State and Federal regulations in all cases does not guarantee that there will not be a fire or explosion. More important, compliance will not guarantee that a mine is fully prepared to respond when a disaster occurs. It is also apparent that all possible contingencies cannot be prevented through regulation. Prevention requires that systematic and comprehensive approaches be used to manage risks. Compliance is an important component of prevention, but it is more important to realize that it is only a starting point in a more comprehensive process of risk management.

A critical action to ensure success of the process for any company is the creation of a "culture of prevention" that focuses all employees on the prevention of all accidents and injuries. In order to achieve this culture, operators, employees, the inspectorate, etc. share a fundamental commitment to it as a value. In essence the process moves the organization from a culture of reaction to a culture of prevention. Rather than responding to an accident or injury that has occurred, the company proactively addresses perceived potential problem areas before they occur.

The tenets of the core business and personal values are critical links to achieving success. Founded on these aspects, a systematic and comprehensive process depends on other keys for success as well, which include the following:

- Focus on ZERO Accidents, Injuries and Occupational Illnesses

  Given the tragic events of 2006, the industry must not only rededicate itself to the prevention of fires and explosions but also to prevent all accidents, injuries and occupational illnesses.

- Use a Holistic Approach

  A holistic approach must be developed, which encompasses continuous improvements in technology, planning, training, etc., and intimately involves the industry's most valuable resource—its employees.

- Identify, Disseminate, and Adopt Best Practices

  The incorporation of *best practices*, as they become known and shown to be effective, throughout the mining industry must be encouraged, so that all employees can be continually involved and rewarded for the value they add. Systematic identification, dissemination, and adoption of best practices are problematic today, especially for small-mine operations.

- Implementation of a Risk Management Process

  The use of a formal risk management process requires commitment to the comprehensive approach. Specifically, a risk management process systematically identifies each operation's strengths and opportunities for improvement by focusing on major potential hazards (or risks) and eliminating or mitigating them to levels of acceptable risk. Detailed knowledge of each operational subsystem and task is critical to addressing safety and health needs in operations.

- Going Beyond Compliance

  Although compliance with regulations is a prerequisite in terms of prevention, it is only a starting point in truly achieving the goal of ZERO fire- and explosion-related incidents. Assessing operational performances against global industry benchmarks establishes targeted benchmark performances for a company's operations and moves the company's actions beyond compliance.

- Minimizing the Footprint

  Excellent operations manage the footprint that will be left when operations cease. Whereas each generation has made the coal industry safer, the overriding goal of achieving the minimum footprint will ultimately lead the industry to its goal of ZERO accidents and injuries.

In the end, the industry must strive toward instilling a paradigm of prevention. There is no single path or approach to fashioning the safety culture. Rather the industry must call upon engineering solutions, education of the workforce, and enforcement as tools to help create this culture. It must also enlist the commitment of all employees to be an integral part of the process aimed at zero incidents. Training is undertaken as a preventative measure, especially for honing critical skill sets for hazard awareness and control for every employee at every level of an operation. This safety commitment is the foundation on which the industry must build to fortify the protection for all employees from incidents or injuries, and not just from fires and explosions. **Thus the commission recommends that a comprehensive approach, founded on the establishment of a culture of prevention, be used to focus employees on the prevention of all accidents and injuries.**

RISK ASSESSMENT AND MANAGEMENT

Risk assessment and management is a well-established process used by high-performing industries, which have reduced accidents in hazardous situations. In the wake of the Columbia space shuttle disaster, the Columbia Accident Investigation Board (2003) held the following three safety programs, which achieved accident-free performances, as exemplars of safety culture:

- The U.S. Navy Submarine Flooding Prevention and Recovery Program,
- The Naval Nuclear Propulsion Program, and
- The Aerospace Corporation's Launch Verification Process.

In citing them, the Board stated that "The safety cultures and organizational structure of all three make them highly adept in dealing with inordinately high risk by designing hardware and management systems that prevent seemingly inconsequential failures from leading to major accidents." The conclusions (page 184 of the report) summarize the keys to successful management of high-risk operations, as follows:

> "The practices noted here suggest that responsibility and authority for decisions involving technical requirements and safety should rest with an independent technical authority. Organizations that successfully operate high-risk technologies have a major characteristic in common: they place a premium on safety and reliability by structuring their programs so that technical and safety engineering organizations own the process of determining, maintaining, and waiving technical requirements with a voice that is equal to yet independent of Program Managers, who are governed by cost, schedule and mission-accomplishment goals. The Naval Reactors Program, SUBSAFE program, and the Aerospace Corporation are examples of organizations that have invested in redundant technical authorities and processes to become highly reliable."

DuPont's safety process is well known as a benchmark program, and the safety group of the company consults globally to assist other companies and organizations to achieve a stellar safety culture (Mottel, Long, and Morrison, 1995). As will be discussed in more detail later, Australia has mandated risk-based management for all industries, including mining. This is a major step toward instituting risk-based processes in the mining industry and is another model for the U.S. to evaluate, with modifications to suit the specific safety issues and characteristics of mines in this country. There are many risk management models that can be used to identify and address major risks. The key to success is for companies to select the method that is designed to fit their needs.

A formal process of risk-based design and management will need to be followed by underground coal mining companies if the industry is to achieve zero fatalities and zero serious incidents. According to Brauer (1990), a former executive director of the Board of Certified Safety Professionals, risk management involves five components:

1. Risk identification.
2. Risk analysis.
3. Eliminating or reducing risks.
4. Financing risks.
5. Administering the risk management process.

Dealing more specifically with the minerals industry, Grayson (1999) outlined the need for a systematic and comprehensive risk management process while focusing on identification and control of major mining hazards, e.g., explosions, fires, inundations, and roof falls. In a proactive statement by coal mine operators, the authors of the RAND study on New Forces at Work in Mining: Industry Views of Critical Technologies (Peterson, LaTourrette, and Bartis, 2001) noted that:

> "Assuring the health and safety of mine workers was an important concern of the study participants, and many noted that health and safety figure prominently in their statements of company objectives. Many mining executives claimed that their operations exceeded regulatory requirements for health and safety and also exceeded average industry performance. Drivers of enhanced health and safety cited were risk management …, reducing lost worker time, improving productivity, maintaining morale, and common sense."

Going a step further toward a systematic process that can be more uniformly applied, the New South Wales Mine Health and Safety Act of 2004 (New South Wales, 2004) now requires a mine safety management plan under Part 5, Subdivision 2, Section 30. The requirements relating to risk assessment follow:

> A mine safety management plan for a mine must provide:
>
> (a) the basis for the identification of hazards, and of the assessment of risks arising from those hazards, by the operator of the mine, and
>
> (b) for the development of controls for those risks, and
>
> (c) for the reliable implementation of those controls.

In an effort to assist mine operators to meet the new risk management law, the Minerals Council of Australia commissioned the Minerals Industry Health and Safety Centre, University of Queensland, to provide risk assessment guidelines (Joy and Griffiths, 2005), stating the following:

> "The Minerals Council of Australia as the initiator of this project is seeking to take risk assessment in the Australian minerals industry to the next level. … This on-line resource is structured to help individuals design and undertake formal and informal risk assessments. … The Council believes this Guideline will make an important contribution in ensuring the Australian minerals industry continues to provide leadership in improving the safety performance of the minerals sector."

In the guideline document the authors note that "Management of risks requires a proactive, systematic approach, applied when key decisions are being made across the life cycle of the industry from exploration through to mine closure." They further note that "… the petrochemical, nuclear, military, aviation and space industries have applied various formal risk assessment techniques for over 30 years."

The commission refers to *risk analysis and risk management* throughout this report. These terms infer different processes and outcomes to different people. Within the mining industry, and particularly in the underground coal sector, many companies employ some form of risk analysis and risk management, ranging from rather informal to very formal processes. The formulation of mining regulations identified hazards and specified requirements for addressing them, which in essence comprises a formal risk-based approach. The roof control plan and the ventilation, methane and dust control plan are examples of plans required to control identified, historical hazards specific to a mine. Risk-based approaches can form a solid foundation for what needs to be an established practice at every mine. For the purposes of this report then, risk analysis and risk management should be described more fully, recognizing that some companies are currently going well beyond the minimum level of practice that is described here.

Risk assessment at the onset of operations planning is important, including how each activity is done safely, i.e. production, support work, maintenance, examinations, inspections, etc., but also in every phase of operations. In proposing risk-related recommendations, the commission is calling attention to major hazards which have recently led to catastrophic events and the important role that government, industry, and workers all play dealing with them. Thus as a minimum each mine should systematically identify their risks for an explosion, fire, or inundation. Some mines will have virtually no risk of one, but perhaps a higher risk of another. Regardless, once the risks are identified throughout the mine, or events have occurred, each must be reduced or eliminated, if possible, and if not, they must be controlled to the point that risks are as low as reasonably achievable, which is the aim of good risk management. The purpose of the risk analysis is to identify the type, root cause(s), and extent of the risk. A variety of qualitative and quantitative tools/processes may be used, and those only matter to the extent that the risks and root causes are defined. The purpose of the risk management effort is to reduce the risk through a variety of site-specific means. In some cases the risk may be reduced or eliminated through engineering, and in other cases engineering or administrative controls may be effective. Most often some risk will remain, and then training or the establishment of protocols or plans to address it, which essentially address behavior, would be developed. Frequently, a combination of actions is required to reduce the risk. Again the specific processes applied to reduce the risk are less important than the outcome, i.e. the extent to which the risk being managed lessens the likelihood of worker injury if an explosion, fire, or inundation should occur.

The stage is now set and the technical resources available for the adoption of a risk assessment process by the U.S. coal mining industry. In addition to the various models and techniques that are outlined in this report, some companies within the U.S. coal mining industry have used various risk management techniques to effectively address their specific needs. Companies can utilize these resources to identify the model and techniques, or combination thereof, that provide the best results. **Therefore, the commission recommends that every mine**

should employ a sound risk-analysis process, should conduct a risk analysis, and should develop a management plan to address the significant hazards identified by the analysis; simple regulatory compliance alone may not be sufficient to mitigate significant risks. The commission recognizes that not all mines have a familiarity with risk management, and therefore recommends that NIOSH develop a series of case studies that mines could use as templates, and that it conduct workshops and seminars to diffuse this approach to safety throughout the industry. As a caution, some risk analysis techniques are effective in identifying risks, but are not effective in determining the probability or severity of incidents. As the implementation of risk management progresses, care must be taken to use the proper tools in order to avoid inability to describe probability and severity adequately, and also to avoid potentially costly over-design.

Ultimately in the broader sense, government and industry should focus their risk-management efforts on reducing the major risks as well as substandard performances, where accountability is also an important ingredient. In this respect, industry safety professionals are encouraged to seek certification as a best practice, which is aimed at elevating professionalism.

It is paramount to understand how to manage the implementation of risk analysis, and introduce the concept in a planned methodical manner. Learning how to use practical approaches to address major risks is the important first step. It is also important to note that a change to risk management is multi-faceted; potentially more than the introduction of major hazard management plans. For example in late 2005 the US-based Phelps Dodge Corporation commissioned a study of leading-practice minerals industry risk management (Joy, 2006). The study involved gathering information from Australian mining companies and sites about their risk management applications. A resultant illustration of a "multi-layered" risk management approach was produced for Phelps Dodge and is currently being used in an Australian coal mining research project to study further improvements in risk management. The site level model includes applications of risk analysis in four areas or layers, as illustrated in Figure 2 below.

In most cases, the other layers are probably necessary for the successful implementation of risk management in mining. Clearly the introduction of risk management should be staged. Not all of the stages are unknown. For example, the 3rd layer from the top involves development of Standard Operating Procedures and Work Task Plans using risk analysis methods such as Job Safety Analysis. MSHA, NIOSH and many mine operators and miners are well versed in this application already, or its newest extension, Job Task Analysis.

Companies that have applied risk analysis and management for many years also recognize that the change to a "culture of prevention" via "systematic and comprehensive risk management" involves a journey. Professor Patrick Hudson from Leiden University, Netherlands (2006) developed an illustration of the journey for Shell Oil, showing the journey as a series of five steps (see Figure 3). Importantly, moving through each of these steps is believed to take several years. A similar more detailed model has also been developed for the Australian mining industry.

Figure 2. Multi-layered approach to risk management.

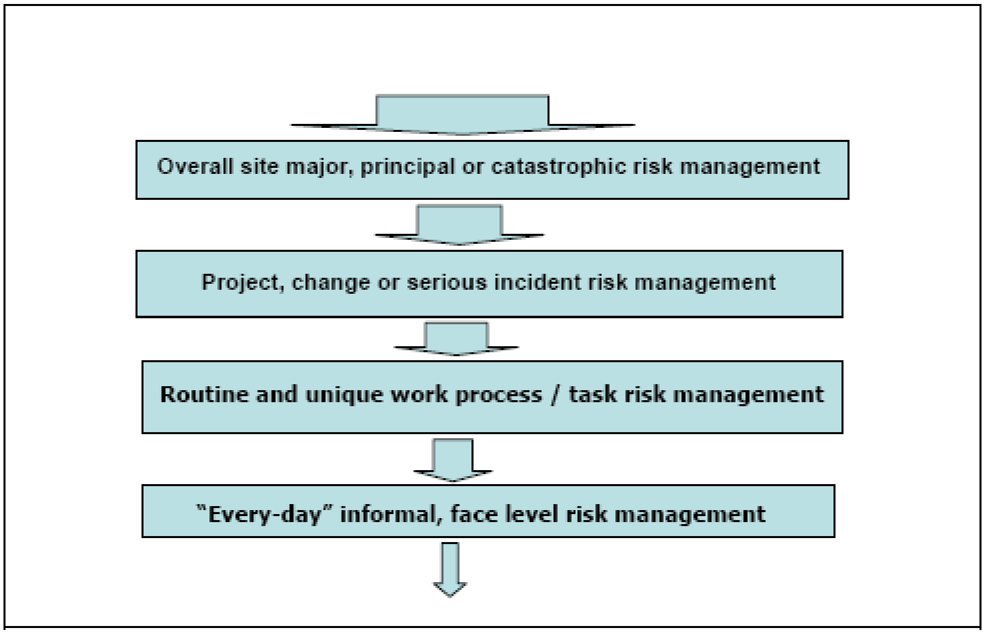
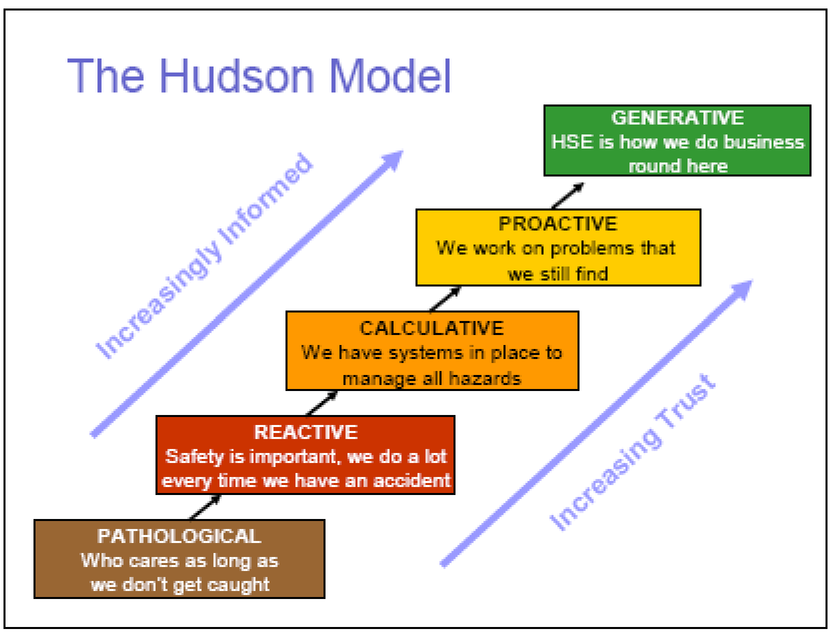


Figure 3. Multi-faceted and evolutional journey toward risk management.



The above illustrations suggest that a move to minerals industry risk management is multifaceted and evolutionary. As stated earlier "the key for success is for companies to select the method that is designed to suit their needs," and to understand needs related to risk management the company, site and other stakeholders must understand where important decisions are made requiring risk to be systematically considered, as well as the current status of their culture or systems so the next step can be ‘actioned’.

In almost 20 years of working within the Australian minerals industry Professor Jim Joy notes that the change is immense and fraught with stumbling blocks. Mining companies, mine management and workforces change. Regulators, unions and contractors change. The change is slow and often difficult to perceive from within the industry. The industry has a long tradition of reactive and people-dependant management systems. Risk management tries to change everyone’s mind set toward proactive, empowered, systems oriented thinking. Developing a good quality major hazard management planning approach at a mine is a good and appropriate start but it is just that – a good start. The commission notes that it is critical for this effort to get off to the right start. If it is perceived that risk management is just another program/requirement, then the concept will not achieve the level of success the commission envisions.

Thus the commission notes that industry, and all of its major stakeholders, must recognize that change management is required to optimize the adoption of risk management and avoid the pit falls of past applications. **Further, the commission recommends that an industry stakeholder working group investigate and suggest optimal approaches to managing the change to a minerals industry risk management paradigm.**

4

Communications Technology

BACKGROUND AND PRESENT

Recent mine emergencies at the Sago, Alma, Darby, Quecreek, and JWR No. 5 mines have highlighted the need for emergency communications between mineworkers inside and personnel outside the mine. Mines generally utilize reliable and effective communications systems[2] for routine operations; however, these systems require hard-wired networks, power supplies, and other infrastructure that are likely to be damaged or destroyed by a catastrophic event, such as a fire, explosion, or water inundation. The recent occurrence of these failures underscores the need for technologies that will function in post-disaster environments.

The Sago Mine disaster has generated much discussion on the benefits of a *miner tracking system*. Knowing the location of individual mineworkers would obviously facilitate rescue operations, yet reliable signal transmission to the outside of a mine after a fire, explosion or inundation still remains a problem. An electronic traffic system requires a reliable communications signal to relay location information to the surface. Thus, the technical barriers to in-mine signal propagation or through-the-earth signal propagation must be overcome before reliable emergency communications and miner tracking will reach an acceptable level of functionality.

The unique characteristics and requirements of underground mining applications, as they affect the feasibility of emergency communications and electronic tracking, are summarized in this chapter. An overview of existing technologies is then presented, followed by recommendations for moving forward.

Unique Characteristics and Requirements of the Coal Mining Application

The ultimate goal for a mine communication system is to provide an uninterruptible capability for locating and communicating with mine workers during an emergency following an explosion, inundation, or fire. Unfortunately, these events are likely to destroy significant portions of the wire-based systems presently used in mines. Besides the physical forces and extreme temperatures that can occur with these events, the physical geometry and electromagnetic characteristics of an underground mine provide an extremely difficult medium for effective signal propagation. Prototype and commercially available technologies, which work well in non-mining applications, have failed when tested in underground coal mines. The constraining characteristics of an underground mine environment are briefly summarized next.

[2] A comprehensive summary of underground coal mine communications and commercially available communications technology in the United States and abroad is presented in Appendix E [Schiffbauer and Mowry, 2006 in draft form].

The dynamic nature of underground coal mining results in a continuously changing maze of mine openings (entries and crosscuts). The mining process follows the undulations of a coal seam, which in turn creates sinuous mine openings. *Line-of-sight* distances may be a few hundred feet or less in many cases, which presents a significant challenge to many wireless-based communications or tracking systems. The *propagation paths* through the mined-out openings may be obstructed by concrete block walls, metal doors, or other structures. Mines can have tens or hundreds of thousands of feet of entries, some interconnected by crosscuts and others dead-ended. As the working areas advance and retreat so must the infrastructure of the mine, including any communications or tracking networks.

The physical mine environment can be quite inhospitable to electronic and electromechanical systems. Humidity, at or near the dew point, is common in mines and results in significant condensation. These high moisture levels, combined with rock and/or coal dust, tend to accumulate in electronic devices reducing their reliability. Vibration and shock, along with the normal wear and tear of constantly moving equipment, can degrade or even damage systems. Over the years, practices have evolved to increase the availability of in-mine electronic systems, but it has required special measures and has limited the application of certain technologies, including the adaptation and adoption of technology from other commercial sectors.

The working environment of a mine, with its low lighting levels, confined spaces, and varied distances between operation centers, is very different than that of a commercial or industrial facility. Historically, communications technology companies have attempted to enter the mining market only to subsequently abandon it, after discovering the extreme technical and maintenance difficulties. The applicability of a communication system for mine service must consider the difficulty of installation, maintenance, calibration, and testing, and a system must be designed and configured for high levels of reliability and maintainability. Thus, the operating environment alone imposes a severe constraint on practical network architectures and system concepts that might be deployed in an underground mine and which have a reasonable chance of working when most needed, i.e. in the post-incident (explosion, fire, or inundation) environment.

Communication signals must be capable of traveling a variety of distances without corruption. Given the rugged conditions encountered underground, flexible communication architectures will be required to accommodate the mixture of long and short distances. The equipment must be flexible and modular to allow for constant change as well as being easily expandable. It must have options for short-term connectivity by radio when cable has not yet been installed or where it is not intended to be installed. The communication network should be able to carry its own power supply for situations when it is not located near a power source.

Dealing with the electromagnetic characteristics of a mine is every bit as challenging as the physical environment. Radio signals require a clear path or open air for optimum signal propagation. However, mine pillars, ventilation stoppings, and/or ground failures can impede or even completely attenuate conventional radio-signal propagation. Radio frequency selection and the electrical properties of coal and other rock strata greatly impact signal propagation and attenuation. Very low frequency signals (<10 kHz) can penetrate, under certain conditions, through tens, hundreds, or even thousands of feet of strata, but carry limited information and require a large loop antenna on the surface or underground. Yet, in other cases, the same signal will penetrate only a few hundred feet. Moreover, the conditions under which a signal will penetrate to greater or lesser depths are not well understood despite a significant body of geophysical research into this topic.

Much higher frequency signals (>3 MHz) can convey significantly more information and employ very small antennas; however, these signals can only travel through air along line-of-sight paths, and are thus unable to turn corners for more than a single crosscut. Consequently, communication design must address how to obtain coverage in adjacent areas, without the need for a large number of repeaters or nodes, which creates practical limitations within a mine's physical environment.

Another limiting factor is interference. For example, signals from the communications system can interfere with each other or with other in-mine electronic systems, such as mine-wide monitoring systems or remotely controlled machines. These interferences can create safety hazards in addition to simply being a nuisance. This problem is exacerbated in the confined space of an underground mine by *multipathing* in which the higher frequencies interfere with themselves, effectively attenuating the signal over short distances. At medium frequencies (from about 100 kHz to 3 MHz) parasitic signal propagation, via inductive coupling, occurs. The medium-frequency signals will *ride* on metallic structures they encounter, such as rail, belt-conveyor structures, and water pipes. In many applications, this is considered an interference problem, but it may be a significant benefit in underground coal mine applications because it could facilitate communications over thousands of feet without the need for an intact hard-wired backbone.

The application of electrical and electronic devices is restricted at locations where there is a probability of encountering explosive levels of methane, such as at the face or inby the last open crosscut. This is an important but very limiting constraint on the application of electronic technologies in underground coal mines. Electronic devices used in these areas must be certified as *permissible* by MSHA, meaning that it is found to be *intrinsically safe* (IS), or otherwise it is housed in an explosion-proof (XP) enclosure, which must also be certified by MSHA. An intrinsically safe device must be incapable of producing an incendive arc or spark during normal and abnormal operating conditions. This permissibility constraint limits the type, and useable range, of communication devices that can be utilized in underground coal mines. An XP enclosure is very heavy and cannot be carried continuously by a miner. In contrast, IS circuits can be made light weight, but the permissibility requirement severely limits the amount of transmitter power, capacitance, inductance, and battery capacity. Thus, its range and performance become extremely limited. The power limitation imposed by the intrinsic-safety requirement is the single most significant challenge to developing an effective emergency communication system.

Finally, global positioning systems (GPS) are often mentioned as a method of tracking a worker's location. However, GPS systems do not work underground because the signals transmitted from GPS satellites are in the GHz range and are unable to penetrate the rock strata.

Routine Underground Mine Communication Systems

Communication systems typically found in underground coal mines include telephone systems, mine radios, leaky feeder systems, and on a limited basis, digital systems. These systems depend upon a hard-wired *backbone*, and if the communications cable becomes damaged or severed at any point, all communications inby that point will be disrupted. Because a fire, explosion, or water inundation is likely to compromise communications cables, they cannot be relied upon for emergency communication purposes. Mines presently use pager phones and leaky feeder systems as the predominate systems for mine-wide communications. Trolley phones and hoist phones meet specialized needs, and certain wireless or *walkie-talkie* style phones are used at some production faces. A detailed summary of communications systems is presented in Appendix E in draft form. The more common types are briefly described as follows:

Mine (pager) telephones are self-contained, battery-powered, two-way communication units that provide loudspeaker paging and handset conversation over a twisted-pair telephone line. When paging, the user's voice can be heard via a loudspeaker at all telephones connected to the system. There is no practical limit to the number of units which can be connected to a telephone system. The units can be placed miles apart or as close together as a few feet. Mine phones are readily available and are MSHA approved. They have the capability of providing two-way voice communication wherever telephone lines are installed. The line itself is inexpensive, easily installed, and reasonably durable for routine mine operations. Mine phones are a mature technology with simple and familiar operation and are relatively immune to interference from other electrical systems. Over the years, a number of electronic enhancements have been made to these systems to allow for better quality and more convenient operation. Nonetheless, the need to hard-wire each phone into the system, their lack of portability, and their dependence on lantern-battery power, have provided ample incentive for the development of wireless or radio-based systems.

Handheld two-way radios are two-way radio transceivers similar to commercially available walkie-talkies but engineered for use in the more rugged mining environment. Currently there are two handheld two-way radios approved by MSHA that are or will be marketed and supported. It is available in both VHF and UHF versions. These portable units can provide good line-of-sight voice communication and have found some application at production faces. The low-power characteristic of these intrinsically safe portable systems limits the line-of-sight distance, and the high-frequency signal is unable to penetrate rock. Therefore, the application of these devices is even limited for routine usage.

A leaky feeder (LF) system is a hybrid system that utilizes both hard-wired and wireless (radio) communications. A specially constructed coaxial cable is used to connect the surface base station with the underground mine, and this cable is installed throughout the mine where communication is desired. The cable is designed to *leak* the signal, which allows radio transmissions to leak into the cable, as well as from the cable. Generally, the handheld radios must be used within tens of feet of the cable to ensure that a signal can be reliably transmitted or received. This short wireless distance is considered a serious limitation of this technology. Bidirectional amplifiers are installed at intervals on the order of 1500 ft to boost signal strength along the entire length of the cable.

Digital Networking is finding increasing application in mines as the desire for enhanced capacity for reliable communication of voice, data, and video signals increases. For basic voice and limited data transmission, the leaky feeder system still provides a good option, but it lacks capacity for very large data transmission, such as video, on-board vehicle diagnostics, and remote control. LAN (Local Area Network) and Wireless LAN (WLAN) technologies have potential for providing advanced communication technology in the underground mining industry and are providing an alternative to leaky feeder technology. These systems offer a quantum leap in bandwidth, and hence voice and data quality and capacity. Digital networks utilize carrier-quality wired and wireless components and can include design criteria that ensure high reliability and maintainability through redundant loop implementations, fault detection, and network management tools. Wireless Access Points (WAP) can provide the mining industry with a high throughput and robust communications infrastructure to support the deployment of general IP applications. Mobile data solutions are implemented over the WLAN and are Wi-Fi compliant, thereby providing voice and text messaging, condition monitoring, personnel and equipment tracking, traffic control, and real-time video. The latest underground equipment being manufactured is capable of digital communication using Ethernet TCP/IP (Transmission Control Protocol/Internet Protocol). The low cost of Ethernet-based communication equipment, along with high-speed, high-capacity voice, data, and video, makes digital networks an attractive communication option for routine purposes. Deploying these systems to provide mine-wide voice communication and *hardening* them for possible use in a post-tragedy environment, however, present significant technical and economic challenges at this time.

Emergency Underground Mine Communication Systems

At present, there is only one MSHA-approved emergency underground mine communication system, which is called PED (Personal Emergency Device) and is manufactured by Mine Site Technologies.

The PED system is a one-way *through-the-earth* receiver communication system that is carried on the belt of each individual miner. When activated, the system dims and flashes the miner's cap lamp for approximately 10 seconds and then sends a text message to the miner. Individual, group, or broadcast messages can be sent. The PED system is currently used in approximately 20 underground mines in the U.S. and has also been deployed at mines in other countries, particularly Australia where a similar number are installed.

The system consists of a high-power transmitter, which is capable of sending communications that can be received as a text message by miners throughout the mine. It utilizes either a surface or underground antenna loop which radiates a very low frequency (VLF) signal, enabling one-way communication to the underground workings at depths of a few hundred to a few thousand feet. However, transmission through some rock layers, aquifers, and other geophysical anomalies or discontinuities is problematic. More success is achieved at shallow depths, but this is not always the case.

The above limitations can be overcome by installing an underground antenna, which is done in most applications. This solution, however, is less than satisfactory for emergency applications because relatively high currents flow through the antenna. Also, the underground antenna could be damaged, but improvements could be made to *harden* the antenna. The safest solution is to locate the antenna on the surface; however, there are other challenges in addition to the previously mentioned ones. The surface must be accessible, which can be difficult in rugged and undeveloped terrain or impractical if the surface is developed with residential, commercial, transportation or other facilities. Safety and security become concerns as well.

Despite the system's inherent limitations, e.g. one-way text messages and no confirmation that the message has been received, a number of situations can be imagined in which the PED system would meet the urgent need to communicate with miners attempting to escape or those trapped in the mine. Furthermore, there are documented cases of PEDs communicating life-saving information in the early stages of an emergency. *Accordingly, if the signal penetrates the intervening overburden between the surface transmitter and the underground receiver (mineworker), these systems will then satisfy a basic emergency communications need and should be considered accordingly. It should be noted that when energized, these systems can interfere with mine monitoring systems and possibly other mining electronic systems, and accordingly should be carefully tested before being deployed.*

No other communications technologies, which would meet the post-tragedy functionality goal, were known to be available for underground coal mine applications. MSHA solicited proposals for communications technologies or products that might be adaptable to coal mine application, and received more than 100 responses. Several of the responders represented that their technology fully met the application needs for an underground coal mine. However, further in-mine testing of the more promising systems revealed that none possessed the necessary functionality. However, a few are quite promising, and with sufficient resources may become commercial realities in the coming years (see the following Mine Safety and Health Administration web page: http://www.msha.gov/techsupp/pedlocatingdevices.asp#consol).

MOVING FORWARD

The most basic requirement of a post-tragedy communication system is to provide a communication link between the underground miner and the surface, after a fire, explosion, or inundation. A two-way system would be immensely more useful than a one-way system, since escaping or trapped miners could relay valuable information outside. Moreover, a voice rather than text system is likely to prove much more useable in emergency conditions[3]. The emergency communication system should be part of a mine's routine system, rather than an entirely separate system, to better ensure that it will properly function when an emergency occurs. The urgent timetable under which these systems must be deployed in underground coal mines means that a phased-in and evolutionary approach will be necessary. Clearly, each mine will find it necessary to employ different mixes of technologies to meet the needs for emergency communication for

[3] The difficulty in using a voice-based system while wearing an SCSR with a mouthpiece must be addressed. This has been resolved for certain military and first responder applications, and those solutions should be adaptable to mining.

its site-specific conditions and infrastructure. Finally, it is unrealistic to expect a system to operate in all parts of the mine. Nonetheless, it is imperative that the system provide the desired functionality in and around active panels and in escape ways.

Presently no system has been demonstrated to meet the most basic requirement for emergency communications, other than the PED system, which is limited in application based on the characteristics of the mine overburden, electromagnetic interference issues, and other application constraints. However, based on the work of the Mine Emergency Communications Partnership[4], there is considerable optimism that one or more two-way voice communication system prototypes could be further developed and brought to a commercialization phase within coming years. Moreover, there are other steps that could be taken immediately to provide miners with emergency communication systems with a reasonable degree of functionality.

It is important to have realistic expectations for the performance of these technologies given the state of technology in general.

1. It is unlikely that any system will work in all parts of all mines. We should strive for systems that will work in most parts of the mine, especially the active panels and the escape ways. Even within the active panels or escape ways there are likely to be dead zones. We should attempt to minimize or eliminate those. Unless we begin with reasonable and achievable performance criteria/expectations, we will be unable to deploy badly needed technologies.

2. It is unlikely that any system will work with every worst-case disaster scenario that can be imagined. While the goal should be to accomplish this ultimate reliability, we should not delay developing or deploying systems which will work for only most cases rather than all cases. If the best system would work only for the majority of explosions that could occur in a given mine, for example, then that system should be deployed.

3. The commercial availability and deployment of newer and better communications technologies could be at least 2 – 3 years into the future. In the meantime, more immediate actions can and must be taken to improve emergency communications. It is important to recognize that these more immediate actions can serve as the building blocks for improved future technologies.

4. The performance requirements and expectations for a communications and tracking system are really mine specific. They should be considered within the context of the mine's risk analysis and management plan, including the mine's overall disaster

[4] This is a partnership organized by NIOSH and includes MSHA, labor unions, various state regulatory agencies, state and national mining associations, manufacturers, and university researchers. The goals of the partnership are to develop uniform performance criteria for communications systems, to test systems under consistent conditions, and to disseminate the finds of the tests.

response system to ensure that the best possible protections are afforded to miners despite limitations in technologies.

The commission recommends that mines utilize hardened[5] mine pager phones or leaky feeder systems, as an interim measure, to meet the immediate need for post-incident emergency voice communications. Guidelines will have to be prepared to address network architectures, the mechanical strengthening of components, altered installation practices, and modifications to the hard-wired network. The preparation of these guidelines or *best practice* documents will require substantial engineering design and testing, but is doable over twelve to eighteen months. **The commission recommends that the development of these guidelines be completed as soon as possible.**

Employing hardened pager systems in escape ways and active panels, for example, is achievable with current technology, and would represent an important step forward. Hardening of leaky feeder systems may require modest system design changes, but even these should be addressable within a year or so. These systems could continue to serve as backup emergency communication systems as more advanced technologies come online. There may also be an opportunity to incorporate these hardened systems into *safe havens* or *refuge rooms*.

While hardened systems can meet an important need for emergency communications in coming years, they really only represent an interim solution until more advanced technologies are successfully demonstrated and commercially available. **The commission recommends that a hybrid communication system be developed to allow reliable wireless communication enhanced by the leaky feeder backbone or other metallic infrastructure, such as wire-core life lines, haulage track, and pipes, and that such a system be deployed in mines as soon as possible.** A Software Defined Radio (SDR) would allow transmission and reception of signals using several different frequencies depending on the goal of the transmission system, and could be used for both routine and emergency purposes. By further refining and adapting technologies developed for military applications, it may be possible to bring such a system to commercialization within the next three years.

Improvements to the communication systems used by mine rescue teams are needed. A particular type of technology system tested under the Emergency Communications Partnership shows particular promise for mine rescue applications with nodes that utilize the IEEE 802.11b WiFi networking standard at 2.4 GHz. The nodes are portable and can be battery powered. Several nodes combine to create an ad-hoc mesh network. The network can be deployed as a stand-alone wireless network as the rescue team advances into the mine. Good-quality voice and data communications can then be established through the network. This system is currently applied by first responders in non-mining applications, such as police and firefighters, and in these applications it has been found to be durable and to provide reliable communications. The current product needs to be re-designed to meet intrinsic safety requirements. **The commission recommends that work be done to adapt this "breadcrumb" technology for use by mine rescue teams.**

[5] A "hardened" system will more likely provide communication after an explosion, fire, or water inundation, and may be achieved though mechanical reinforcement of system components, for example, as well as through changes to the network such as providing redundancy, among other steps.

The implementation of an electronic miner-tracking system will depend heavily on the existence of a communications system's ability to transmit the tracking data outside of the mine in a post-tragedy environment. Thus the applied research and engineering developments recommended in this section are a prerequisite to a successful tracking system. Assuming that effective wireless communication systems begin to come on-line during the next three years, the details of implementing the tracking in the vast expanses of an underground coal mine must be addressed. It is likely that a radio frequency identification (RFID) tagging system will be adapted for use. While the use of such a system in a normal production environment is straightforward, it is not for a post-fire/explosion setting. **The commission recommends that work be conducted to develop an RFID-based tracking system that will function with the emergency communication systems that are under development, such as software-defined radio, and that the system be demonstrated as soon as the emergency communication systems are developed.**

Communications for underground mining is unregulated – a Federal Communications Commission does not exist for underground mines to allocate frequency bands, power levels, and to take other measures to ensure the interoperability of devices or that devices do not interfere with each other. There are already examples of interference, and if these routine and emergency communication and tracking systems are to operate harmoniously with mine-monitoring systems, remote-controlled machinery, and so forth, standards must be developed. **The commission recommends that NIOSH lead the development of standards for wireless communications in underground mines.**

The above recommendations are based primarily on the need to bring emergency communications and tracking technologies on-line as soon as possible. At the same time the commission recognizes that several different technologies, in various stages of maturity, are in process, and it recognizes that these must be moved forward to ensure that emergency communications and tracking will fully meet all of the needs of the mining community. This must be a continuous process of improving technology and integrating it into the mines. **Accordingly, the commission recommends that alternative and promising emergency communications and tracking systems be developed and commercialized for the long-term enhancement of mine safety.**

5
Emergency Response and Mine Rescue Procedures

When disaster strikes, mine emergency response systems must function to save lives. Mine Rescue teams are a central part of this process. Mine rescue capability has long been required by law. But recent events have brought home the value of having well-trained, well-equipped mine rescue teams and procedures. Even with an enlivened safety consciousness in the mining industry, the probability of disaster will never be zero. Thus a robust mine rescue capability is imperative, and a review of current capacity is warranted. To this point, mine `rescue capability nationally has evolved haphazardly, fueled by historic experience with accidents, guided by skeletal legislation, but largely driven by the efforts and commitment of volunteer rescuers across the nation who strive to assure that help will be ready when tragedy strikes. In light of recent events, it is appropriate to consider how the mine rescue endeavor can further mature to a more formalized, standardized, professionalized function.

To this end, the commission sought to identify ways in which mine rescue procedures and capabilities can be improved. The commission queried industry safety and mine rescue experts about gaps and remedies in this area. This section presents the findings in several major areas of concern, as well as recommendations for improvement. These recommendations have been validated by mine rescue teams across the country–east and west, coal and metal/non-metal—including team trainers, captains, and members from Arch Coal, BHP, Bowie Resources, Consol Energy, the Deserado mine, Eastern Associated Coal, Energy West Mining, Massey Energy, Peabody Energy, and the Waste Isolation Pilot Project.

MISSION AND DESCRIPTION OF MINE RESCUE TEAMS

The primary purposes of mine rescue teams are to rescue survivors and recover a mine in the event of an accident. In pursuit of these goals, teams can be called to provide a variety of functions, including exploration, removing or isolating ignition sources, building ventilation structures, setting roof support, and implementing ventilation plans. In addition, teams often have skilled first-aid providers (often certified Emergency Medical Technicians) and firefighters, who may also perform their associated functions.

Mine rescue began in the early 1900’s when mine rescue railroad cars and stations were established at coal fields. Personnel who staffed these stations and cars investigated disasters, assisted in rescue, gave first-aid, trained miners in safety, examined safety conditions at mines, and recommended safety improvements.[6] From four stations in 1909, to 76 by 1915, mine rescue rapidly grew into a sophisticated set of practices and procedures. By 1915 the Bureau of Mines helped to manage almost fifty inter-company and inter-state mine rescue contests, at which rescuers demonstrated their skills in rescue and first-aid, and their proficiency in the use of breathing apparatus, safety lamps, and other safety appliances.

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[6] http://www.msha.gov/MineRescue/EARLY.htm

Today, there are over 300 mine rescue teams operating nationwide, including 141 coal, 127 metal/non-metal, and 45 surface mine teams.[7] These teams are configured as company teams (supported and operated by one or more private mine operators), contract teams (commercial teams provided under contract by a third party vendor), or state teams (supported and operated by a state agency). Underground teams report having 7 members on average (the requirement is five and an alternate), while surface teams are about double that size. Most teams are company teams (about 70 % of all teams) and are typically comprised of volunteers who accept mine rescue as an additional duty. Company mine rescue teams are usually a component of a mine's safety organization along with an array of industrial safety functions as well as activities such as the mine's fire brigade or first responders.

Mine rescue teams are governed by Title 30 of the Code of Federal Regulations, Part 49, which implements the provisions of Section 115(e) of the Federal Mine Safety and Health Act of 1977, and requires that "every operator of an underground mine shall assure the availability of mine rescue capability for purposes of emergency rescue and recovery." Since this commission was convened, the President signed the Mine Improvement and New Emergency Response Act of 2006 (the MINER Act), which amends some of the requirements of the 1977 Act. By law, all mines must have two equipped and trained teams available. Under the MINER Act, the requirements for access to mine rescue teams is even more stringent, requiring that their station be within one hour ground travel time.

Mine rescue teams must have six members with underground experience. Teams usually are comprised of the following positions and functions: a captain (the team leader), the #1 gas man (who backs up the captain and checks for the presence of gas), a map man (who maps locations of conditions in the mine and actions taken by the team), the #2 gas man (who makes gas checks at every intersection and also pulls the stretcher), a co-captain (who receives advance and retreat orders from the briefing officer and relays information from inside the mine to the fresh air base), and a briefing officer (who remains at the fresh air base and directs the team according to command center orders, and also informs the command center of mine conditions found during exploration).

Teams must also meet minimum training requirements. Members must pass an annual physical examination, receive twenty hours of initial training on breathing apparatus, training on mine map and ventilation procedures, and then forty hours of refresher training annually. Teams must train underground at least once every six months, and must wear and use breathing apparatus at least two hours every two months. The new legislation also specifies that teams must participate in at least two contests per year and be familiar with all mines they cover.

The law also covers basic equipment requirements for rescue teams. It requires that teams operate out of a mine rescue station where equipment is stored and maintained. They must have twelve breathing apparatus, as well as extra oxygen bottles for each, CO_2 scrubbing agent, and a cascade system to recharge them. They must also have the supplies and trained personnel required to test and maintain ("bench") the apparatus. They must also have cap lamps and a charging system, gas and oxygen detectors, and a communications system with 1000' of cable. While this is not a lengthy equipment list, this equipment is specialized, and thus expensive to

[7] http://www.msha.gov/MineRescue/MAP/ASP/minerescuehome.asp

obtain and maintain. And most teams also need additional equipment to fulfill missions specific to their mines, such as bunker gear or appropriate protective equipment, non-sparking tools, and first-aid supplies.

It is important to recognize the nature of the interaction between government and industry with respect to mine rescue. While private companies generally have the discretion to dictate operations at their mines within the law, federal and state government agencies have powerful authority to regulate and even direct mine-related operations. In particular, the Department of Labor's Mine Safety and Health Administration (MSHA), plays a dominant role during emergencies, and MSHA officials often closely supervise the activities of mine rescue teams. In fact, the 1977 act says that, "In the event of any accident occurring in a coal or other mine, where rescue and recovery work is necessary, the Secretary or an authorized representative of the Secretary shall take whatever action he deems appropriate to protect the life of any person, and he may, if he deems it appropriate, supervise and direct the rescue and recovery activities in such mine."

TRAINING QUALITY

The nation's mine rescue capability rests more heavily on training than on any other aspect of the mine emergency response system. Especially since emergency incidents are relatively rare, the predominant way teams keep their skills sharp, and develop cohesion, enthusiasm, and trust, is through training.

We find that the minimum amount of training required of teams is insufficient to develop and sustain their proficiency. Currently, "…all team members shall receive at least 40 hours of refresher training annually. This training shall be given at least 4 hours each month, or for a period of 8 hours every two months" (30 CFR § 49.8). Four hours of training per month is not enough time to accomplish adequate instruction on all relevant topics and practice with skills, much less to prepare for participation in contests. Greater quantity of training does not assure better quality, but quantity of training is certainly correlated with team proficiency.

Beyond this, it is hard to know how much training teams actually do accomplish. The current approach to auditing the amount and quality of training that has actually occurred is weak. In effect, MSHA checks training records, but training records can be inaccurate and generally do not reflect much detail about the nature and substance of the training that was conducted. While we have seen no evidence of deception on the part of mine rescue teams, the lack of rigor in the documentation process itself and in the validation of team training leaves room for slack in the system and provides no systematic check that teams have developed needed skill levels.

We also find that training often is not realistic enough. Since events are rare, replicating the conditions and stress of a real event in a training environment is essential. Not all training needs to be high-fidelity—there is great value in classroom instruction, basic skills practice, and simple exercises—but some training must require teams to apply their skills and knowledge under the conditions they would face in a real emergency. Moreover, success during the chaos of disaster requires strong teams, and teams who understand each other at a deep level. Team members need to know each other's strengths and weaknesses and, most importantly, need to be able to trust each other. This requires teams to be subject to realistic, stressful training conditions that push them to grapple with substantial challenges. While teams typically do conduct some training underground in their own mines, this is often limited because it is logistically challenging. It is hard to create smoke conditions that do not affect ongoing work in other areas of the mine and other workers, and live firefighting practice in coal mines is impossible.

In addition, training programs rarely include mines other than a team's own mine. Teams are often unfamiliar with the mines they are formally responsible for covering, much less other mines at which they could find themselves. They may not have current maps of these mines, may not have visited them, and may not even know how to get to them. Fortunately, the Miner Act of 2006 now requires that mine rescue team members participate regularly in mine rescue training at the underground coal mine(s) covered by their mine rescue team.

We also find that the role of contests in developing mine rescue capacity is under-exploited. Currently, 38% of underground coal mine rescue teams and 34% of mine rescue teams overall report that they do not compete. Contests can be an important enabler of mine rescue team capacity. They can incentivize competency, help to formalize standard operating procedures, promote relationships and trust within and between teams, and provide opportunities to share ideas, strategies, and techniques. The new legislation requires participation in at least two contests per year. Teams employed by large operators and Eastern teams already far exceed this minimum. In the West (where teams are more sparse) and at smaller companies, teams tend to participate in fewer contests, often because the cost of travel is prohibitive. The new requirement should generate more participation, but contest quality then becomes a very important consideration. Teams will likely devote at least some—and possibly a lot—of their mandated training time to contest preparation. If contest problems are not realistic and substantively challenging, then contest preparation cannot adequately enhance capability to respond to "real" emergencies.

Finally, contests and training alone, even if well-configured, are inadequate preparation for response to a mine emergency. Teams must also engage with mine managers and MSHA in non-competitive but realistic "full up" exercises that meaningfully test their ability to respond to an incident "end-to-end" from initial notification through demobilization. It is important that exercises be progressive in nature, following the military-style crawl → walk → run structure where participants first learn expectations about appropriate actions and decisions (crawl), then move slowly through a scenario taking the time to practice decision-making (walk), and then pick up the pace and the challenges as they get more adept (run). It is also important for exercises to be followed by a careful review of lessons learned and a plan to inculcate successful practices and to devise and implement corrective actions for problems or mistakes revealed by the exercises.

Recommendations

- **The minimum amount of training required of mine rescue team members should be increased to eight hours per month. Even eight hours per month should be considered a bare minimum—as a practical matter, adequate preparation for contests alone demands at least this level of commitment. The better teams already surpass this requirement.**

- **MSHA should better validate mine rescue training by observing training in progress in addition to checking training logs. To accomplish this, MSHA would be well served by staffing a small team dedicated to working with mine rescue teams throughout the year. This would both allow MSHA direct visibility into the level and quality of training teams are getting, and help them to understand and trust the teams' capabilities at a deeper level. An ongoing relationship like this would also help to build trust between MSHA and the teams, which would put MSHA in a better position to help teams improve their training programs. And, on a real incident, MSHA and the teams would know each other and be better able to work together.**

- **In conjunction with the requirement to certify teams, MSHA should conduct a systematic review of the skills required of teams. Foundational capabilities and specialized functions should be clearly identified and the capabilities, tasks, and skills required to fulfill them determined. In addition, as broader sets of skills are recognized as being relevant to team capability; training requirements, resources, and contests should expand to include them. The inclusion of pre-shift and first-aid in contests are examples that demonstrate the precedent for formalizing key skill sets. Many teams we spoke with emphasized the need for more rigorous and comprehensive training with respect to mine gases and the instruments used to detect them.**

- **Federal and state government agencies and industry should partner to develop more joint training facilities that provide realistic environments, such as the National Institute for Occupational Safety and Health (NIOSH) Lake Lynn Laboratory experimental mine facility near Pittsburgh and at experimental mines located at academic institutions or other organizations. These should be located to be accessible to teams nationwide.**

- **The new legislation requires that operators make available two teams that receive at least annual (semi-annual for mines with less than 36 employees) training at their mine, and possibly more depending on the type of teams the mine uses. While this is a very important start, the requirement should be expanded so that every mine rescue team is familiar with all mines to which it is committed to respond. With the support and assistance of operators, mine rescue teams should pursue strategies for cross-training at other mines. This should include tours that would inform the team members about how to get to the mines, the configuration of ventilation systems, and the presence of special hazards unique to these mines. Teams should proactively develop relationships with key points of contact at other mines so that when an incident occurs the team has a clear interface. Local mine rescue associations could play an important role in this process. They could facilitate visits to all mines represented in the association on a rotating schedule. This would enhance all teams' familiarity with the facilities they might support, and would also facilitate further collaboration between the teams. Associations could also facilitate dissemination of regular updates to maps for all mines covered by the association, though teams themselves must be responsible to be sure they have regularly updated maps for the mines they cover formally. MSHA may have to intervene to ensure operators regularly share updated maps with the teams that service them.**

- **The new requirement for mine rescue teams to participate in a minimum of two mine rescue competitions per year is also an important capacity enhancement. Operators must recognize that reasonable preparation for a contest requires about twenty hours above and beyond the commission's recommended monthly eight-hour training requirement. Teams also need the equipment necessary to practice with–a field and props for practice problems. While it is preparation and participation, not winning, that most enhances readiness and builds camaraderie within and across teams, the belief that a high competency level will be developed is a strong incentive for teams to work hard and improve their skills, which could at times be emphasized by a winning performance. The prestige associated with doing well (winning) also helps them attract new members. Given that most teams depend on volunteers, companies should recognize individual and team success at contests with monetary and non-monetary rewards. Finally, for contests to add value to rescue team capability, participation must be meaningful. It will be important for MSHA to carefully articulate standards for compliance with the new contest participation requirement.**

- **MSHA should establish criteria for the development and use of contest problems to ensure that time to complete a problem, which is easy to assess during a competition, should not displace other important skill-based performances as primary contest objectives. Likewise, contest problems should emphasize functions that teams will likely be called to perform during an emergency.**

- **In addition to devising contest problems, MSHA should help operators and teams devise exercise plans that will help them practice all aspects of mine emergency response. It is important that these drills exercise the plans that mines intend to use in the event of an emergency, to include testing procedures for family relations, media relations, and command center management. The results of the exercises should then be used by operators to refine their plans.**

- **Miner training is also directly relevant to improving mine rescue and life safety. Mine rescue is, in truth, co-produced—that is, it is the actions of miners in combination with the actions of mine rescue teams that can result in lives saved. Requirements and recommendations for sound miner training are discussed extensively elsewhere in this report.**

COLLABORATION

There is a great deal of skill, knowledge, and expertise housed in the more than 300 individual mine rescue teams across this country—but this capability varies. Some teams are very strong and others less so. Some have experience with miner rescue, some with property recovery, and some have no experience on actual incidents. Some have special strengths in benching apparatus, or pre-shift, or first-aid, or exploration.

This suggests that one important means of improving performance in mine rescue is collaboration. Teams need to be able to share ideas, learn from each other, and work together to develop better practices. In the course of the committee's research, it became apparent that the industry does not have a broad perspective on mine rescue capacity available nationwide. We do not have good insight into how many rescue teams are available today, where they are located, what their capabilities are, and who they have agreed to support. Some basic information is available from sources such as MSHA, NIOSH, the National Mine Rescue Association (NMRA), the United States Mine Rescue Association (USMRA), and other associations, but it is difficult to access and is not detailed or validated. This lack of information makes it hard for teams to form collaborative networks and work together to generate knowledge. Unfortunately, some operators may be unwilling to share information about their teams for fear of exposing weaknesses. This reticence must be remedied by providing non-adversarial, "safe" forums for sharing information.

Beyond this, metal/non-metal, coal, and surface mine rescue teams rarely have contact with each other. There is little interaction despite important similarities in operating environments, life safety objectives, and skills. As a result, we forego opportunities to share knowledge and experience, and for teams to support each other during incidents, especially in areas of the country where there are fewer teams. Metal/non-metal teams operate under the same regulation as coal teams, and in many cases share relevant skill sets. By virtue of their own responsibilities, surface teams have skills that could provide very useful support to underground operations, such as first-aid and rope rescue. With additional training, they could provide further support.

Finally, there is no assured, trusted, audited process for sharing successes, best practices, and lessons learned across mines and teams. While there are reports published after incidents, MSHA does not share data and analysis beyond what is in formal investigation reports. Furthermore, these reports do not typically focus on mine rescue operations, usually providing little detail about them. Detailed lessons relevant to mine rescue are rarely identified and assessed so that practices can be improved. Instead, information-sharing across mine rescue teams is informal and haphazard. At best, individual team members may find opportunities to ask each other about their experiences at venues like contests.

The merit of formal learning processes is well established across the emergency services professions. The infrequency with which disasters occur makes it hard for responders to test and improve their strategies to ensure that they can be counted on to mitigate threats and hazards predictably, and to resolve their consequences effectively. As a result, various mechanisms for sharing experiences have emerged. These mechanisms are generally termed "lessons learned" processes, and include tools like in-progress reviews, after action reviewing and reporting, "hotwashes," and various kinds of debriefings. The appeal of learning from experience–both to avoid duplicating mistakes and to be able to repeat successes–is widely perceived, and many organizations across the emergency response disciplines have formal procedures for identifying, documenting, and disseminating lessons from incidents in hopes that they and others will be able to learn from past experience and improve future responses. While these processes vary, they have the common goal of sharing performance information in order to prevent the recurrence of adverse events and actions and to better contend with situations and problems that are likely to arise again. Most processes involve some version of three core components: 1. evaluating an incident (through systematic analysis of what happened and why); 2. identifying lessons (strengths to be sustained and weaknesses to be corrected); and 3. learning (inculcating behavioral changes consistent with the lessons).

It should be acknowledged that knowledge is in part a function of resources. Large mines tend to have more in-house mine rescue knowledge and experience. To the extent that they are willing to share their expertise with smaller operators, the nation's mine rescue capacity will be improved overall. On the other hand, smaller operations need to make a serious commitment to attaining sound rescue capability. The argument that small mines do not have the resources to at least meet minimum acceptable practices is untenable. Mines that cannot meet safety requirements, including the availability of capable rescue teams, should not be in operation.

Recommendations

- **MSHA, NIOSH, state agencies, industry, and the mine rescue associations should collaborate to conduct a system-wide assessment of teams' locations, availabilities, and capabilities. The findings of this assessment should be compiled as a knowledge-base that is regularly updated. This assessment could then serve as a basis for identifying gaps in capability and opportunities to fill them. It could help to facilitate the development of broader forums for information-sharing across operators and teams. Some resources are already available. For example, NIOSH does examine on the order of 100 teams per year. Likewise, MSHA maintains a Mine Emergency Operations database that contains information about mine emergency services, mine emergency teams and federal, state and local contacts in proximity to a specific mine. While information garnered from these sources is available, it is not broadly and systematically disseminated, especially to the level of mine rescue teams and their trainers, and may not be in a form and level of detail that is actionable by them.**

- **After any major exercise or incident, the mine rescue teams involved should be required to write a report that described their operations, focusing especially on lessons learned, recommended practices, and required improvements. These reports should be disseminated to all mine rescue teams nationwide.**

- **The industry should support joint training between teams. MSHA should collaborate with states and operators to support joint contests. In cases where metal/non-metal, coal, and surface mines are near each other, formal agreements should be developed to assure support during incidents.**

- **MSHA should convene an annual learning conference for all mine rescue teams (metal/nonmetal, coal, and surface) and those who directed or coordinated responses to past emergencies to facilitate collaboration and information-sharing. At such a conference, teams could discuss after action reports about events that occurred during the year, as well as new innovations with respect to equipment, procedures, and training. Such a conference could be coupled with MSHA's annual contest rules meeting. Given the new contest participation requirements, this would help assure broad participation.**

STANDARDIZATION

While the basic skill sets required for mine rescue are well-recognized, standards for positions, knowledge, and performance are not standard across teams. Team roles, functions, and procedures are adopted as a matter of convention and are formalized to some extent in contest rules promulgated by MSHA and reviewed by the industry executive committee. Contests provide some motivation for standardization, but this has so far only applied to teams that participate in contests. Moreover, the contest environment differs somewhat from reality, so rather than having standards written for the environment that are adapted for the contest, teams use rules written for contests that may not work well in a real-world incident. In short, there are no standardized position descriptions and performance standards designed for real-incident operation to which all teams must conform. Without standardization, teams cannot be "plug-and-play" (one team member may not be able to join another team seamlessly), teams do not work together as well as they might, and teams do not have an objective basis for trusting each other's capabilities. The bottom line is—it is essential that teams train and operate the same way. This does not mean that they will be identical—it is appropriate that they adapt themselves to local conditions and special missions, but all teams should share a common foundation.

This lack of standardization also applies to training curricula. Teams do not necessarily follow standard training curricula. MSHA does publish a training manual and other relevant publications. Other sources make some course materials available for certain topics. Some of these are incomplete, not detailed enough, out of date, or not configured as teaching materials. Team trainers must develop their own training plans, devise curricula, and pull together their own materials. As a result, teams do not get the same training in terms of substance, depth, coverage, or emphasis. Moreover, team quality is contingent on the quality of the trainer, and his ability to marshal a strong training program.

Recommendations

- **As part of its requirement to certify teams, MSHA should establish detailed qualification, certification, and substantive training requirements for mine rescue team members and all team positions and functions. The mining industry internationally has set a precedent for qualification in other functional areas (foreman, electrician, etc.) and could readily extend this to mine rescue. Likewise, the various emergency services professions have long valued standard qualifications. The emergency medical field operates with requirements for EMT certification, and the National Fire Protection Association has established a widely adopted set of consensus firefighter professional qualifications. Similarly, the wildland fire community employs a rigorous position-based qualification system to train and certify all personnel from basic firefighter through incident commander.**

- **Standardize procedures so that all teams of a particular type (surface or underground, coal or metal/non-metal) operate according to common conventions. We recommend that this be facilitated by MSHA but ultimately achieved through a consensus process, similar to that used by various standards-setting entities.**

- **Support these requirements with standard training curricula, manuals, materials that are published, regularly updated, and disseminated to all teams.**

- **Create a federally-sponsored national mine rescue academy for the purpose of building a national community of policy and practice. This would be an institution analogous to**

the U.S. Fire Administration's National Fire Academy. Its main role would be to offer resident and distance learning courses and programs that would enhance and standardize the training and capability of mine rescue team members. It could also help to identify and disseminate lessons learned and best practices, to facilitate promulgation of standards for teams, to develop standard teaching curricula, and to collaborate with universities to conduct advanced or specialized training for mine rescue personnel. Under a national academy model, team members should receive federal funding to attend academy training.

TEAM EXPERTISE AND SUSTAINABILITY

Mine rescue is a specialized activity that requires well-developed expertise in communications, systematic exploration, ventilation systems, gases and explosive ranges, the use of breathing apparatus, as well as how to function as a disciplined team. Team members must also understand the underground operating environment. To this end, it is valuable for team members to have ongoing underground experience, so they are familiar with the current mine operation. Moreover, if a team has members working in different areas of the mine, the team gains the benefit of sound knowledge of the whole mine. This is admittedly harder to achieve at a smaller mine than at a larger one. Team effectiveness is further enhanced when teams have members with particular kinds of specialized expertise related to the mine (such as knowledge of the mine's electrical system or the belt line), or related to rescue (such as paramedic-level skills or firefighting).

An important threat to team expertise is difficulty retaining members. The causes of turnover are multiple. At many mines, there are few incentives and little support for mine rescue. As a result, team members may become disheartened and leave the team after only a few years. In some cases, members sign up without understanding what they're getting into and they simply quit. Others lose interest over time, especially if they never see actual duty because "real" incidents are few and far between—while team members never wish harm to anyone, they train for rescue and crave the opportunity to use the skills they have worked so hard to attain. Some team members face resistance from their supervisors who are loath to allow their employees to take time away from their "regular" jobs for mine rescue training or contests. Similarly, team training and contests take members away from their families. Beyond this, anecdotal evidence also suggests teams are getting older. Maturity helps cohesiveness, but older members may lack the hunger to train hard, win at contests, or learn new techniques.

Another disincentive to team membership is risk and liability. Mine rescue operations are dangerous. Miners can be reluctant to expose their families to the possibility of disability or death. Furthermore, if mine rescue teams are exposed to too much liability, they will be incentivized against taking even reasonable risks. These concerns are even stronger when a team responds to another company's emergency, where it is less clear who will bear the cost if a mine rescue team member is hurt or killed. It is important for mine rescue teams to be willing to respond to their own mines and to support other operators and other teams, and so teams' risk and liability concerns must be relieved. The new Miner Act has taken an important step in this direction, stating that "No person shall bring an action against any covered individual or his or her regular employer for property damage or an injury (or death) sustained as a result of carrying out activities relating to mine accident rescue or recovery operations." MSHA certification of teams may afford additional protection.

Overall, teams face an important workforce challenge: how to recruit and retain active, committed members. Fundamentally, teams need adequate management support to be able to address this problem. Lack of support is demoralizing to members and especially to team coordinators and trainers. One response to this challenge has been the proposal to make mine rescue team positions full-time jobs. This has advantages and disadvantages. On one hand, compensation for the work could generate competition for the jobs, so that teams could be more selective. And, teams could develop much higher proficiency, since they could dedicate more time to training. On the other hand, team members would likely lose their currency with daily mine operations. More importantly, the infrequency of events makes it hard to justify full-time teams. Volunteers are adequate to meet current demand. Indeed, if a safety consciousness and zero-accident mentality truly take hold in the industry, there will be even less call for mine rescue capability. Boredom could set in—it does already with teams that are not currently full-time.

Recommendations

- **Core mine rescue team members ideally have current or very recent underground experience. The strongest teams include personnel drawn from a wide variety of jobs. Teams should strive to obtain and maintain broad-based and current underground expertise. Teams should also pursue formal mechanisms for augmenting their capability with specialized expertise, such as through agreements or relationships with physicians, paramedics, or firefighters. While issues of training and liability of non-miners will need to be evaluated, mine operators, and especially small operators, should explore integrating local first responders into their mine emergency response organizations.**

- **Teams should develop strategic workforce and succession plans to identify and plan for key personnel requirements.**

- **Mines should consider incentive programs for rescue team participation that include monetary and non-monetary rewards for performance, certification, specialized qualifications, training, contest success, and other examples of commitment to the operation above and beyond basic job requirements.**

- **Key team management positions (team coordinator and trainer) should be recognized by mine management as a primary duty. In particular, the trainer needs to have adequate time to prepare/develop teams for potential emergencies. In some cases, full-time mine rescue personnel may be justified.**

- **If a team is deployed to an incident at another operator's mine, then they and their employer should be held harmless, as long as mine rescue teams are acting within their training and procedures and making reasonable judgments. The scope of protection in this regard guaranteed by the new legislation should be specified so that mine rescue teams understand it fully.**

- **Since mine rescue team volunteers are asked to take risks above and beyond those associated with normal mining work, operators that staff teams should carry extended life insurance policies for every mine rescue team member so that families are not penalized for their voluntary sacrifices.**

RESPONSE TIME

Emergency medicine has a standard of a "golden hour" within which a critically injured patient must receive definitive care in order to survive. If primary objectives of mine rescue are to ensure life safety and to optimize the chance of rescue and survival for accident victims, then mine rescue teams must strive to get to victims as quickly as possible. It is widely acknowledged, however, that for a host of reasons it takes too long to get mine rescue teams on site and ready to go when an accident occurs. At the Sago mine disaster on January 2, 2006, for example, it took more than four hours for the first mine rescue team to arrive on site. The new legislation seeks to mitigate this kind of delay. It requires that mines have access to teams that are within one hour ground transport time. But problems other than distance from the mine rescue station to the mine lengthen response times. Other relevant factors include the time it takes to notify the team members (typically accomplished by telephone), the time it takes members to travel to the rescue station if they are not at work, and the fact that there is no assurance that volunteer mine rescue team members who are not at work will be available to respond. (Team members could be away at training or on vacation, sick, inebriated, or for some other reason unable to respond.) When responding to a mine for which a team is not formally responsible, these factors are more severe. The team's employer must allow the team to respond, and they may be far away. And, once a team does arrive at the mine where the incident is, the team has to locate and make contact with the command center, stage its equipment, and be briefed before it can enter the mine. Entry may be further delayed if back-up personnel are not available.

Recommendations

- **Require that adequate resources are dedicated to minimizing response times. Attention should be given to four key factors:**

  1. **Notification. Teams should employ a formal notification process. They should keep and continuously update contact information for all team members. They should consider using paging technology.**

  2. **Personnel availability. Teams should use clear accountability mechanisms so that the status of team members is known at all times. Teams should consider using duty schedules to assure that a minimum number of personnel are always available to respond immediately and can arrive at their mine within a set time period, though we acknowledge that contractual issues may limit this in some cases in the immediate term.**

  3. **Transportation. Teams should have access to a dedicated vehicle and trailer to transport team members and equipment to other mines in case of an emergency.**

4. **Coordination. Teams should have current points of contact at all mines for which they are formally responsible. They should establish in advance a process by which they can receive current mine maps and an initial situation briefing electronically in the event of an emergency so that they can study them while they are en route.**

- **Develop training programs that can improve the skills of designated miners to act as initial responders to emergencies. Emergency response systems work best if they are developed in depth, with those most likely to be first at the scene of a problem equipped with skills necessary to help stabilize the incident until more definitive help arrives. Providing at least some miners more advanced training in areas such as first aid makes it more likely that injured miners will get help faster.**

TEAM DEPLOYMENT

Once a team is on site, staged, and ready to go, further delays often occur. The mine rescue team operates only at the discretion of mine management or MSHA, who tend to be very conservative about allowing teams to enter the mine when unknown hazards are present. Rescue teams engage in hazardous work in hopes of saving the lives of trapped or injured miners. The possibility of survivors does not automatically justify endangering the lives of rescue team members, however. Appropriately, a rescue team's own safety is primary. More pragmatically, even under the most urgent circumstances, a rescue team is useless if its members get injured or killed, and in fact becomes a greater burden on an already taxed system. Nevertheless, decisions about rescue operations should consider the relationship between risks and outcomes/benefits. Arguably, the decision to deploy rescue teams is typically too risk-averse when miners are trapped, especially in cases where there is a great deal of margin built into the safety parameters under which teams operate. It is justifiable to relax some of these constraints when lives are at stake. Moreover, overly conservative standards that are not warranted by conditions exhaust teams and consume their resources. Finally, the special expertise and informed judgment of teams should be considered. Teams see the conditions in the mine first hand and have unique insight into how they may best be negotiated. At the same time, when multiple teams are operating in a mine, each team has only a narrow perspective on the entire emergency operation. Under such circumstances, it is very important that teams do not exceed their authority and make judgments that may unwittingly affect other teams. A competent and disciplined command center is especially important when multiple teams are operating.

Recommendations

- **The safety of the rescue team should remain the first priority. On any emergency event, a team should not be deployed underground unless and until existing conditions, risk, and threats to the team's safety are assessed.**

- **Any time a team is in harm's way–even if there is no rescue requirement–adequate support must be available for that team. To this end, back-up teams should be available underground and outside whenever anybody is underground during an emergency (miners or another team), whether they are engaged in rescue or property recovery.**

- **In cases where miners are trapped, mine operators should act proactively to understand the situation so that their teams can be briefed and deployed expeditiously. Operators should be afforded discretion and authority to deploy their teams as is warranted by a careful assessment of conditions, risk, and potential to save lives.**

- **Mine operators should be afforded the flexibility and discretion to relax conservative safety standards in accordance with the conditions they face. Similarly, while minimum safety standards must still be enforced, it is appropriate that they be more stringent when property recovery is the objective than when lives are at stake. Teams that are deemed certified should be permitted a greater measure of flexibility, discretion, and autonomy commensurate with their skills and qualifications to allow them to respond appropriately to the conditions they experience underground, and to use their resources as efficiently as possible. Examples of conventions and procedures where flexibility may be enhanced include:**

  1. **Systematic exploration should be used when conditions warrant, but it takes a long time. A six-person mine rescue team may be split to facilitate more expeditious exploration, if conditions permit (sometimes called "shot-gunning exploration").**

  2. **The l000-foot limit may be relaxed. This limit has evolved around the regulatory requirement that teams carry at least 1000 feet of communications cable, rather than based on operating criteria. Conditions should dictate an appropriate limit, rather than constraining operations with an arbitrary standard that may be too stringent when visibility is good and lives are at stake, but too relaxed for smoke conditions.**

  3. **Working barefaced at a greater level of carbon monoxide (perhaps, for example, up to 100 ppm for 4 hours) and a lower percent of oxygen (perhaps, for example, as little as 19.0%) may be permitted when lives are at stake, so that operations can be speeded up and teams will become exhausted less quickly. (The current standard is that use of apparatus is required at less than 19.5% oxygen and more than 50 ppm for carbon monoxide.) The appropriate allowable limits for oxygen and carbon monoxide should be studied, specified, and disseminated.**

  4. **A set of acceptable expedient procedures for management of the fresh air base in circumstances where miners are missing could be developed.**

INCIDENT COMMAND AND DECISION-MAKING

Typically mine rescue teams are not well-integrated into decision-making during mine emergencies, despite their expert knowledge of exploration procedures and their first-hand awareness of mine conditions. In effect, teams feel that they are treated as pawns rather than informed participants in the search and rescue the process. A particular problem is weak communication between teams and management during an emergency event. The briefing/debriefing process through which a team receives instructions and reports back its findings and actions is often informal. Sometimes confusion arises because direction is passed through several people and the message gets distorted. There is no process to assure that communications were clearly understood the same way by all involved. More importantly, mine managers, MSHA officials, and teams often are not clear with each other about objectives, process, what needs to be done, or sequence of actions during an incident. Teams are reluctant to engage in real discussion (ask questions, raise concerns, or debate options). These communication challenges also extend to difficulties communicating with families, the media, and other outside parties.

In part, these problems stem from a lack of disciplined command center operations and incident management procedures. Incident command and management principles are not fully or consistently understood or employed during mine emergencies. Moreover, those who work in command centers during incidents often do not understand mine rescue procedures. Command centers themselves are not carefully controlled operating environments and are often crowded with people who do not have a direct decision-making role with respect to underground operations. At the same time, the committee discovered broad confusion among the members of several mine rescue teams the committee met with about exactly who is in charge during an incident. The scope of MSHA's authority, especially with respect to the invocation and meaning of "j" and "k" orders (orders promulgated under Section 103 of the Federal Mine Safety and Health Act of 1977), was not well understood by many of those with whom the committee spoke.

Recommendations

- **Broad requirements for common command center training should be established. Command center exercises that include interactions with teams should be conducted regularly, and at least a few command center personnel should train with their mine rescue teams. NIOSH's Mine Emergency Response Interactive Training Simulation (MERITS) and MSHA's Managerial Emergency Response Development (MERD) are two available command decision-making training tool.[8] MERD and MERITS should be evaluated to ensure that they appropriately represent the realities of command decision-making requirements during an emergency event. MERD and MERITS or another command-center exercise should be used regularly (at least every two years) by anyone who could be involved in directing a rescue operation, including mine managers, MSHA officials, and mine rescue teams.**

- **Mine managers, MSHA officials, and mine rescue teams should receive formal training in using the functionally-oriented Incident Command System (ICS) for directing responses to mine emergencies. This is the state of the art and current standard in emergency response. It can be tailored to the type, scope, scale, complexity, and dynamism of the incident. Emergency responders use ICS to systematize multiple tasks, disciplines, jurisdictions, and responsibilities on an emergency scene under one organization that incorporates five functions: command, logistics, plans, operations, and finance/administration. ICS is a scalable concept–it can be employed to direct relatively small, simple events or to manage large, complex disasters. On larger incidents, sophisticated ICS approaches include adoption of a formal Unified**

[8] According to NIOSH, MERITS "provides trainees an opportunity to gain command center experience during a simulated underground coal mine emergency." It is an interactive, computer-based emergency simulation exercise that "allows trainees to practice information gathering, situation assessment, decision-making, and coordination skills without risk to personnel or property." (see http://merits.niosh.cdc.gov/merits/)

Command, a multi-agency governance structure that incorporates officials from agencies with jurisdictional or functional responsibility at the incident scene and allows them to jointly provide management and direction within a commonly conceived set of incident objectives and strategies. If mine managers, MSHA officials, and mine rescue teams understood and used ICS, they would capitalize on three decades of professional knowledge about how to manage incidents effectively, and they would be better able to work with state and local fire, police, and emergency medical responders. Courses in ICS are broadly available through FEMA and most state emergency management organizations.

- **Develop training for mine rescue teams and mine managers on team-based decision-making and how to communicate effectively.**

- **The linkage between teams and the command center should be strengthened. In particular, the communications and decision-making process should be formalized so that teams have a clear position in the communication "loop." Teams should have a clear, single point of contact in the command center who is knowledgeable about both team operations and mine management. When robust communications are in place, a future option to consider when revising command center protocols would be eventual relegation of the Fresh Air Base to a staging area.**

- **The briefing/debriefing process should be systematized, and should involve the entire team.**

- **A more rigorous process for developing a shared understanding of priorities and objectives should be developed and adopted universally. Joint planning meetings for each operational cycle should be conducted and should include team inputs. Teams should be able to voice ideas and concerns without fear of retribution.**

- **The industry should develop protocols for communicating with the media and other outside parties. All mines should train on these.**

- **Protect the integrity of internal communications and prevent information leaks by isolating communications between the command center, fresh air base, and teams. If this is accomplished, communications can rely on clear text rather than codes, which will help to avoid confusion and miscommunication.**

- **Operators and teams should improve the precision of their knowledge of the scope and authority of mine managers and MSHA, the conditions under which this knowledge may change, and the mechanisms that alter authority during an emergency.**

EQUIPMENT AND TECHNOLOGY

Beyond what is specified in Part 49, which is inadequate for missions and conditions teams are likely to confront, teams do not operate with a standard set of equipment. To some extent, contest rules extend Part 49 requirements. Some teams, especially those who do not participate in contests, are under-resourced. The new Miner Act requirement for contest participation may remedy this somewhat. However, "pushing" team equipment standards through contest rules does not automatically assure that equipment is appropriately tailored to true mine emergencies.

Teams also face some important technology challenges. By far the most pressing concern is assured communications. Current communications capability is inadequate. Communications cable is unwieldy and difficult to deploy and handle in rough terrain or over long distances. Wireless communications would be very valuable but capabilities are currently limited and unreliable. Another serious challenge is power. If all power to a mine is shut off, no power is available for water (needed for firefighting), atmospheric monitoring systems, and compressed air systems. A safe power supply can greatly enhance team operations. The most crucial piece of equipment rescue teams use is their breathing apparatus. Rapid, on-site maintenance support for apparatus minimizes interruptions in mine rescue operations because of apparatus repair and rehabilitation. Finally, from a broader perspective, fire protection is well established as a very effective part of rescue team effectiveness and miner survivability, but it gets inadequate attention and mines spend relatively little on implementing and enhancing these systems.

Beyond current systems, new technologies can greatly enhance team capability and mine safety more generally. There are several technologies that are already available and that have been shown to have potential utility, but that are not widely deployed. There are others that could be available with relatively small research and development investments. Some examples include the use of stench gas as a warning system, green lasers and other lighting improvements, and systems for locating miners that would provide clues about chosen escape routes and location after an event.

One area that has gotten a great deal of attention is robotic technology. The robots currently employed by MSHA are inadequate to the challenges of mine exploration. Better capability may be able to be developed with some research and development investment, but the track record of robotic technology for mine applications has been disappointing. A great deal of funding has been invested but with little success surmounting the challenging environment of a coal mine. During the Sago disaster, for example, precious time was wasted struggling to use robots that got stuck in the mud. Mine rescue team members expressed frustration at this—as one team member lamented, "NASA can operate a robot on Mars but we can't operate one underground." At the same time, technologists rightly argue that there are other more salient capabilities (most especially communication) that deserve attention and have a better development track record than robotics. Three robotic applications appear to have some promise, however, and deserve focused attention: 1. The ability to deploy a robot with autonomous navigation ability down a bore hole for exploration and communications; 2. The ability of a robot to follow a miner or rescuer "like a puppy dog" while carrying heavy equipment "like a pack mule"; and 3. The ability to enable a robot for close-in fire suppression.

Recommendations

- **Investments should be made to demonstrate, test, and field available technologies that show potential for improving team operations. Research and development efforts should target promising technologies that could enhance survivability and mine rescue**

capability. In particular, MSHA should work to prioritize and expedite the approval and certification process for technologies that can improve life safety.

- **Apparatus support for emergencies should be upgraded. In particular, a trained benchman should be posted at the fresh-air base to handle minor apparatus problems. Portable facilities for cleaning, benching, and drying apparatus that can provide direct support to multiple teams should be developed and deployed.**

- **Mines should consider ways to keep power on for safety support systems or establish a separate electrical circuit for the communications, monitoring, water, and compressed air systems.**

- **In advance of improved communications technologies (discussed elsewhere in this report), current mine communications systems should be hardened and the ability of teams to operate communications technologies should be improved. Teams could be augmented with a crew trained in communications equipment who could help deploy, handle, and maintain systems, especially when the terrain is rough and the team is operating under apparatus.**

- **Each mine should have, on a constant basis, arrangements for competent survey personnel and equipment to be immediately available at each mine to expeditiously identify surface locations for drill sites, and each mine should maintain arrangements for emergency drilling equipment as part of the mine emergency response plan.**

- **The equipment requirements for mine rescue teams should be periodically reviewed and updated in light of current technologies and typical missions. New requirements might include things like redundant communications (wired and wireless), bunker gear, infrared thermal imaging devices, and fist-aid equipment. Once developed, new equipment should be displayed and demonstrated at national and regional training venues.**

CONCLUSIONS

The conditions under which teams operate are unstable, dangerous, and unpredictable. The exigencies are extreme when lives are at stake. There are two fundamental enablers of success under these kinds of circumstances: the skill of team members and their level of trust for each other, other teams, and those directing them. Our recommendations target these two goals in particular. Beyond the Miner Act of 2006, the provisions of which are consistent with our own conclusions, there are some important efforts already under way to enhance mine rescue practices and procedures. We hope to lend credence to these efforts with our observations.

Meeting these recommendations will be a difficult balance for the industry and government to strike—competent, well-equipped mine rescue teams are expensive. This can present a substantial burden, especially for small operators. At the same time, we believe that a mine should not be allowed to operate unless is can do so, and at least meet a minimum acceptable standard that applies to all. To make it possible for smaller operators to meet standards necessary for a sound mine rescue capability industry-wide will require collaboration, but small operators will not be the only beneficiaries. The increased professionalization of the discipline of mine rescue that comes through standards and standardization will better serve any mine that faces disaster.

6
Training for Preparedness

This section discusses the issues of emergency self-escape and aided-rescue, with particular emphasis on training strategies designed to improve the ability of miners to survive a mine-wide emergency. While the section's primary focus centers on the emergency-response competencies of underground miners, it also discusses the competency levels of other mine-site positions with responsibility to respond to an emergency, i.e., supervisors, mine managers, and responsible persons on the surface.

The specific questions discussed in this chapter are:

- What competencies do underground miners need to successfully escape, or be rescued, during a mine emergency?
- What skill/knowledge gaps currently exist with the greatest potential to improve the ability of miners to escape or be rescued during a mine emergency?
- What "best practice" self-escape and aided-rescue training examples are currently used by the Mining Industry?
- What new training materials need to be developed to improve the ability of underground miners to escape or be rescued during a mine emergency?

Our recommendations in the area of "training for preparedness" are predicated on some fundamental beliefs. In order for self-escape and aided-rescue training to be effective, certain basic concepts need to be in place. In particular, the training must be:

- Focused on the primary objective of preparing miners to escape during a mine-wide emergency.
- Based on a comprehensive emergency response plan that is risk-based and mine-specific.
- Performance-oriented in that it considers non-training related factors, such as the physical capability of miners to walk their escape ways.
- Competency-based with a focus on the critical skills/knowledge miners need for successful self-escape or aided-rescue.
- Systems-based and designed according to sound instructional design concepts.
- Based on identified training needs that are determined by evaluating miners' competencies and analyzing mine-wide emergency incident and near-miss trends.
- Reviewed and revised at least on an annual basis.

A comprehensive, mine-specific emergency response plan is a key component to successful escape (or rescue) during a mine emergency. The commission maintains that all mines should have an emergency response plan that is designed to address the specific risks identified at that particular mine. In addition to identifying potential risks, a comprehensive risk analysis should be conducted to analyze the likelihood of the risk(s) occurring, the potential magnitude of the risk(s), and the appropriate countermeasures necessary to eliminate or acceptably mitigate all identified risks.

A systems-based instructional design process is also a critical component in delivering effective self-escape/aided-rescue training to miners. A process of this type starts by identifying the competencies miners need to successfully escape (or be rescued) from a mine emergency. It next determines the training needs of miners by evaluating their competency levels. Once training needs are identified, training interventions are designed to specifically address identified competency gaps. After training is delivered, trainees are evaluated to determine the effectiveness of the intervention. The final phase of the process is to revise (improve) the training intervention to address the gaps identified by the evaluation process.

KEY SKILL/KNOWLEDGE AREAS

In general, the commission identified three key skill/knowledge areas that are critical to the ability of miners to escape or be rescued during a mine-wide emergency. These areas include:

- Knowledge of Escape/Rescue Technologies

  In order to successfully escape or be rescued during a mine-wide emergency, miners must be competent in the use of those technologies designed to assist them during an emergency situation. They must be proficient in the use of Self- Contained Self- Rescuers (SCSR), directional life lines, refuge chambers, gas-monitoring devices, and similar types of technologies. As a last resort, they must also be familiar with how to construct a proper barricade.

- Mine-Specific Knowledge

  In addition, successful escape/rescue is predicated on the miner's knowledge of his/her mine. They must be intimately familiar with their mine's escape ways, ventilation system, mine map, SCSR storage locations, life lines, escape capsules, communication networks, and other emergency systems. In addition, miners must be proficient in the specifics of their mine's emergency response/evacuation plan and related mine-rescue protocols.

- Escape/Rescue Conceptual Knowledge

  A key escape/rescue competency often overlooked is the ability of miners to think and adapt to changing emergency situations. When a mine-wide emergency occurs, miners are confronted with a complex problem to solve. They are no longer working in a stable mine environment. Normal routes of egress may be blocked. Ventilation systems may be interrupted or reversed. The miners may have to escape through a smoke-filled or toxic environment. In addition, those trying to escape may have inaccurate information about the nature of the problem.

In these types of situations, it is imperative that miners have effective problem-solving and decision-making skills. The ability of miners to define the nature of their problem, identify alternative escape strategies, effectively use available technology, and execute their decisions all depends on their ability to think.

Miners need "conceptual knowledge" of the common issues related to mine disasters. They also need the ability to apply this conceptual knowledge to their specific situation. Conceptual knowledge is a higher level of understanding. It is not gained by rote instruction. Instead, it is attained by exposing the learner to examples (and non-examples) of the concept they are trying to understand. Within the context of "training for preparedness," miners can better understand the concepts of self-escape and aided-rescue if they are exposed to various types of mine-disaster scenarios.

Miners must be competent in all three skill/knowledge areas to successfully escape or be rescued during an emergency. They must be proficient in their knowledge of the mine, and competent in using the available technology. They must also have the ability to solve complex problems, and the fortitude to make critical decisions. *In our opinion, the escape/rescue training need with the greatest potential to improve the ability of miners to successfully escape during a mine-wide emergency is in the area of* ***Escape/Rescue Conceptual Knowledge*****.**

REVIEW OF NIOSH RESEARCH

The commission's "training for preparedness" recommendations are based on existing research. NIOSH has conducted considerable research into the behavioral aspects of escaping an underground mine during an emergency. The body of their research is incorporated into two books:

- *The Behavioral and Organizational Dimensions of a Mine Fire* (2000)
- *An Oral History of Mine Emergency Response* (2004)

The NIOSH research involved structured interviews with forty-eight (48) coal miners who successfully evacuated three mine fires in Pennsylvania in the 1990's. The mine fires in question occurred at the Adelaide, Brownfield, and Cokedale mines. On average, the miners interviewed were 42 years of age and had 17 years mining experience.

Escape/Rescue Training

In general, NIOSH found that U.S. miners were less well-trained in the areas of self-escape and aided-rescue than many of their foreign counterparts. To some extent, the researchers attributed this finding to the prevalent training methods used in the U.S. mining industry. They described these methods as over-relying on the rote learning of information and passive methods of instruction (i.e., videos and films). In general, current approaches to self-escape and aided-rescue training in the U.S. mining industry tend to focus on providing miners with discrete chunks of safety-related information. What it lacks is training that provides miners with the conceptual framework on how to apply this information in real-life situations.

The NIOSH research in this area is very thought provoking. It generated a number of comprehensive recommendations as to what key components are necessary to make a mine-wide evacuation successful. The researchers found that while mine-wide emergencies are unique, they also have a number of common characteristics. In general, they found that mines that evacuated miners successfully:

- Prepare for potential emergencies,
- Develop comprehensive emergency response plans, and
- Provide miners training on how to implement their plan.

Group Response

One key finding identified by the NIOSH research was that miners tend to respond to mine-wide emergencies as a group, as opposed to acting as individuals. In the three mine fires analyzed by the researchers, the forty-eight miners evacuated in eight distinct groups. Their group response did not always follow a formal organizational structure. The researchers concluded that a new informal structure, the "escape group" often emerges during a mine emergency evacuation.

The "escape groups" analyzed by the NIOSH researchers varied in terms of their effectiveness. The key variables identified by the researchers which determined "escape group" effectiveness were:

- The amount of time the group had spent together.
- The group's collective knowledge of the mine.
- The completeness of information the group had about their problem.
- The age and physical limitations of group members.
- The quality of leadership within the escape group.

Quality of Leadership

With regard to the "escape groups" involved in the evacuations analyzed by NIOSH, the key success factor was the "quality of group leadership." The quality of group leadership had a significant impact on the "escape group's" perception of the problem, its ability to cope with stress, the effectiveness of its problem-solving, and overall group behavior in response to the problem. It should be noted that escape-group leadership was not always provided by the supervisor. It often emerged from unexpected sources.

The NIOSH researchers developed a profile of an effective escape-group leader. In the eight groups they studied, the most effective leaders had certain common characteristics. The successful group leaders were:

- Alert to their environment,
- Retained key escape information,
- Took charge naturally,
- Decisive, yet flexible,
- Open to input from others, and
- Logical in their approach to decision-making.

Since miners tend to respond to emergencies as a group, the researchers recommended that this factor be considered by mine operators when they design emergency procedures. They recommended that:

- Emergency response plans allot time for miners to gather as a group.
- Emergency response plans identify strategic meeting locations.
- Mine operators consider experience and an individual's mine knowledge when selecting supervisors.
- Mine operators consider leadership ability when designing work crews.

Quality of Decision-Making

The NIOSH research also found that the quality of decision-making was closely related to the effectiveness of an escape group's evacuation. The group's ability to detect and analyze their problem, identify their escape options, and select/execute their best option was critical to their success. The key variables that influenced the quality of the escape group's decision-making were:

- *Internal State:* The group's composite level of skill/knowledge.
- *Degree of Uncertainty:* The accuracy of the group's information about the emergency (problem).
- *Stress Level:* A factor influenced by the quality of leadership.
- *Complexity of the Escape:* A factor influenced by whether the escape involved exposure to smoke.

As a result of their findings, the researchers identified a number of key escape/rescue training needs. The researchers concluded that improved training in the areas listed below would improve the ability of miners to escape or be rescued in a mine-wide emergency:

- *SCSR Donning/Transfer:* This is a fundamental escape skill. If miners do not have the ability to quickly don their SCSRs, they have no chance of successfully escaping through CO and/or smoke**.** Many of the miners interviewed had difficulty donning their SCSR. A miner's ability to don (or transfer an SCSR) in a crisis can be influenced by his/her emotional state or the presence of smoke. Miners need hands-on training in the SCSR donning (and transfer) procedure. In addition, SCSR training needs to be repeated frequently, or it tends to be forgotten.

- *SCSR Expectations*: Of the miners interviewed, 63% had difficulty breathing through their SCSR. In most cases, the miners were over-breathing their SCSRs. They did not understand the need to "slow their pace" and breathe with the unit. SCSR expectations training involves having miners actually breathe through their SCSRs to provide them a realistic idea of what to expect from this device in an emergency.

- *Simulated Smoke*: A considerable body of research indicates that the presence of smoke complicates a mine evacuation. The presence of smoke limits visibility. It can also diminish an individual's motor skills, and affect the ability of miners to don their SCSRs. In addition, a smoke-filled environment can affect a person's emotional stability and the quality of decision-making.

  The current research also indicates that miners who are familiar with their escape routes, and trained in a simulated smoke-filled environment, are less likely to panic. Miners who experience the sensation of smoke are better able to control their emotions. As a result, they tend to make better decisions.

- *The Effects of Carbon Monoxide (CO)*: Many of the miners involved in the mine-fire evacuations studied by NIOSH delayed donning their SCSR. They attempted to conserve these one-hour devices until they "really needed them." Many miners in emergency situations fail to understand that CO may be present at dangerous levels prior to the presence of heavy smoke. They may delay donning their SCSR past the point when it's safe. Consequently, increased training on the dangers posed by CO may improve the ability of miners to survive a mine-wide emergency.

- *The Concept of Ventilation Leakage*: In the NIOSH study, several miners perceived their problem (fire) as more significant than it was in fact. Their misperception developed when they encountered smoke in unexpected areas. They didn't realize that the smoke they encountered was the result of ventilation leakage. Instead of continuing to walk though the smoke (caused by the ventilation leakage), they unnecessarily changed their direction of travel in search of another escape route. A better understanding of this concept may improve the problem-solving ability of miners confronted with a similar situation.

- *Way-Finding*: "Way-finding" or being "mine-wise" is a miner's knowledge of alternative escape routes (other than the primary escape way) to evacuate the mine. It also involves the ability to utilize alternative directional devices, i.e. track, belt lines, etc. to successfully exit the mine in limited visibility. The NIOSH study concluded that additional training in this area could significantly improve the self-escape capabilities of miners.

- *Effective Warnings*: Of the eight escape groups involved in the NIOSH study, only one asked the responsible person on the surface about the location of their fire. The researchers found that escape groups who had accurate information as to the nature, location, and severity of their problem (fire) had the least difficulty evacuating the mine. These findings strongly suggest that miners and responsible surface personnel need to know how to give and receive effective emergency warnings.

- *Problem-Solving/Decision-Making Skills*: As previously mentioned, the escape groups interviewed by NIOSH varied in their ability to analyze their problem and make effective decisions. In response to this finding, the NIOSH researchers recommended additional training for miners to develop their problem-solving and decision-making skills.

The NIOSH research indicates that the primary factors influencing an escape group's ability to diagnose a problem are:

- Effectiveness of their warning message,
- Group's knowledge of the mine, and
- Quality of the group's leadership.

In addition to encouraging mine operators to identify individuals with leadership potential, the NIOSH researchers recommended additional training for miners in these areas:

- Critical Judgment Skills
- Escape ways
- Communications Skills

What is the best way to provide this training to miners? The NIOSH researchers recommend the increased use of simulation exercises and mock drills. These types of interventions can be either table-top exercises or large scale (mine-wide) simulations/drills. Their primary objective is to expose miners to different types of emergency scenarios in order to improve their knowledge of the common escape/rescue concepts.

Another instructional method recommended by the researchers was the use of narrative instruction. This method of instruction would involve using miners who survived disasters, or mine rescuers, to share information about the actual emergency events (or near misses) in which they were involved. Narrative instruction is an effective method for providing trainees real-life examples of the common issues involved in a mine-wide emergency. Training of this type could be effectively delivered in a video format.

- *Team-Building/Leadership*: The NIOSH research indicates that miners tend to respond to emergencies and solve emergency-related problems as a group. It also found that the quality of decision-making was influenced by the quality of group leadership. As a result, training to improve miner's critical judgment skills should be a group exercise.

  When responding to an emergency, miners need to be able to work as a team. To effectively work as a team, they must have an effective leader. The group leader must have a style that is conducive to a collective approach to problem-solving. Team-building and leadership development training has the potential to improve the decision-making process miners engage in during a crisis. As a consequence, it has the potential to improve their ability to escape and/or be rescued during a mine-wide emergency.

BEST PRACTICE TRAINING EXAMPLES

One aspect of the committee's analysis involved an evaluation of available training materials. Forty-two distinct instructional programs available through the MSHA Training Academy Resource Library and/or NIOSH were evaluated. The programs focused on self-escape, aided-rescue, and emergency response for underground coal miners. A summary of these resources is attached as Appendix B.

There is a wealth of useful training materials available in these subject areas. There is not, however, one comprehensive training program that encompasses all the required skills an underground miner needs to effectively escape (or be rescued) from a mine disaster. There is no single resource that covers all the possible scenarios a miner might encounter during an emergency.

Most of the training materials reviewed were in the subject categories of *Breathing Apparatus, Fire, Gases, Inundations, and Mine Emergency and Rescue***.** These resources include a wide spectrum of useful information. For purposes of this analysis, we grouped the resources reviewed into these sub-categories:

- Technical Subject-Specific
- Mine Rescue and Emergency Operations
- Hazard-Specific
- Conceptual/Problem-Solving

Technical Subject-Specific

A number of the training resources reviewed dealt with technical subject-specific issues. These resources are generally formatted as videos and instructional guides. They focus on narrow topics, i.e., mine inspection, SCSR apparatus (care and use), diesel equipment, fire extinguishers (types), and basic firefighting principles. Also included in this category were informative booklets on basic mining systems, i.e., mine maps, escape ways, mine ventilation, etc.

The training materials in this category are generally short in length and narrowly focused on a specific technical subject. They are designed to develop the fundamental knowledge and technical skills of new miners. These materials can also be used in refresher training for experienced workers.

In our opinion, these training materials can be effective when coupled with hands-on training. Their limitation is in the fact that they are subject/task-specific. In terms of self-escape and aided-rescue, they only cover the basic principles of certain types of mine emergency technologies.

Mine Rescue and Emergency Operations

There is a tremendous amount of comprehensive, in-depth training resources available at the MSHA Academy in the area of Mine Rescue and Emergency Operations. Examples of available topics include:

- *The Fundamentals of Mine Rescue*
- *Emergency Ventilation*
- *Advanced Mine Emergency Operations*
- *Mine Rescue and Recovery Guides*

These training materials tend to focus specifically on developing an advanced skill-set and knowledge-base for mine emergency response personnel. These resources would be very beneficial in training a Mine Rescue Team. It is unlikely, however, that most underground miners would be exposed to this type of advanced training. Training materials in this category are complex and time intensive. These materials are great resources, but their application and exposure is limited to mine rescue team members, command center personnel, mine management and other emergency response personnel.

A significant gap exists in the availability of intermediate-level escape/rescue training materials for underground miners. Self-escape and aided-rescue training resources are needed to bridge the gap between basic skills and advanced-level mine rescue/emergency response. The existing resources tend to underestimate the likelihood that underground miners will be involved in a real-life emergency that requires them to utilize emergency problem-solving and/or decision-making skills.

Hazard-Specific

A majority of the multimedia materials at the MSHA Academy deal with hazard-specific training and awareness. These materials are typically reactive in nature. They attempt to educate miners about the existence of specific hazards and injury/illness trends. They also cover the details of historic mine disasters. Topics contained in this category include but are not limited to the following:

- Respirable Coal Dust
- Equipment Guarding
- Stockpile Safety
- Welding/Cutting Hazards
- Powered Haulage
- Berm Safety

These training materials are informative. They also highlight important safety concerns. Their shortcoming from a self-escape and aided-rescue standpoint is that they are narrow in focus. They present discrete bits of safety information in a rote-learning format. They do very little to develop a miner's cognitive skills or emergency decision-making skills.

Conceptual/Problem-Solving

The best available training resources for developing the conceptual skills of underground miners are the NIOSH simulated emergency exercises. These materials include, but are not limited to these exercises:

- *I Can't Get Enough Air*
- *Travel Through Smoke*
- *The Belt Fire*
- *Smoke on the Section*

The above exercises provide the trainee with detailed, fact-specific problem-solving scenarios. They require trainees to react to complex, changing situations and to integrate their knowledge of basic mine-emergency concepts. These scenarios are developed in a latent-image format and were designed according to the concepts of programmed instruction. While this instructional design is fundamentally sound, the latent-image format is somewhat outdated. These materials provide an excellent starting point for developing new mine-specific emergency evacuation training simulations.

The latent-image exercises are not stand-alone materials. To use them effectively, a miner must have foundation knowledge in basic technical areas that include, but are not limited to the following:

- SCSR apparatus
- Firefighting
- Mine gases
- Ventilation
- First aid

These exercises force the trainees to think, react and make decisions as if they were the decision-makers during an emergency. They focus on the importance of problem-solving, effective communication and leadership during a mine-wide emergency. These types of problem-solving and decision-making exercises can be very effective if tailored to mine-specific emergency situations and company-specific emergency procedures. These simulation exercises might have a greater impact if they were converted to a computer-based-training format.

Summary

Overall, there are considerable training resources available at the MSHA Academy for mine rescue team members and advanced mine emergency response personnel. They also have considerable resources available to train new miners in the basic skill/knowledge areas they need to work safely. A significant training resource gap exists, however, at the intermediate knowledge level. More self-escape and aided-rescue training materials are needed that focus on developing the problem-solving and decision-making skills of underground miners, section foremen, and responsible surface personnel who respond to emergencies.

An effective self-escape and aided-rescue program for miners should combine training on fundamental technical concepts, i.e., SCSR, CO, ventilation, etc. with training that improves the problem-solving and decision-making skills of miners. It should also attempt to deliver the training in a group setting, as a means of improving the ability of miners to work in teams.

Some basic technical skills are best learned through rote-learning techniques and hands-on training. The higher level of conceptual knowledge that miners need to escape (or be rescued) from a mine disaster, i.e., problem-solving, decision-making, communication, leadership, etc., can only be developed through interactive simulation-type exercises/drills. The NIOSH simulation exercises represent the best examples of this type of training. More materials of this type in a computer-based-training format need to be developed.

TRAINING FOR PREPAREDNESS SURVEY

The commission administered a "training for preparedness" opinion survey (Survey), which is attached as an exhibit in Appendix C. The Survey sought the opinion of Industry and MSHA safety professionals on key "training for preparedness" issues. The training issues addressed by the Survey include:

- The escape/rescue competency levels of miners.
- Methods of evaluating competency levels.
- The need to develop new/better training materials.

Survey questions were prepared with assistance from NIOSH. They were based on the issues highlighted by the previously discussed NIOSH research. The results of the Survey support the conclusion reached by NIOSH with regard to the need for additional (improved) training for miners in the areas of:

- SCSR Training, i.e., donning, transfer, expectations, etc.
- Simulated Smoke Training
- Decision-Making
- Leadership
- Team-Building
- Effective Warnings
- Way-Finding
- Carbon Monoxide
- Ventilation Leakage

The surveys were distributed to fifty (50) MSHA participants and fifty (50) Industry participants. Surveys were completed and returned to the commission by thirty-nine (39) MSHA participants and forty (40) Industry participants. This represents a return rate of seventy-nine (79) percent. The United Mine Workers of America (UMWA) was invited to participate, but could not because of the number of activities occurring following the mine tragedies.

Background Characteristics of Survey Responders

Individuals responding to the Survey had significant experience in the Coal Industry. They also had considerable experience as safety/training and mine rescue/emergency response professionals. On average, the Survey participants had these background characteristics:

- General Mining Experience: 29.8 years
- Mine Rescue/Emergency Response Experience: 18.4 years
- Safety/Training Experience: 22.3 years
- Experience in Mine-Wide Emergencies: 87%
- Experience in Mine Rescue/Recovery Operation(s): 88%

Survey responses were submitted by participants from eleven (11) states (Alabama, Colorado, Illinois, Indiana, Kentucky, Ohio, Pennsylvania, Virginia, West Virginia, and Wyoming); and from nine (9) MSHA Coal Districts (2, 3, 4, 5, 6, 7, 9, 10, and 11). Those participating in the Survey represented a cross-section of the U.S. Coal Industry.

Survey Perspective

In the commission's opinion, the combined survey responses represent a valuable body of opinion on self-escape and aided-rescue competencies and training needs. While the sample size is not sufficient to support strong generalized conclusions, it does provide a solid base of opinion on "training for preparedness" to compare to the NIOSH research.

Overall, the survey responses (and comments) of the Industry and MSHA participants were similar in nature. The Industry survey responses were predominately from larger coal mining companies. As a result, the Industry's survey responses tend to represent the opinion of companies with comprehensive safety/training programs and mine rescue/response capabilities. While the Survey results may be biased in this regard, they tend to support the same conclusions reached by the NIOSH researchers.

Survey Assumptions/Analysis

This part of the "training for preparedness" chapter discusses the assumptions underlying the commission's analysis of the Survey's responses. A summary of the Survey results is contained in Appendix D.

Part I of the Survey asked participants for their opinions of the existing self-escape and aided-rescue competency levels. It also sought their input on the training needs of underground coal miners, mine managers, and responsible persons on the surface. Participants were asked to respond to a series of items (statements and questions) based on their perception of the "miners they were familiar with." Part I of the Survey asked participants for their opinion in these skill/knowledge areas:

- Self Rescuers
- Escape ways

- Emergency Procedures
- Ventilation
- Barricading
- Decision-Making
- Leadership
- Team-Building

In analyzing the participant responses, the commission operated on the assumption that a high level of competency in each of these skill/knowledge areas was essential for miners to successfully escape (or be rescued) during a mine disaster. In the commission's opinion unless all miners are proficient in these areas, a training need exists. As a result, our analysis of the Survey responses reflects our view that these are critical self-escape and aided-rescue skill/knowledge areas.

Part I of the Survey consisted of items framed in two types of Likert-Scale formats. One of these formats asked participants their opinion of the escape/rescue competencies (or the need for additional training). Participants were asked to indicate one of the following responses:

- Almost All
- More than Half
- Half
- Less than Half
- Almost None
- Don't Know
- Not Applicable

Since each competency was considered essential to a miner's ability to successfully escape (or be rescued) from a mine disaster, the commission looked at the *percentage of responses in all response categories other than "Almost All."* A participant response indicating that "Almost All" of "the miners they were familiar with are competent" was interpreted as meaning that no skill/knowledge gap existed in this area. If any other response option was chosen, i.e., More than Half, Half, Less than Half, Almost None, etc., the respondent was telling us that a training need existed. *The items with the highest percentage of responses in all categories other than "Almost All" were considered to represent the competency areas with the greatest training needs.*

Part I of the Survey contains forty-one (41) items requesting the participants to respond based on the format discussed above. *Only five (5) items asking for participant opinions on miners' escape/rescue competencies have a combined response percentage of more than 50% in the "Almost All" category.* Those areas with a greater than 50% combined response in the "Almost All" category include:

- Miners knowing the location of their SCSR cache.
- Miners being sufficiently familiar with their mine's communication system.
- Mining operations having a comprehensive emergency/evacuation response procedure.

- Miners knowing that escaping the mine is their first priority in an emergency.
- Miners knowing that barricading is the last resort in an emergency.

The combined "Almost All" responses to all of the Survey's other competency-related items are 50% or less. As a result, the commission concluded that significant training gaps exist in virtually all basic competencies related to preparing miners to successfully escape (or be rescued) during a mine disaster.

The next step in our analysis was to identify the most significant skill/knowledge gaps. *To identify the most prominent training needs, we looked at those items in which the respondents indicated that "Half or Fewer" of "the miners they were familiar with" were competent.* We assumed that if a respondent indicated that Half, Less than Half, or Almost None of the miners they were familiar with were competent in an area, a more significant skill/knowledge gap existed. Those Survey items with the highest percentage of responses indicating that "Half or Fewer" of the miners were competent were considered the gaps with the most significant potential to improve the ability of miners to escape (or be rescued) from a mine disaster.

A number of the Survey items asked the participants to comment on the need for additional training in key areas. The commission's logic in analyzing the responses to these items was the reverse of the logic used for the deficiency-related items. We looked at the percentage of responses in the Almost All, More than Half, and Half categories to identify the priority areas where additional training was recommended. Those items with the highest percentage were considered the top priorities.

The second type of response format used in Part I of the survey asked participants to indicate the extent they agreed or disagreed with a competency level of training-related items. There were sixteen items using this format in the survey. The response scale included these options:

- Strongly Agree
- Agree
- Slightly Agree
- Slightly Disagree
- Disagree
- Strongly Disagree

To analyze overall response patterns for these Survey items, the commission looked at the percentage of responses in terms of the broader categories of "Agree" (Strongly Agree, Agree, Slightly Agree) and "Disagree" (Slightly Disagree, Disagree, Strongly Disagree). Those statements with the highest percentage of "agreement" were identified by the commission as priority training needs.

Escape/Rescue Competency Levels: Survey Part I

Part I of the Survey was intended to get input from Industry and MSHA safety professionals to these following questions:

- What competencies do underground miners need to successfully escape, or be rescued, during a mine emergency?

- What skill/knowledge gaps currently exist with the greatest potential to improve the ability of miners to escape or be rescued during a mine emergency?

As previously stated, the commission maintains that all of the competencies referenced in Part I of the Survey are essential areas of skill/knowledge that miners need to successfully escape (or be rescued) from a mine disaster. In our opinion, the Survey results and participant comments support this conclusion.

The survey responses, however, indicate that the degree of the skill/knowledge gaps in these areas vary significantly. The summary that follows is intended to identify those competency areas that represent the most significant training needs and/or skill/knowledge gaps with the greatest potential to improve the ability of miners to escape (or be rescued) from a mine emergency.

<u>Self Rescuer</u>

In the area of Self Rescuers (SCSR), the Survey responses strongly support the conclusion that *the 3+3 method is an effective way to train miners to don an SCSR*. Survey Respondents were also of the opinion that *"hands-on training" is the best way to train miners to don an SCSR*. They also felt that *SCSR training should be repeated frequently* so that miners don't forget how to use them; and that *miners should be required to actually breathe through the SCSR* during training to improve their expectation of how these devices function.

The survey responses also indicated that additional training in the areas listed below would improve the ability of miners to escape (or be rescued) in a mine disaster:

- *Transferring from one SCSR to another in a toxic environment.*

- *Understanding the need to slow their pace when they encounter resistance to breathing through an SCSR.*

- *Understanding the stress they may experience while using an SCSR.*

<u>Escape Ways</u>

With regard to Escape ways, the Survey responses indicate that *many miners are not physically capable of walking their escape ways*. In addition, *seventy-four (74) percent of the participants agreed that miners should be required to walk their escape ways in emergency drills***.** Respondents also expressed strong support for the statement that *"well-designed job aids and directional signs enhance the ability of miners to escape during an emergency."*

The Survey responses also indicate that additional training in these areas would improve the ability of miners to escape (or be rescued) in a mine disaster:

- *"Way-Finding" or understanding the use of alternative means of finding your way out of the mine, such as track, belt lines, etc.*

- *Understanding how stress may affect their behavior and the behavior of their co-workers during an emergency escape.*

Emergency Procedures/Miners

In the area of Emergency Procedures, the Survey responses indicate that *few mine emergency/evacuation response plans have provisions for post-incident counseling.*

The responses also indicate that additional training in the areas listed below would improve the ability of miners to escape (or be rescued) in a mine disaster:

- *The critical facts to communicate during a mine emergency.*
- *Their mine's emergency escape/evacuation plan.*
- *Firefighting procedures.*
- *General Mine Rescue procedures.*
- *Understanding how to deal with stress in a mine emergency.*
- *The protocol they should follow when notified of a mine emergency.*
- *Training Mine Managers in Mine Rescue Command Center Protocol.*

Ventilation

The Survey responses indicate that additional training in the areas listed below would improve the ability of miners to escape (or be rescued) in an emergency:

- *Knowledge of their mine's ventilation system.*
- *Understanding the concept of "ventilation leakage."*
- *Understanding the effect of carbon monoxide (CO) and other mine gases***.**

Barricading

Participant comments strongly support the position that barricading is a survival technique only used as a last resort during a mine emergency. The priority strategy in all underground emergencies is to escape the mine. To enhance the ability of miners to barricade when escape is not possible, the respondents indicate that *mines should develop a checklist and frequently inspect to assure they have sufficient quantities of barricading materials on the working section(s).*

The Survey responses also indicate that additional training in the areas listed below would improve the ability of miners to escape (or be rescued) in a mine disaster:

- *Understanding the psychological aspect of barricading.*
- *Knowing how to erect an effective barricade.*

Decision-Making

One of the most critical skill/knowledge gaps identified by the survey is in the area of escape/rescue decision-making. The Survey responses strongly support the need for additional training in the areas listed as necessary to improve the ability of miners to escape (or be rescued) in an emergency, as follows:

- *Knowing how to make effective decisions during emergencies.*
- *Knowing how to identify alternate escape routes (other than designated escape ways) during an emergency.*
- *Knowing how to escape if smoke is present.*
- *Training Mine Managers on how to make decisions during emergencies.*
- *Training Responsible Persons on the Surface on how to make decisions during emergencies.*

Leadership/Team-Building

Similar to the NIOSH research, the Survey respondents expressed strong support for these statements:

- *Effective teamwork is a key factor in a successful escape during an emergency.*
- *Leadership is a key factor in a successful escape during an emergency.*
- *Leadership skills should be a factor in determining the composition of work groups.*

The Survey responses also strongly indicate that additional training in the areas listed below would improve the ability of miners to escape (or be rescued) in a mine disaster:

- *Team-Building training.*
- *Leadership training for Supervisors.*

Evaluation of Emergency Response Capabilities/Competencies – Survey Part II

The initial phase of a systems-based training process focuses on identifying training needs or skill/knowledge gaps. Phase two involved designing training interventions to address the most significant gaps between required competencies and existing skill/knowledge levels. The third phase of a systems-based training process is to determine the effectiveness of the training intervention. This is accomplished by evaluating the competency levels of participants after training to determine what they've learned.

Part I of the Survey is focused on identifying the most significant "training for preparedness" needs of underground miners. The overall Survey results provide the Industry with a good starting point in terms of what deficiencies need to be addressed. Part II of the Survey tries to address the issue of training evaluation.

Survey participants were asked their opinion on whether "suitable methods existed to evaluate the capability/competency" of miners in eight (8) key escape/rescue areas. The available response options included:

- Suitable methods of evaluating this capability/competency exist.
- Better information is needed with respect to evaluating this capability/competency.
- This competency does not need to be evaluated.
- I don't know if suitable evaluation methods are available.

Participant responses in Part II of the Survey clearly indicate that the Industry needs to improve how it evaluates underground miners (and other key emergency response positions) with regard to their ability to escape (or be rescued) during a mine disaster. *Of the eight (8) competency items listed in Part II, more than 50% of the respondents indicated a need for improved evaluation methods in all but two categories.*

Listed below are the most significant areas in which improved evaluation methods are needed. The percentage of overall responses in the category *"Better information is needed with respect to evaluation of this capability/competency"* is listed in parentheses following each item. Similar to the responses in Part I of the survey, the responses in Part II highlight the need to focus on "decision-making" and the "ability of miners to escape in a smoke-filled environment."

- Miners' ability to make decisions during an emergency (68%).
- Responsible Persons' (on the surface) ability to make decisions during an emergency (66%).
- Miners' ability to escape in a smoke-filled environment (65%).
- Miners' knowledge of emergency/evacuation response procedures (58%).
- Miners' knowledge of escape ways, life lines, and way finding (55%).
- Miners' knowledge of their ventilation plan and mine gases (53%).

Need for New/Better Training Materials/Miners – Survey Part III (A)

Part III (A) of the Survey asked participants for their opinion on the type of training materials that need to be developed (or improved) to enhance the ability of miners to escape (or be rescued) during a mine emergency. It includes nineteen (19) items related to the escape/rescue competencies of underground miners. Survey participants had four response options for each item. These included:

- Training materials do not exist
- Training materials exist, but need improvement
- Suitable training materials are available
- Don't know

In order to analyze the most significant training material needs, the commission grouped the overall responses in the categories "Training materials do not exist" and "Training materials exist, but need improvement." The Survey items in Part III (A) with the highest percentage in these two combined categories represent the most significant gaps in available escape/rescue training material.

The most significant training material gaps are in the areas listed below. Similar to the other sections of the "training for preparedness" chapter, these responses call attention to the need to develop new/improved training materials in the areas of: 1) escaping the mine in a smoke-filled environment, 2) decision-making, 3) team building, and 4) using an SCSR during an emergency.

- Escaping the mine in a smoke-filled environment (79%).
- How to make decisions during emergencies (76%).
- Team-Building training (small- group behavior during emergencies) (75%).
- Using SCSR units during an escape (73%).
- Ventilation leakage (62%).
- Firefighting procedures (62%).
- General Mine Rescue procedures (62%).
- When/How to Barricade (61%).
- Using escape ways (60%).
- Way-Finding (59%).
- Carbon monoxide (and other mine gases) (57%).
- Donning SCSR units (56%).
- Mine ventilation system (55%).
- Protocol that miners should follow if miners are notified of an emergency (55%).
- Location and use of life lines (55%).
- Emergency escape plan (55%).
- Protocol for notifying responsible person on the surface of an emergency (54%).
- Communication systems at the mine (50%).

Need for New/Better Training Materials/Mine Managers and Responsible Person on the Surface – Survey Part III (B)

Part III (B) of the Survey asked participants for their opinion on the type of training materials that need to be developed (or improved) to enhance the ability of Mine Managers, i.e., the top management position at the mine, and Responsible Person(s) on the Surface, i.e., the dispatcher or mine-monitoring person. At an underground mine, both of these positions have critical roles in organizing the response to an emergency situation.

Part III (B) included six (6) items related to the escape/rescue competencies of Mine Managers and Responsible Person(s) on the Surface. Survey participants had four response options for each item. These included:

- Training materials do not exist
- Training materials exist, but need improvement
- Suitable training materials are available
- Don't know

In order to analyze the most significant training material needs, the commission grouped the overall responses in the categories "Training materials do not exist" and "Training materials exist, but need improvement." The Survey items in Part III (B) with the highest percentage in these two combined categories represent the most significant gaps in available escape/rescue training material for Mine Managers and Responsible Person(s) on the Surface.

The most significant training material gaps are in the areas listed below. Similar to the other sections of the Training for Preparedness report, they emphasize the need to develop improved training materials in the areas of mine rescue protocol and emergency response decision-making.

- Mine Rescue Command Center Protocol (72%).
- Emergency Communication Protocol (72%).
- Decision-Making during Emergencies (71%).
- Emergency Response Procedures (64%).
- Mine Monitoring (60%).
- Mine Communication Systems (53%).

Survey Summary and Recommendations

General

In the commission's view, the results of the Survey confirm the findings of the NIOSH research with regard to improving the ability of miners to escape (or be rescued) during a mine emergency. The Survey's results also lend foundation to the following general recommendations in the area of "training for preparedness."

The commission recommends:

- **The primary objective of self-escape and aided-rescue training must focus on preparing miners to escape during a mine emergency.**

- **Training miners to escape (or be rescued) during a mine emergency must be based on a comprehensive emergency response plan that is risk-based and mine-specific. All mine operators must prepare for emergencies and train miners thoroughly on their emergency response/rescue plan(s).**

- **To be effective, "training for preparedness" interventions must be performance-oriented. In addition to training content, the intervention must consider non-training-related factors, such as the physical capability of miners to walk their escape ways.**

- **"Training for preparedness" must be competency-based. It must focus on the critical skills/knowledge miners need in order to successfully escape (or be rescued) during a mine emergency.**

- **"Training for preparedness" interventions should be systems-based. Interventions should be designed to address identified training needs (gaps in performance). They should also be designed according to sound instructional design concepts.**

- **In order to better identify "training for preparedness" needs, the Industry needs to improve methods of evaluating miners' competencies. The performance of miners, mine managers, and responsible persons on the surface should be evaluated during emergency response drills and mock-disaster exercises. In addition, actual mine-wide emergency incidents and near-miss events should be analyzed to identify "lessons learned."**

- **"Training for preparedness" programs and interventions should be reviewed and revised at least on an annual basis.**

<u>Regulatory Training</u>

On March 9, 2006 MSHA published an Emergency Temporary Standard (ETS) on Emergency Mine Evacuation. In addition, on June 14, 2006 President Bush signed the Mine Improvement and New Emergency Response Act (MINER Act). These legislative and regulatory initiatives were prompted by the Sago, Alma, and Darby mine tragedies that occurred in the first half of 2006.

The MSHA ETS and the Miner Act both contain provisions requiring improved emergency response-related training for miners (and other key emergency response personnel). These new training provisions include, but are not limited to: 1) more frequent emergency escapeway exercises, 2) disaster-scenario training, 3) more frequent SCSR training, 4) increased requirements for mine-rescue training, and 5) improved training on mine emergency/response plans.

In our opinion, many of the key "training for preparedness" needs identified by the NIOSH research and the commission's Survey will be addressed if mine operators comply with these new training requirements. **The commission recommends that the priority training needs identified below be addressed in this manner.**

- **SCSR Training**

    - **Donning an SCSR**
    - **Transferring from one SCSR unit to another SCSR**
    - **Expectations training (breathing through an SCSR)**
    - **Location of SCSR caches**

- **Escape ways**

    - **Location of escape ways**
    - **Walking key portions of an escape ways**
    - **Location and use of life lines (and other directional devices)**

- **Way-finding (utilizing alternate escape routes)**

- **Ventilation**

  - **Mine ventilation systems**
  - **Ventilation leakage**
  - **Effects of carbon monoxide and other gases**

- **Barricading**

  - **Barricading as a last resort**
  - **How to erect an effective barricade**

- **Emergency Response Procedures**

  - **Training on mine emergency response plan**
  - **How to give/receive effective emergency warnings**
  - **Firefighting training**

While regulatory training can address many of the "training for preparedness" needs, the commission believes additional self-escape/aided-rescue training should be offered to miners. Part 48 (and other required emergency response) training requirements are not sufficient to deal with the training gaps that exist in this area. **In order to adequately prepare miners for self-escape/aided-rescue, the Mining Industry needs to provide employees with training in addition to what's required by law. A particular emphasis should be placed on providing additional self-escape/aided-rescue training for supervisors and other individuals with critical emergency response responsibilities.**

In addition, **the commission recommends that MSHA use their existing authority to approve training plans to improve the quality of training provided to miners. Improved competency-based training designs are needed to improve the effectiveness of regulatory training. In addition, improved instructional designs should be applied to regulatory training to make it more interactive and interesting to miners.**

Priority Training for Preparedness Needs

*In the commission's opinion, the escape/rescue training needs with the greatest potential to improve the ability of miners to successfully escape during a mine-wide emergency are in the area of **Escape/Rescue Conceptual Knowledge.*** Miners need "conceptual knowledge" of the common issues related to mine disasters. They also need the ability to apply this conceptual knowledge to their specific situation. Conceptual knowledge is a higher level of understanding. It is not gained by rote instruction. Instead, it is attained by exposing the learner to examples (and non-examples) of the concept they are trying to understand. Within the context of "training for preparedness," miners can better understand the concepts of self-escape and aided-rescue if they are exposed to various types of mine-disaster scenarios.

In these types of situations, it is imperative that miners have effective problem-solving and decision-making skills. The ability of miners to define the nature of their problem, identify alternative escape strategies, effectively use available technology, and execute their decision all depends on their ability to think.

Miners must be proficient in their knowledge of the mine and competent in using the available technology. They must also have the ability to solve complex problems, and the fortitude to make critical decisions.

Training in the area of Escape/Rescue Conceptual Knowledge is only partly addressed by the MSHA ETS and the MINER Act. **The commission recommends that the Industry, MSHA, and NIOSH focus their "training for preparedness" efforts in this critical area. These efforts should concentrate on the development and delivery of training interventions in the following areas:**

- **Emergency Response Decision-Making Training for:**
    - **Miners**
    - **Mine Managers**
    - **Responsible Persons on the Surface**
- **Leadership Training for Supervisors**
- **Team-Building Training**
- **Simulated Smoke Training**
- **Dealing with Stress during:**
    - **Emergency Escape**
    - **Barricading**
    - **SCSR use**
- **Command Center Protocol for Mine Managers**

Training in the area of Escape/Rescue conceptual knowledge should focus on underground miners, mine managers, and responsible persons on the surface. It should expose training participants to various types of disaster scenarios, and be designed in multiple formats, i.e., annual refresher training, safety meetings, shift-wide drills, mine-wide exercises, large- scale MERD exercises, etc.

<u>Evaluation Methods</u>

The Survey results in Part II (Evaluation Methods) support the findings in Part I (Capabilities/Competencies). **As a result, the commission recommends that the industry, MSHA, and NIOSH focus on developing and/or improving methods of evaluating the self-escape and aided-rescue competencies of underground miners (and other key emergency personnel) in the following areas:**

- **Emergency/Response Decision-Making**
- **Coping with a Smoke-Filled Environment**
- **Implementing Emergency Response Procedures**
- **Locating Escape ways and Life lines**
- **Way-Finding (identifying alternative escape routes)**

<u>Need for New/Better Training Materials</u>

A significant gap exists in the availability of intermediate level escape/rescue training materials for underground miners. Self-escape and aided-rescue training resources are needed to bridge the gap between basic skills and advanced level mine rescue/emergency response**.** The existing resources tend to underestimate the likelihood that underground miners will be involved in a real-life emergency that requires them to utilize emergency problem-solving and/or decision-making skills.

The results from Part III of the Survey support this conclusion. **As a result, the commission recommends that industry, MSHA, and NIOSH focus resources on developing new/improved training materials in the areas listed below:**

- **Simulated Smoke Training**
- **Emergency/Response Decision-Making for:**
    - **Miners**
    - **Mine Managers**
    - **Responsible Persons on the Surface**
- **Team-Building**
- **Leadership Training for Supervisors**
- **SCSR Expectations Training**
- **Building Effective Barricades**
- **Mine Rescue Protocol Training for:**
    - **Mine Managers**
    - **Miners (Basic Concepts)**

CONCLUSION

In closing, the commission wishes to emphasize that the "training for preparedness" performance needs identified in this section will not improve on their own. The demographics in the U.S. Mining Industry are undergoing significant transformation. A significant percentage of the Industry's workforce is over fifty (50) years of age. As we move forward, more and more new, inexperienced miners will be entering the Industry. This fact makes it imperative that we close the skill/knowledge gaps in this critically important area. Increased emphasis must be placed on passing the knowledge of retiring exemplary workers to succeeding generations of miners as well, not only in these critical areas but in others like hazard awareness and control, which is part of every task in mining.

7
Escape and Protection Strategies

As emphasized earlier in the report, prevention of fatalities and serious injuries through a systematic and comprehensive risk management-based planning and design process is paramount. **The commission recommends that mine-specific escape and rescue plans be required for each underground coal mine, and such plans must specify measures to be taken to address specific hazards at the mine that are responsive to the mine's characteristics.**

In the event that a mine emergency should occur, the importance of escape from the mine as the primary response of miners cannot be over-emphasized. Preparedness for escape is a critical skill, and training for preparedness is covered elsewhere in this report as a separate topic. Admittedly, based on history, miners will not be able to escape from every emergency situation that could develop. Thus a last-resort decision, based on a thorough assessment of the entire situation as augmented by communications with the surface, miners will have to find a safe area in the mine until they can be rescued. Means for enhancing escape and for protecting miners when escape cannot be achieved are covered individually next. Specific recommendations given reflect the nature of varying mine-specific characteristics, and highlight that strategies for addressing specific hazards may be quite different for mines with different characteristics, e.g., different numbers of ventilation shafts and different mining heights.

ESCAPE STRATEGIES

Escape Always High-Priority Strategy

Miners need to be intimately familiar with critical decision-making for emergency response. The decisions they make will impact their survivability. Being able to integrate information well in a stressful time is a critical skill, which often will lead to a successful escape. Knowing when the primary strategy of escape can be executed safely provides critical knowledge, and intense training in mock emergencies could provide these skills. This aspect is covered in detail in another part of this report.

Carrying SCSR on Person

At present the Mine Act does not require miners to wear an SCSR on their belts, and in thin coal seams or confined spaces it is problematic. When it is not feasible, a self-rescuer that only provides protection against carbon monoxide may be worn and used to access an SCSR stored near where a miners work. A provision that requires miners to wear oxygen on SCSRs on their belts, even if the device has less capacity (say, provide 30 minutes of oxygen), would eliminate the need for switching from a self-rescuer to an SCSR in an environment that is potentially toxic. **The commission recommends that improved technology for oxygen provisions be pursued so that devices can be practically worn by the miner.**

Many companies are moving to the M-20 Ocenco oxygen supplied unit for their employees to wear on their belt. Therefore, the reference above which states (say, provide 30 minutes of oxygen) should be changed to (say, provide 10-30 minutes of oxygen) or "provide oxygen on the belt" would be more appropriate.

Incorporating Life Lines in Escape Routes

Under an MSHA emergency temporary standard, life lines must be installed in both designated escape routes (primary and secondary), continuous from a working area to the surface. Some life lines have cones on them indicating the proper direction of travel during an emergency with dense smoke. These devices would reduce the chances for traveling the wrong way in an escape route. **The commission recommends that life lines, preferably with a metal core to facilitate emergency communications, or other direction-indicating devices be installed in all designated escape ways.**

Based on MSHA's ETS, the regulation requires installation in both the primary and alternate escape way. The above reference to "may be installed in one or both, needs to only refer to both.

Tag Line Availability at Strategic Locations

A tag line would link escaping miners one with another and keep them together once they are linked. Making tag lines available at strategic locations, including at the beginning of an escape route in a working area, would greatly reduce the chances of miners getting separated from the group. **The commission recommends that tag lines be made available at strategic locations in a mine, including near the beginning of all designated escape ways.**

Locating SCSRs in Caches at Some Designated Distance Throughout Mine on Escape Path

The provision of oxygen devices for miners is critical for escape from a mine facing an emergency. Until recently, small mines were required to have only one SCSR for each miner, and each SCSR was approved based on provision of at least 60 minutes of oxygen during use. Today the majority of underground coal mines are developed two to three miles, or more, into a coal reserve. Often, provision of a single SCSR to a miner, as approved, would generally not give an adequate supply of oxygen for escape under such distance situations. Some major coal mining companies have been providing additional SCSRs in their mines to address this need, but it has not been a requirement of law, until recently. Determining an appropriate distance for locating SCSR caches throughout a mine must be mine specific, and location of them in escape routes, or adjacent to the escape routes in a safe area, is paramount. Safe areas could be established and located in crosscuts between primary and secondary escape ways and could house other emergency supplies. The commission supports the use of caches containing sufficient 60-minute SCSRs, until newer technology is commercially available, for the maximum number of miners working in any inby area in a mine be established at intervals not exceeding 30 minutes walking time along all designated escape ways. **The commission recommends that such caches may be located in a substantially constructed area between adjacent designated escape ways, which would require MSHA approval.**

Locating CABA Units Incorporating Refill Stations at Designated Distances

The use of a compressed-air breathing apparatus (CABA) for fire-fighting or rescue purposes was regulated in Poland and is being considered in the United Kingdom. Australia is using CABA refill stations, with a back-up power source for the air compressor, where the oxygen demand requirement exceeds approximately one and one-half hours (usual capacity for a twin-cylinder CABA). In light of recent concerns regarding the reliability of SCSRs or miners' ability to use them properly under duress, CABA units would provide an alternative technology to SCSRs in mines with adequate height. **The commission recommends that MSHA-approved compressed air breathing apparatuses and refill stations, or other approved oxygen-supplying devices, may be substituted for SCSRs in a mine, provided devices are not mixed.**

Shortening Escape Paths with an Additional Shaft to Include Emergency Escape Facilities

The Mine Act requires two separate and distinct escape ways in each mine, continuous to the surface. In many mines, the two escape ways lead to two different shafts or slope, often separated by long distances. When a mine has such shafts, equipped for escape, then often one of the escape routes is much shorter than the other. This situation would reduce the distance for escape by miners significantly. A strategy for development of multiple shafts would provide an alternative way of facilitating quicker escapes by miners during emergencies and would also reduce the requirement for locating SCSR caches, or alternative supplies of oxygen. It would also shorten the distance that miners who must crawl out of the mine would have to travel. **The commission recommends that the use of strategically located ventilation or escape shafts equipped with escape hoists be incorporated by mines when feasible and consistent with a risk analysis as a strategy to reduce escape times from a mine during an emergency.**

Holding Annual Mock Emergencies to Assess Effectiveness of Escape Strategies

This strategy was covered in much more depth in another section of the report. Holding mock emergencies and evaluating the effectiveness of miners in escaping from the mine would have potentially great benefit, if done comprehensively and audited for effectiveness.

Developing Self-Escape Management Plan

As mentioned previously in the report, a risk-based mine safety management plan is required of mine operators in New South Wales, Australia. An investigation report on the Moura No. 2 Mine explosion in 1994 (Warden's Inquiry, 1996) recommended a self-escape management plan as well, which is incorporated into a mine's safety management plan. Such a plan deals specifically with analyzing eventualities for risks that could impact self escape from a mine emergency and determining ways to eliminate or reduce the risks. Examples of such plans do exist in Australia now, and mine operators and the inspectorate there would undoubtedly share such plans with U.S. operators. Once plans are formulated, they need to be periodically reviewed and updated as changes occur (personnel, infrastructure, etc.) and tested for effectiveness and reliability; initial and periodic training are also important.

Developing Emergency Evacuation Hazard Management (Risk Assessment Based) Plan

The nature of an emergency evacuation hazard management plan would be similar in process to the management plan for self escape. This plan has also been incorporated in Australia into a mine's safety management plan. It, too, is a risk management-based plan. Examples of such plans would be shared by Australian operators or the inspectorate for application in the U.S.

PROTECTION STRATEGIES

The commission notes that an overriding goal for emergency equipment and structures which will be adopted in mines for emergency purposes is that they be installed so they will be reliably functional during emergencies. Another overriding goal is that they should be designed, located and equipped in a sound engineering manner to withstand accidents such as mine fires, explosions and roof falls. To assure availability when needed, they should be maintained and constantly tested and examined to assure, as far as achievable, they are reliable and functional.

Improving SCSR Technology

SCSR technology could be improved in order to provide additional functionality. Currently, there is a unit weight-benefit trade-off, and SCSR technology needs to change. Specifically, the devices must provide adequate oxygen to effect escape, be capable of renewing the oxygen source without removing the face piece, and be more practically wearable. **The commission recommends that research and/or development to accomplish these objectives be pursued.**

Safe Rooms

Much like rest areas along an interstate highway, hardened, isolated "safe rooms" could be constructed along escape ways where escaping miners may take off their SCSRs, rest, get food and water, and through borehole service, call outside for a status update (both ways). Miners could then move on to the next "safe room." **The commission recommends that standards to govern specifications for a safe room be fully developed for future optional implementation. The implementation of safe rooms should be based on risk analysis.**

Upgrading Fire-Protection Systems

Significant productivity increases in coal mines over the last few decades has led to incorporation of larger equipment and supporting systems, including belt-line components. Fire-protection systems specified in the 1977 Mine Health and Safety Act were based on existing equipment, and the specifications have not been upgraded for modern, larger belt systems. Fire protection systems are a crucial aspect of life safety strategies. If fires are contained, other emergency response related activities will be enhanced. **The commission recommends that specifications for fire-suppression systems, the flow quantity and pressure required for water lines, and other fire-protection measures be evaluated for compatibility with modern technology, and any required modifications must be evaluated by a means of risk analysis.**

Fire Brigades

A key element in developing a risk-based approach to dealing with mine emergencies is the adoption of effective countermeasures to minimize risks. The potential for a fire is an ever-present risk in underground coal mines. Using mine-wide monitoring systems effectively can give early warning, and once an abnormal condition is detected, an immediate response can be initiated. In particular catching a fire in its incipient stage is critical, and utilizing fire brigades, first responders, etc. would be an important early response function. As a result, **the commission recommends that the industry further expand its ability to control fires, and mitigate the risk of a major fire, by developing "Fire Brigades," first responders, etc.**

The commission recommends that every underground mine adopt the Fire Brigade, first responder, etc. concept. Every production shift at an underground mine should have a cadre of individuals who receive advanced firefighter training. These firefighting teams should also be provided with the necessary equipment to fight/control underground mine fires.

The objective of adopting this strategy is to control small fires before they escalate to the point of requiring a major "mine rescue" operation. The cost of training and implementing Fire Brigades, first responders, etc. at all underground mines would clearly be offset by the value gained in preventing a major underground fire and the potential loss of human life. These Fire Brigades, first responders, etc. could be stand-alone teams, or an expanded aspect of the operation's Mine Rescue team.

The commission also recommends that MSHA provide support for Fire Brigades, first responders, etc. by developing relevant, effective training materials. MSHA should also sponsor Fire Brigade, first responder workshops to familiarize the industry with firefighting technology and techniques. A particular emphasis should be placed on developing scenario training to improve the decision-making skills of Fire Brigade, first responder, etc. members.

Ventilation

Maintaining effective ventilation throughout the mine is critical to the safe operation of the mine. Actions in one part of the system should not be taken without regard to consequences elsewhere in the mine. For example, balancing the ventilation of mined-out areas and bleeders with active-panel and section ventilation is a complicated task that requires consideration of entire ventilation system interactions. Furthermore, a risk analysis of possible fire and explosion scenarios will identify risks that could be avoided or mitigated through mine ventilation practices, including options for addressing mined-out or gob areas. **The commission recommends that a systems approach to mine ventilation be applied utilizing mine personnel familiar with overall ventilation-system complexities to analyze different possible modifications of the ventilation system for potential hazards and assure that risks are identified and addressed.**

Escape Way Stopping Construction

When explosions and fires occur, stoppings that control air flow in underground mines are often widely compromised. Stoppings used to isolate escape ways are critical to the safe escape of miners. **Research is needed to determine whether new science-based, practically achievable specifications for stopping construction along escape ways are needed to better preserve the escape routes for use in emergencies.** Ultimately the U.S. should adopt practices for construction of ventilation controls similar to those used in Australia, but with the exact specifications based on engineering and science research applied to underground coal mines in the U.S.

Revaluation of Seal Criteria

The Sago and Darby mine disasters raised questions about the adequacy of the constructed seals that isolated an abandoned area of the mine. Omega-block seals at both mines failed, raising concerns about government approval criteria for seals, seal design, installation and certification practices, monitoring and inspection practices for seals and the sealed areas, and other general application issues. **The commission recommends that new criteria for the approval of seal designs and installation be established through research. Seal design and installation must be certified, and mines must conduct a risk-based assessment of all potential hazards related to sealed areas, to determine how to manage identified risks.**

Expanding Mine-Wide Monitoring to 'Critical Locations', Including in Abandoned Areas

Mine-wide monitoring systems have been implemented by many operators in their underground mines, with approximately 650 systems in underground coal mines today. These systems could be invaluable during a mine emergency by providing information on incipient fires, gas concentrations and other parameters. However, they are often damaged during the emergency and rendered inoperable, or they are powered down based on current regulations requiring all power to be removed from the mine. Additionally, the current configuration of the battery back-up for these systems is considered a potential hazard in the post explosion/fire mine atmosphere. **The commission recommends that "hardened" monitoring systems be developed and that methods for safely and effectively utilizing monitoring during emergencies be established.** For more effective use of such systems, issues such as which sensors should be incorporated and optimal locations for various sensors at critical monitoring points should be examined. Afterwards a guideline document on best practices should be prepared by NIOSH, MSHA, or a task-specific work group and disseminated broadly.

Additionally, there may be an expanded role for mine monitoring systems in those mines where sealed areas are going to be monitored, based on the risk analysis and management plan for that mine. As examples, if there were a risk of spontaneous combustion or if the plan identified the need to monitor the explosive mixture of gases behind the seal, then a continuous monitoring system would be strongly indicated. **The commission recommends that research and development be conducted to identify opportunities and practices for safety improvement through an expanded use of mine monitoring systems.**

Maintenance of Trapped Miners

History indicates that not all miners can escape from an underground coal mine when an emergency occurs but rather are trapped in the mine. When the situation does occur, then miners have been taught to build a substantial barricade at a location that has 'clean' air and sufficient area to support life over an extended period of days.

In many underground non-coal mines, and in some underground coal mines outside the U.S., refuge/rescue chambers are provided as a safe haven for trapped miners. The designs for refuge chambers range from simple to complex. Some operate on mine power, some have no power, and others have back-up battery power. Communications from the surface could be provided.

The commission recommends that additional research be conducted on strategies and technologies to maintain miners trapped underground and to facilitate their rescue. The commission also recommends that mines need to employ a range of strategies and technologies that are consistent with their risk analysis and management plan. The commission further recommends that mines have mine rescue management plans that look at the hazards, decisions, and actions that could be taken for any given situation by miners, managers, mine rescue teams, and incident management teams. Using a risk management-based process, more likely scenarios would be assessed for hazards and interventions taken to reduce the risks.

8
Summary of Recommendations

RISK MANAGEMENT

1. The commission recommends that a comprehensive approach, founded on the establishment of a culture of prevention, be used to focus employees on the prevention of all accidents and injuries.

2. Further, the commission recommends that every mine should employ a sound risk-analysis process, should conduct a risk analysis, and should develop a management plan to address the significant hazards identified by the analysis; simple regulatory compliance alone may not be sufficient to mitigate significant risks.

3. The commission recognizes that not all mines have a familiarity with risk management, and therefore recommends that NIOSH develop a series of case studies that mines could use as templates, and that it conduct workshops and seminars to diffuse this approach to safety throughout the industry.

COMMUNICATIONS TECHNOLOGY

4. The commission recommends that mines utilize hardened mine pager phones or leaky feeder systems, as an interim measure, to meet the immediate need for post-incident emergency voice communications.

5. The commission recommends that the development of these guidelines be completed as soon as possible.

6. The commission recommends that a hybrid communication system be developed to allow reliable wireless communication enhanced by the leaky feeder backbone or other metallic infrastructure, such as wire-core life lines, haulage track, and pipes, and that such a system be deployed in mines as soon as possible.

7. A particular type of technology system tested under the Emergency Communications Partnership shows particular promise for mine rescue applications with nodes that utilize the IEEE 802.11b WiFi networking standard at 2.4 GHz. The nodes are portable and can be battery powered. Several nodes combine to create an ad-hoc mesh network. The commission recommends that work be done to adapt "breadcrumb" technology for use by mine rescue teams.

8. The commission recommends that work be conducted to develop an RFID-based tracking system that will function with the emergency communication systems that are under development, such as software-defined radio, and that the system be demonstrated as soon as the emergency communication systems are developed.

9. The commission recommends that NIOSH lead the development of standards for wireless communications in underground mines.

10. The commission recommends that alternative and promising emergency communications and tracking systems be developed and commercialized for the long term enhancement of mine safety.

EMERGENCY RESPONSE AND MINE RESCUE PROCEDURES

Training Quality

11. The minimum amount of training required of mine rescue team members should be increased to eight hours per month. Even eight hours per month should be considered a bare minimum—as a practical matter, adequate preparation for contests alone demands at least this level of commitment. The better teams already surpass this requirement.

12. MSHA should better validate mine rescue training by observing training in progress in addition to checking training logs. To accomplish this, MSHA would be well served by staffing a small team dedicated to working with mine rescue teams throughout the year. This would both allow MSHA direct visibility into the level and quality of training teams are getting, and help them to understand and trust the teams' capabilities at a deeper level. An ongoing relationship like this would also help to build trust between MSHA and the teams, which would put MSHA in a better position to help teams improve their training programs. And, on a real incident, MSHA and the teams would know each other and be better able to work together.

13. In conjunction with the requirement to certify teams, MSHA should conduct a systematic review of the skills required of teams. Foundational capabilities and specialized functions should be clearly identified, and the capabilities, tasks, and skills required to fulfill them determined. In addition, as broader sets of skills are recognized as being relevant to team capability; training requirements, resources, and contests should expand to include them. The inclusion of pre-shift and first-aid in contests are examples that demonstrate the precedent for formalizing key skill sets. Many teams we spoke with emphasized the need for more rigorous and comprehensive training with respect to mine gases and the instruments used to detect them.

14. Federal and state government agencies and industry should partner to develop more joint training facilities that provide realistic environments, such as the National Institute for Occupational Safety and Health (NIOSH) Lake Lynn Laboratory experimental mine facility near Pittsburgh and at experimental mines located at academic institutions or other organizations. These should be located to be accessible to teams nationwide.

15. The new legislation requires that operators make available two teams that receive at least annual (semi-annual, for mines with less than 36 employees) training at their mine. While this is a very important start, the requirement should be expanded so that every mine rescue team is familiar with all mines to which it is committed to respond. With the support and assistance of operators, mine rescue teams should pursue strategies for cross-training at other mines. This should include tours that would inform the team members about how to get to

the mines, the configuration of ventilation systems, and the presence of special hazards unique to these mines. Teams should proactively develop relationships with key points of contact at other mines so that when an incident occurs the team has a clear interface. Local mine rescue associations could play an important role in this process. They could facilitate visits to all mines represented in the association on a rotating schedule. This would enhance all teams' familiarity with the facilities they might support, and would also facilitate further collaboration between the teams. Associations could also facilitate dissemination of regular updates to maps for all mines covered by the association, though teams themselves must be responsible to be sure they have regularly updated maps for the mines they cover formally. MSHA may have to intervene to ensure operators regularly share updated maps with the teams that service them.

16. The new requirement for mine rescue teams to participate in a minimum of two mine rescue competitions per year is also an important capacity enhancement. Operators must recognize the reality that, depending on a team's current level of proficiency, reasonable preparation for a contest requires about twenty hours above and beyond our recommended monthly eight-hour training requirement. Teams also need the equipment necessary to practice with–a field and props for practice problems. While it is preparation and participation, not winning, that most enhances readiness and builds camaraderie within and across teams, the belief that winning is achievable is a strong incentive for teams to work hard and improve their skills. The prestige associated with winning also helps them attract new members. Given that most teams depend on volunteers, companies should recognize individual and team success at contests with monetary and non-monetary rewards.

17. MSHA should establish criteria for the development and use of contest problems to ensure that time to complete a problem, which is easy to assess during a competition, should not displace other important skill-based performances as primary contest objectives. Likewise, contest problems should emphasize functions that teams will likely have to perform during an emergency.

18. In addition to devising contest problems, MSHA should help operators and teams devise exercise plans that will help them practice all aspects of mine emergency response. It is important that these drills exercise the plans that mines intend to use in the event of an emergency, to include testing procedures for family relations, media relations, and command center management. The results of the exercises should then be used by operators to refine their plans.

Collaboration

19. MSHA, NIOSH, state agencies, industry, and the mine rescue associations should collaborate to conduct a system-wide assessment of teams' locations, availabilities, and capabilities. The findings of this assessment should be compiled as a knowledgebase that is regularly updated. This assessment could then serve as a basis for identifying gaps in capability and opportunities to fill them. It could help to facilitate the development of broader forums for information-sharing across operators and teams. Some resources are already available. For example, NIOSH does examine on the order of 100 teams per year. Likewise, MSHA maintains a Mine Emergency Operations database that contains information about mine

emergency services, mine emergency teams and federal, state and local contacts in proximity to a specific mine. While information garnered from these sources is available, it is not broadly and systematically disseminated, especially to the level of mine rescue teams and their trainers, and may not be in a form and level of detail that is actionable by them.

20. After any major exercise or incident, the mine rescue teams involved should be required to write a report that described their operations, focusing especially on lessons learned, recommended practices, and required improvements. These reports should be disseminated to all mine rescue teams nationwide.

21. The industry should support joint training between teams. MSHA should collaborate with states and operators to support joint contests. In cases where metal/non-metal, coal, and surface mines are near each other, formal agreements should be developed to assure support during incidents.

22. MSHA should convene an annual learning conference for all mine rescue teams (metal/nonmetal, coal, and surface) and those who directed or coordinated responses to past emergencies to facilitate collaboration and information-sharing. At such a conference, teams could discuss after action reports about events that occurred during the year, as well as new innovations with respect to equipment, procedures, and training. Such a conference could be coupled with MSHA's annual contest rules meeting. Given the new contest participation requirements, this would help assure broad participation.

Standardization

23. As part of its requirement to certify teams, MSHA should establish detailed qualification, certification, and substantive training requirements for mine rescue team members and all team positions and functions. The mining industry has set a precedent for qualification in other functional areas (foreman, electrician, etc.), and could readily extend this to mine rescue. Likewise, the various emergency services professions have long valued standard qualifications. The emergency medical field operates with requirements for EMT certification, and the National Fire Protection Association has established a widely adopted set of consensus firefighter professional qualifications. Similarly, the wildland fire community employs a rigorous position-based qualification system to train and certify all personnel from basic firefighter through incident commander.

24. Standardize procedures so that all teams of a particular type (surface or underground, coal or metal/non-metal) operate the same way. We recommend that this be facilitated by MSHA, but ultimately achieved through a consensus process, similar to that used by various standards-setting entities.

25. Support these requirements with standard training curricula, manuals, materials that are published, regularly updated, and disseminated to all teams.

26. Create a federally-sponsored national mine rescue academy for the purpose of building a national community of policy and practice. This would be an institution analogous to the U.S. Fire Administration's National Fire Academy. Its main role would be to offer resident

and distance learning courses and programs that would enhance and standardize the training and capability of mine rescue team members. It could also help to identify and disseminate lessons learned and best practices, to facilitate promulgation of standards for teams, to develop standard teaching curricula, and to collaborate with universities to conduct advanced or specialized training for mine rescue personnel. Under a national academy model, team members should receive federal funding to attend academy training.

Team Expertise and Sustainability

27. Core mine rescue team members ideally have current or very recent underground experience. The strongest teams include personnel drawn from a wide variety of jobs. Teams should strive to obtain and maintain broad-based and current underground expertise. Teams should also pursue formal mechanisms for augmenting their capability with specialized expertise, such as through agreements or relationships with physicians, paramedics, or firefighters. While issues of training and liability of non-miners will need to be evaluated, mine operators, and especially small operators, should explore integrating local first responders into their mine emergency response organizations.

28. Teams should develop strategic workforce and succession plans to identify and plan for key personnel requirements.

29. Mines should consider incentive programs for rescue team participation that include monetary and non-monetary rewards for performance, certification, specialized qualifications, training, contest success, and other examples of commitment to the operation above and beyond basic job requirements.

30. Key team management positions (team coordinator and trainer) should be recognized by mine management as a primary duty. In some cases, full-time mine rescue personnel may be justified.

31. If a team is deployed to an incident at another operator's mine, then they and their employer should be held harmless, as long as mine rescue teams are acting within their training and procedures and making reasonable judgments. The scope of protection in the regard guaranteed by the new legislation should be specified so that mine rescue teams understand it fully.

32. Since mine rescue team volunteers are asked to take risks above and beyond those associated with normal mining work, operators that staff teams should carry extended life insurance policies for every mine rescue team member so that families are not penalized for their voluntary sacrifices.

Response Time

33. Require that adequate resources are dedicated to minimizing response times. Attention should be given to four key factors:

- Notification. Teams should employ a formal notification process. They should keep and continuously update contact information for all team members. They should consider using paging technology.

- Personnel availability. Teams should use clear accountability mechanisms so that the status of team members is known at all times. Teams should consider using duty schedules to assure that a minimum number of personnel are always available to respond immediately and can arrive at their mine within a set time period.

- Transportation. Teams should have access to a dedicated vehicle and trailer to transport team members and equipment to other mines in case of an emergency.

- Coordination. Teams should have current points of contact at all mines for which they are formally responsible. They should establish in advance a process by which they can receive current mine maps and an initial situation briefing electronically in the event of an emergency so that they can study them while they are en route.

Team Deployment

34. The safety of the rescue team should remain the first priority. Any time a team is in harm's way–even if there is no rescue requirement–adequate support must be available for that team. To this end, back-up teams should always be available underground and outside whenever anybody is underground during an emergency (miners or another team), whether they are engaged in rescue or property recovery.

35. In cases where miners are trapped, mine operators should exercise their authority to direct rescue teams to begin operations. They should not wait for MSHA direction to do so.

36. Mine operators should be afforded the flexibility and discretion to relax conservative safety standards in accordance with the conditions they face. Similarly, while minimum safety standards must still be enforced, it is appropriate that they be more stringent when property recovery is the objective than when lives are at stake. Teams that are deemed certified should be permitted a greater measure of flexibility, discretion, and autonomy commensurate with their skills and qualifications to allow them to respond appropriately to the conditions they experience underground, and to use their resources as efficiently as possible. Examples of conventions and procedures where flexibility may be enhanced include:

    - Systematic exploration should be used when conditions warrant, but it takes a long time. A six-person mine rescue team may be split to facilitate more expeditious exploration, if conditions permit (sometimes called "shot-gunning exploration").

    - The l000-foot limit may be relaxed. This limit has evolved around the regulatory requirement that teams carry at least 1000 feet of communications cable, rather than based on operating criteria. Conditions should dictate an appropriate limit, rather than constraining operations with an arbitrary standard that may be too stringent when visibility is good and lives are at stake, but too relaxed for smoke conditions.

- Working barefaced at a greater level of carbon monoxide (perhaps up to 100 ppm for 4 hours) and a lower percent of oxygen (perhaps as little as 19.0%) may be permitted when lives are at stake, so that operations can be speeded up and teams will become exhausted less quickly. (The current standard is that use of apparatus is required at less than 19.5% oxygen and more than 50 ppm for carbon monoxide.)

- A set of acceptable expedient procedures for management of the fresh air base in circumstances where miners are missing could be developed.

Incident Command and Decision-Making

37. Broad requirements for common command center training should be established. Command center exercises that include interactions with teams should be conducted regularly, and at least a few command center personnel should train with their mine rescue teams. NIOSH's Mine Emergency Response Interactive Training Simulation (MERITS) and MSHA's Managerial Emergency Response Development (MERD) are two available command decision-making training tool.[9] MERD and MERITS should be evaluated to ensure that they appropriately represent the realities of command decision-making requirements during an emergency event. MERD and MERITS or another command-center exercise should be used regularly (at least every two years) by anyone who could be involved in directing a rescue operation, including mine managers, MSHA officials, and mine rescue teams.

38. Mine managers, MSHA officials, and mine rescue teams should receive formal training in using the functionally-oriented Incident Command System (ICS) for directing responses to mine emergencies. This is the state of the art and current standard in emergency response. It can be tailored to the type, scope, scale, complexity, and dynamism of the incident. Emergency responders use ICS to systematize multiple tasks, disciplines, jurisdictions, and responsibilities on an emergency scene under one organization that incorporates five functions: command, logistics, plans, operations, and finance/administration. ICS is a scalable concept–it can be employed to direct relatively small, simple events or to manage large, complex disasters. On larger incidents, sophisticated ICS approaches include adoption of a formal Unified Command, a multi-agency governance structure that incorporates officials from agencies with jurisdictional or functional responsibility at the incident scene and allows them to jointly provide management and direction within a commonly conceived set of incident objectives and strategies. If mine managers, MSHA officials, and mine rescue teams understood and used ICS, they would capitalize on three decades of professional knowledge about how to manage incidents effectively, and they would be better able to work with state and local fire, police, and emergency medical responders. Courses in ICS are broadly available through FEMA and most state emergency management organizations.

39. Develop training for mine rescue teams and mine managers on team-based decision-making and how to communicate effectively.

[9] According to NIOSH, MERITS "provides trainees an opportunity to gain command center experience during a simulated underground coal mine emergency." It is an interactive, computer-based emergency simulation exercise that "allows trainees to practice information gathering, situation assessment, decision-making, and coordination skills without risk to personnel or property." (see http://merits.niosh.cdc.gov/merits/)

40. The linkage between teams and the command center should be strengthened. In particular, the communications and decision-making process should be formalized so that teams have a clear position in the communication "loop." Teams should have a clear, single point of contact in the command center who is knowledgeable about both team operations and mine management. When robust communications are in place, a future option to consider when revising command center protocols would be eventual relegation of the Fresh Air Base to a staging area.

41. The briefing/debriefing process should be systematized, and should involve the entire team.

42. A more rigorous process for developing a shared understanding of priorities and objectives should be developed and adopted universally. Joint planning meetings for each operational cycle should be conducted and should include team inputs. Teams should be able to voice ideas and concerns without fear of retribution.

43. The industry should develop protocols for communicating with the media and other outside parties. All mines should train on these.

44. Integrity of internal communications should be protected and information leaks should by prevented by isolating communications between the command center, fresh air base, and teams. If this is accomplished, communications can rely on clear text rather than codes, which will help to avoid confusion and miscommunication.

45. Operators and teams should improve the precision of their knowledge of the scope and authority of mine managers and MSHA, the conditions under which this may change, and the mechanisms that alter authority during an emergency.

Equipment and Technology

46. Investments should be made to demonstrate, test, and field available technologies that show potential for improving team operations. Research and development efforts should target promising technologies that could enhance survivability and mine rescue capability. In particular, MSHA should work to expedite permissibility for technologies that can improve life safety.

47. Apparatus support for emergencies should be upgraded. In particular, a trained benchman should be posted at the fresh-air base to handle minor apparatus problems. Portable facilities for cleaning, benching, and drying apparatus that can provide direct support to multiple teams should be developed and deployed.

48. Mines should consider ways to keep power on for safety support systems or establish a separate electrical circuit for the water system and compressed air going underground.

49. In advance of improved communications technologies (discussed elsewhere in this report), current mine communications systems should be hardened, and the ability of teams to operate communications technologies should be improved. Teams could be augmented with a crew trained in communications equipment who could help deploy, handle, and maintain systems, especially when the terrain is rough and the team is operating under apparatus.

50. Each mine should have, on a constant basis, arrangements for competent survey personnel and equipment to be immediately available at each mine to expeditiously identify surface locations for drill sites, and each mine should maintain arrangements for emergency drilling equipment as part of the mine emergency response plan.

51. The equipment requirements for mine rescue teams should be carefully reviewed and updated in light of current technologies and typical missions. New requirements might include things like redundant communications (wired and wireless), bunker gear, infrared thermal imaging devices, and fist-aid equipment. Once developed, new equipment should be displayed and demonstrated at national and regional training venues.

TRAINING FOR PREPAREDNESS

General

52. The commission recommends:

- The primary objective of self-escape and aided-rescue training must focus on preparing miners to escape during a mine emergency.
- Training miners to escape (or be rescued) during a mine emergency must be based on a comprehensive emergency response plan that is risk-based and mine-specific. All mine operators must prepare for emergencies and train miners thoroughly on their emergency response/rescue plan(s).
- To be effective, "training for preparedness" interventions must be performance-oriented. In addition to training content, the intervention must consider non-training- related factors, such as the physical capability of miners to walk their escape ways.
- "Training for preparedness" must be competency-based. It must focus on the critical skills/knowledge miners need in order to successfully escape (or be rescued) during a mine emergency.
- "Training for preparedness" interventions should be systems-based. Interventions should be designed to address identified training needs (gaps in performance). They should also be designed according to sound instructional design concepts.
- In order to better identify "training for preparedness" needs, the Industry needs to improve methods of evaluating miners' competencies. The performance of miners, mine managers, and responsible persons on the surface should be evaluated during emergency response drills and mock-disaster exercises. In addition, actual mine-wide emergency incidents and near-miss events should be analyzed to identify "lessons learned."
- "Training for preparedness" programs and interventions should be reviewed and revised at least on an annual basis.

Regulatory Training

53. The commission recommends that the priority training needs identified below be addressed in this manner.

- SCSR Training

- Donning an SCSR
- Transferring from one SCSR unit to another SCSR
- Expectations Training (Breathing through an SCSR)
- Location of SCSR caches

- Escape ways
  - Location of escape ways
  - Walking key portions of escape ways
  - Location and use of life lines (and other directional devices)
  - Way-Finding (utilizing alternate escape routes)

- Ventilation
  - Mine ventilation systems
  - Ventilation leakage
  - Effects of Carbon Monoxide and other gases

- Barricading
  - Barricading as a last resort
  - How to erect an effective barricade

- Emergency Response Procedures
  - Training on mine emergency response plan
  - How to give/receive effective emergency warnings
  - Firefighting Training

Priority Training for Preparedness Needs

54. The commission recommends that the Industry, MSHA, and NIOSH focus their "training for preparedness" efforts in this critical area. These efforts should concentrate on the development and delivery of training interventions in these following areas:

- Emergency Response Decision-Making Training for:
  - Miners
  - Mine Managers
  - Responsible Persons on the Surface

- Leadership Training for Supervisors

- Team-Building Training

- Simulated Smoke Training

- Dealing with Stress during:
  - Emergency Escape
  - Barricading
  - SCSR use

- Command Center Protocol for Mine Managers

Evaluation Methods

55. The commission recommends that the Industry, MSHA, and NIOSH focus on developing and/or improving methods of evaluating the self-escape and aided-rescue competencies of underground miners (and other key emergency personnel) in these following areas:

- Emergency/Response Decision-Making
- Coping with a Smoke-Filled Environment
- Implementing Emergency Response Procedures
- Locating Escape ways and Life lines
- Way-Finding (identifying alternative escape routes)

New/Better Training Materials

56. The commission recommends that Industry, MSHA, and NIOSH focus resources on developing new/improved training materials in the areas listed below:

- Simulated Smoke Training

- Emergency/Response Decision-Making for:
  - Miners
  - Mine Managers
  - Responsible Persons on the Surface

- Team-Building

- Leadership Training for Supervisors

- SCSR Expectations Training

- Building Effective Barricades

- Mine Rescue Protocol Training for:
  - Mine Managers
  - Miners (Basic Concepts)

ESCAPE AND PROTECTION STRATEGIES

Escape Strategies

57. The commission recommends that mine-specific escape and rescue plans be required for each underground coal mine, and such plans must specify measures to be taken address specific hazards at the mine, responsive to the mine's characteristics.

58. The commission recommends that improved technology for oxygen provision be pursued so that devices can be practically worn on miners' belts.

59. The commission recommends that life lines, preferably with a metal core to facilitate emergency communications, or other direction-indicating devices be installed in all designated escape ways.

60. The commission recommends that tag lines be made available at strategic locations in a mine, including near the beginning of all designated escape ways.

61. The commission recommends that required oxygen-supply device caches may be located in substantially constructed areas between adjacent designated escape ways, and would require MSHA approval.

62. The commission recommends that MSHA-approved compressed air breathing apparatuses and refill stations, or other approved oxygen-supplying devices, may be substituted for SCSRs in a mine, provided devices are not mixed.

63. The commission recommends that the use of strategically located ventilation or escape shafts equipped with escape hoists be incorporated by mines when feasible and consistent with a risk analysis as a strategy to reduce escape times from a mine during an emergency.

Protection Strategies

64. The commission recommends that research and/or development on oxygen-supply devices be pursued such that the devices must provide adequate oxygen to effect escape, be capable of renewing the oxygen source without removing the face piece, and be more practically wearable.

65. The commission recommends that standards to govern specifications for a safe room be developed for future optional implementation. Hardened, isolated "safe rooms" could be constructed along escape ways where escaping miners may take off their SCSRs, rest, get food and water, and through borehole service, call outside for a status update (both ways). Miners could then move on to the next "safe room." The implementation of safe rooms should be based on risk analysis.

66. The commission recommends that specifications for fire-suppression systems, the flow quantity and pressure required for water lines, and other fire-protection measures be evaluated for compatibility with modern technology, and any required modifications be evaluated by a means of risk analysis.

67. The commission recommends that the industry expand its ability to control fires, and mitigate the risk of a major fire by developing "Fire Brigades," first responders, etc. and further recommends that every underground mine adopt the Fire Brigade, first responder, etc.

concept. The commission also recommends that MSHA provide support for Fire Brigades, first responders, etc. by developing relevant, effective training materials.

68. The commission recommends that a systems approach to mine ventilation be applied utilizing mine personnel familiar with overall ventilation-system complexities to analyze different possible modifications of the ventilation system for potential hazards and assure that risks are identified and addressed.

69. Research is needed to determine whether new science-based, practically achievable specifications for stopping construction along escape ways are needed to better preserve the escape routes for use in emergencies.

70. The commission recommends that new criteria for the approval of seal designs and installation be determined through research. Seal design and installation must be certified, and mines must conduct a risk-based assessment of all potential hazards related to sealed areas, to determine how to manage identified risks.

71. The commission recommends that "hardened" monitoring systems be developed and that methods for safely and effectively utilizing monitoring during emergencies be established.

72. The commission recommends that additional research be conducted on strategies and technologies to maintain miners trapped underground and to facilitate their rescue.

73. The commission also recommends that mines need to employ a range of strategies and technologies that are consistent with their risk analysis and management plan.

74. The commission further recommends that mine operators develop mine rescue management plans that look at the hazards, decisions, and actions that could be taken for any given situation by miners, managers, mine rescue teams, and incident management teams. Using a risk management-based process, more likely scenarios would be assessed for hazards and interventions taken to reduce the risks.

75. With the myriad recommendations made and the driving goal of creating a risk management-based culture of prevention comes an onus for supporting change for the high-risk underground coal mining industry. Accordingly, the commission recommends that Congress study the level of funding that would be commensurate with the need to support research and development, cultivation of safety and technical professionals, addressing the serious shortage of miners and mine supervisors, and other issues for this high-risk industry.

9
Conclusions

Mine safety in the U.S. has dramatically improved since the Mine Safety and Health Act of 1977, and fatalities have dropped dramatically over the past two decades. Recent tragedies have challenged that record, however, causing concern among all constituencies of the underground coal industry and reminding us that such an excellent record of improvement can be compromised quickly.

The commission believes that strong measures need to be adopted by all constituencies of the industry now to move the safety performance level forward to a leadership position globally, matching the industry's leadership in productivity. The commission has outlined the details of a comprehensive, risk assessment-based approach toward prevention, which should significantly increase the odds of survival for miners in emergency situations, but also provides a guideline for pursuing zero accidents from all sources. Further, details are also included in the areas of communications technology, emergency response and mine rescue procedures, training for preparedness, escape and protection strategies, along with 75 recommendations for systematically achieving the overarching goals of zero fatalities and zero lost-time accidents.

In particular in order to move forward safely and productively, the commission believes that a number of broad issues framed by our recommendations deserve serious attention, and should be used to fundamentally change the management approaches and work practices taken to fulfill basic safety requirements. First and foremost, risk-based decision-making must be emphasized, employed, and improved in all aspects of design, assessment, and management. It is imperative that a risk assessment-based approach be used, founded on the establishment of a value-based culture of prevention that focuses all employees on the prevention of all accidents and injuries. Importantly, every mine should employ a sound risk-analysis process, should conduct a risk analysis, and should develop a management plan to address the hazards and related contingencies identified by the analysis; simple regulatory compliance alone is not sufficient to mitigate significant risks. The commission strongly believes that companies which do not pursue the outlined approaches aimed at fulfilling fundamental safety requirements should not be permitted to operate underground coal mines.

In partnership, the commission exhorts industry to pursue further research, development, and deployment of promising new technologies to protect miners at much higher levels. Technology gaps for protecting miners and emergency responders exist in communications, mine rescue equipment, realistic training, SCSR technology, and means for maintaining trapped miners. Recommendations were made in the report regarding the salient research and development needs that must be pursued.

At the same time, while solutions to many mine safety problems are enabled by technology, they are not technology problems, rather, they are management and organizational problems. The commission made numerous recommendations to address such areas, involving miners, mine rescuers, mine managers, and incident command teams. The recommendations span needs for facilities, realistic training, familiarity with mines and escape routes, mine rescue teams' capabilities and needs, and processes and protocols for responding to emergencies.

Broader and deeper professionalization of the mine rescue function is also much needed. Certification and training of teams are critical aspects as well as the skill-composition of teams and standardization of procedures. Facilities, organizations, and structure to facilitate the development of professionalization are needed as well.

More sophisticated miner training on critical skills and key performance-oriented competencies for successful self-escape and aided-rescue is needed, and it must be well grounded in the principles of effective-learning evaluation. Further, much more realism must be embedded in the training, even to the point that miners and emergency responders interact in mock emergencies with practice anchored in deployment based on existing comprehensive emergency plans. In these areas, significant research and development needs exist; our recommendations address these in detail.

Although the initial goal of this study was to significantly increase the odds of miners' survival in emergency situations, the overriding issues mentioned above came to the forefront as the commission realized that much needs to be done systematically across a broad range of areas to achieve the ultimate goal of zero accidents. In the end, the commission is hopeful that its comprehensive recommendations, once adopted, will make a significant difference in preventing fatalities and serious injuries from occurring in the future.

Certainly other major issues are pressing the mining industry now, and no small problem is the shortage of miners and mining professionals, including those who must engineer and manage mines as well as do the research and development work. In particular concerning research and development recommendations, retirement of researchers from NIOSH is problematic. Accordingly the commission acknowledges that a major effort must be undertaken to enhance the ties between universities and Federal mine health and safety research efforts, so that students view research into developing technological solutions to address mine safety problems as an attractive career option.

With the myriad recommendations made and the driving goal of creating a risk management-based culture of prevention comes an onus for supporting change for the high-risk underground coal mining industry. Other organizations and industries with high-risk missions, such as NASA, the Navy's nuclear submarine fleet, and the nuclear power industry, require substantial facilities and recurring funding to address their safety risks well. Such should be the case for underground coal mining, particularly reflective of the most current compromises of miner safety. **Accordingly, the commission recommends that Congress study the level of funding that would be commensurate with the need to support research and development, cultivation of safety and technical professionals, addressing the serious shortage of miners and mine supervisors, and other issues for this high-risk industry.**

Finally, in this report the commission has specified what the needs and gaps are concerning mine safety, what constitutes a risk management-based culture of prevention, and what should be pursued as basic safety requirements or options. It is not the role of the commission to specify the means for achieving them, since various means for achieving the recommended changes exist, and the options should be debated in a broad mine safety process or processes. The commission envisions that all major stakeholders should be involved in any process seeking to actuate various recommendations, including Congress and MSHA as well as representatives of miners and mine operators. Implementation options for specific recommendations range from voluntary, joint development of Industry Safety Standards embodying Best Practices; legislation with follow-up regulation (Congress); regulation alone (MSHA and/or states); and peer pressure-based Best Practice evolution. The commission is hopeful that the details of the recommendations will be embraced and acted upon by all stakeholders.

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APPENDICES

A

Biographical Sketches of Commission Members

R. Larry Grayson, *Chair*, is Chairman, Department of Mining and Nuclear Engineering, University of Missouri-Rolla, and formerly the Associate Director of the Office for Mine Safety and Health Research, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (NIOSH). A former coal miner and mine superintendent, Dr. Grayson also directs the $4 million NIOSH-funded Western U.S. Mining Safety & Health Training and Translation Center. He chaired the National Research Council committee on Material Flows Accounting of Natural Resources, Products and Residuals. He has a Ph.D. in Mining Engineering from West Virginia University and is a certified Mine Foreman and a registered Professional Engineer in Pennsylvania.

Mark N. Beauchamp is Mine Rescue Trainer, Twentymile Coal Company. A 25-year veteran of underground mines, Beauchamp has extensive experience as a rescue team member in Colorado and Utah, where he has won numerous state and national awards for mine safety. He has MSHA certification as an underground mine foreman among others.

Anthony Bumbico is currently Vice President of Safety for Arch Coal, Inc., Bumbico directs the health and safety functions for each of Arch's 10 subsidiaries, which operate in six different states and employ over 4,000. Previously he had served as Vice President of Safety for Horizon Natural Resources as well as Director of Human Resources and Safety for AEP Fuel Supply Co. He holds an M.S. in Human Resource Development, Ohio State University.

Stanley I. Cohn is Executive Vice President - Concepts to Operations, Inc. He has broad experience in 9-1-1 and telephone systems, radio-spectrum management, large- and small-scale voice and digital telecommunications systems, public safety conventional and 800 MHz trunked radio systems, microwave and mobile radio systems, CAD and MDT design, management information systems, and in total system design projects that include proposal evaluation and turnkey vendor selection. Mr. Cohn (BSEE and MSEE) has over fifty-two (52) years of telecommunications experience. He has participated in, and directed many telecommunications projects for Federal, state, and local government, public safety and commercial clientele.

Amy K. Donahue is Associate Professor of Public Policy at the University of Connecticut. She has served as Technical Advisor to the U.S. Department of Homeland Security's Science & Technology Directorate since 2002. She also serves on the Aerospace Safety Advisory Panel, a Congressionally mandated body that advises NASA on safety issues. She is a much-decorated former commissioned officer in the U.S. Army and has received the NASA Public Service Medal for her service during the Space Shuttle Columbia disaster recovery effort. She holds a Ph.D. in Public Administration from Syracuse University.

J. Brett Harvey is President and CEO of CONSOL Energy, Inc. and was formerly President and CEO of PacificCorp Energy Inc., a subsidiary of PacifiCorp, one of the country’s largest electric utility companies. He served as Vice President of PacifiCorp Fuels Department and President and Chief Executive Officer of Interwest Mining Company. He has held numerous positions of distinction in the mining and power industries, including Vice Chairman of the World Coal Institute, board member of the Center for Energy & Economic Development and of the Coal Based Generation Stakeholders, and member of the National Coal Council. He recently won the John E. Wilson Distinguished Alumnus Award from the University of Utah.

Jeffery L. Kohler is Associate Director for Mining and Construction, Centers for Disease Control and Prevention (CDC), National Institute for Occupational Safety and Health (NIOSH). CDC is the federal agency responsible for conducting mine safety and health research. He formerly served as Director of the NIOSH Pittsburgh Research Laboratory, and prior to that was an Associate Professor of Mining Engineering at Penn State. He is an expert in mine safety and health and has done extensive work in mine electrical systems including communications and monitoring. He holds a Ph.D. in Mining Engineering from the Pennsylvania State University, and is a Certified Mine Safety Professional.

Thomas Novak is Chairman, Department of Mining and Mineral Engineering, Virginia Polytechnic Institute and State University. Previously he headed the department of civil and environmental engineering at the University of Alabama. He is internationally known for his research on electrical applications in the mining industry and has developed several short courses for continuing education for professional engineers. He holds a Ph.D. in Mining Engineering from the Pennsylvania State University.

Cecil E. Roberts, Jr. is President of the United Mine Workers of America (UMWA). A sixth-generation coal miner, he is the preeminent union representative of mining workers. After serving three times as union vice president, he became the UMWA president in 1995, and in 2004 he won election to a new five-year term - winning the presidency by acclamation for the third time. He was awarded an Honorary Doctorate in Humanities from West Virginia University of Technology.

H. F. "Buddy" Webb is First Vice President of the U.S. Mine Rescue Association and Mine Rescue Trainer of the Waste Isolation Pilot Plant, Carlsbad, New Mexico. He currently serves as a Member of the MSHA National Mine Rescue Advisory Committee. He began his career in mine rescue in 1978 as a rescue team member at the Kerr-McGee Potash Corporation and that year became the first secretary and founding member of the New Mexico Rescue Association. His expertise in mine rescue is recognized nationwide, and he has been called upon by most rescue teams across the country. His position with MSHA allows him to play a leading role in formulating mine rescue procedures.

B

Summary of MSHA/NIOSH Emergency Training Materials

Title	Subject	Catalog No.	Available	Media Type	Date Produced	Catalog Description	Summary
Strategies for Improving Miners Training	Accident Prevention & Investigation	IG-34	Yes	Book	NIOSH - 2002	Information circular and supplement from a series of workshops. The first three papers in this document present basic principles for teaching adults. The five remaining papers are intended to illustrate how these principles can be applied to the development and implementation of effective training for miners. (54 pg.)	An excellent resource and guide for developing new training. Somewhat dated, it highlights fundamentals of comprehensive and responsive training. Good ideas for active & experienced based learning and how to relate subject matter in an interrelated context for miners.
Draeger BG 174A Breathing Apparatus	Breathing Apparatus	IG-21	Yes	Book / PowerPoint	MSHA - rev 2003	Designed to show step-by-step, the proper use of this mine rescue apparatus. (31 pg.)	Thorough and comprehensive material on the Draeger unit. Dated material. Could be used as part of initial training / review. Video would be better.
MSA W-65 Self Rescuer	Breathing Apparatus	IG-2	Yes	Book	MSHA - rev 2000	Instructs UG workers in the proper use of this filter type self rescuer. Provides students with a working knowledge of the device and the ability to use it properly in an emergency. Covers 8 basic steps.	Thorough and comprehensive. Details components, inspection & proper use of W-65 filter rescuers. Could be an effective reference to augment hands on training.
Respirators - Your Last Defense	Breathing Apparatus	VC-982	Yes	Video	MSHA - 2002	Describes the different types, styles, sizes and shapes of respirators and their purpose / common use - protection from silica dust. Illustrates the importance of respirators in protecting your health. (21 min.)	Good footage & in-depth silica description. Covers largely industrial applications & non-metal mining and plant operations. Defines respirable dust, sampling, dust control, types & function of respirators. Informative and instructional, however very little applicable to coal mining.

Self-Contained Self-Rescuers an Efficient Method for Donning	Breathing Apparatus	VC-911,912,913,914	Yes	Video	MSHA - 1987	Program shows a method for rapidly donning a SCSR. Miners with little or no hands-on experience can quickly don an SCSR after learning the positions and simplified techniques shown in this program. Individual tapes available for different manufacturers' units: CSE, Ocenco, Draeger, & MSA. (9-12 min.)	Dated material. Very thorough description of donning four older SCSR units. Proper techniques, step-by-step drills, demonstration. Would be excellent for teaching individual skills as part of new miner training. Short and to the point.
Self-Contained Self-Rescuers Inspection, Care & Use: CSE100	Breathing Apparatus	VC-883	Yes	Video	MSHA - 2003	Describes the importance of proper inspections, care, and use of this lifesaving apparatus. (18 min.)	Excellent current instructional video. Clearly covers proper inspection, care and use of modern CSE 100 SCSR. Excellent tool for new miner training / retraining.
Inspection, Care and Use of the Ocenco EBA 6.5 & M-20 Self-Contained Self-Rescuer(SCSR)	Breathing Apparatus	VC-935 & DVD513	Yes	Video/DVD	MSHA 2004	Non-interactive videos demonstrate the proper inspection, maintenance and donning procedures of Ocenco SCSRs. (16 min & 11 min)	Comprehensive and thorough. Each covers care and use of SCSR. Short and to the point, these could be used in conjunction with hands on training in an effective new miner/retraining program. Good asset.
Belt Fire Exercise	Fire	NI-3	Yes	Workbook	NIOSH	Problem solving workbook for an 8 person section reacting to a belt fire 5,000' outby. Section must gather information about the location and scope of the fire, decide what equipment to take, and then determine if they should fight the fire or evacuate the mine.	Excellent, accurate & detailed training scenario. Covers: Mine fire assembly points, primary&secondary escapeways, effective communication among crews & surface, importance of gathering accurate information about the situation, strategies & procedures for locating, fighting/escaping a mine fire. (70-75 minutes) Should be tailored to mine specific conditions. Great training aid.

Belt Fire Injury	Fire	NI-4	Yes	Workbook	NIOSH	Problem solving workbook for the section foreman and only EMT reacting to an employee with a spinal injury located outby a belt fire. Covers First aid and emergency evacuation.	Excellent training scenario. Covers: How to prioritize fire fighting, first aid, and escape actions & strategies. Heavily first aid focused it incorporates a realistic mine emergency. Could be very effective when tailored to mine specific conditions. Recommended length is 40-45 minutes.
CM Fire	Fire	NI-17	Yes	Workbook	NIOSH	Problem solving workbook for a CM section foreman reacting to a CM fire, 1 injured miner, & 2 missing miners. Covers emergency assessments, first aid & fire fighting priorities given a serious fire and an injured miner, organizing & implementing fire fighting procedures, and emergency evacuation.	Excellent training scenario. First aid and burn focused. Answer/discussion has excellent points on the importance of accountability for all UG miners on the section, leadership and delegation of work, and proper planning for UG firefighting. Great resource.
Escape from a Mine Fire	Fire	NI-24	Yes	Workbook	NIOSH	Problem solving workbook for a LW development foreman reacting to an outby fire when ordered to immediately evacuate the mine.	Excellent training scenario. Covers escape strategies & procedures, choices of routes, use of SCSRs, information gathering & communications. Also highlights import points on the disparity in miners physical conditions due to age, health, weight, etc. and the resulting complications during an emergency evacuation. Great discussion points.

Escape from Mine Fires	Fire	VC-882	Yes	Video	BuM - 1990	Illustrates the importance of knowing effective self-rescue and escape procedures in the event of a mine fire. Two miners describe their experiences escaping a mine fire in 1988. (49 min.)	Dated, studio interview w/ Gary & Joy who escaped an outby belt fire. Demonstrates improper use of SCSRs, poor escape coordination & absence of leadership during an emergency evacuation. Personal stories highlight important points.
Fire Fighting in the Mineral Industry	Fire	VC-827	Yes	Video	BuM - 1970	Concerns techniques of fire fighting in noncoal mining and related industries. Shows the classifications of fires(A, B, and C). Provides instruction on proper use of various types of extinguishers. Demonstrates how to control fires by "sealing them off" with foam, asphalt, and other chemical sealants. (16 min.)	Dated, discusses basic fundamentals of fire & fire fighting. Covers common ignitions sources and types of mine fires(CH4, Electrical, Oil, Combustible materials). Demonstrates outdated methods of fighting UG fires. Does not cover firefighting decision making.
Fire Protection	Fire	CI-5	Yes	Book	MSHA	Designed to train Federal mine inspectors in the inspection of fire protection systems and equipment in both UG & SU mines. (128 pg.)	Comprehensive manual detailing fundamentals of fire, types of fires and proper fire protection. Extensively covers UG & SU fire protection requirements under 30 CFR. Would be a good resource for mine compliance.
Fire Safety	Fire	SM-13	Yes	Book	MSHA - rev1990	Deals with the hazards associated with fires, and the procedures used to prevent fires and to protect life and property when fires do occur. (42 pg.)	Small, dated handbook on the basics of fire, gases and fire prevention. Not terribly useful.

Fire Suppression - How it Works	Fire	VC-952	Yes	Video	MSHA - 2000	Video emphasizes the need for a fire risk analysis on every piece of mining equipment. With a properly sized, installed, and maintained fire suppression system, a fire could be controlled and extinguished. (15 min.)	Current material. UG diesel equipment focus. Details suppression system components (function & interface). Also details fed requirements, inspection criteria, mandatory services. Would make a great introduction video for new diesel mechanics at UG/SU operations.
Focus on prevention: Conducting a Fire Risk Assessment	Fire	NI-25	Yes	Workbook	NIOSH - 1999	Training guide outlines the 6 steps to completing a fire risk assessment and the identification and prioritization of fire safety hazards in employee work environments.	Basic training guide to fire risk assessments and tools. Covers fundamentals & necessity of specific and measured assessments: identifying hazards, probability and severity. Brief but informative. Complete w/ examples, could be used as part of task training & retraining.
Magic of Fire	Fire	VC-809	Yes	Video	BuM -1965	Deals with fire, it composition, uses and control, also illustrates how fires and explosions occur. Describes the safe use and control of commonly used gases and flammable liquids. Gives instruction on fire prevention. (23 min.)	Very dated and basic introduction to fundamentals of combustion and fire fighting. Home and industrial application focus. Little value to coal.
Travel Through Smoke	Fire	NI-67	Yes	Workbook	NIOSH	Problem solving workbook for section foreman evacuating a mine while traveling through smoke on a mantrip and in the primary escapeway.	Excellent training scenario. Covers: escape strategies and procedures, choices for escape routes & methods, donning & use of SCSRs, information gathering & communication, and the importance of leadership & decision making during an emergency. Great resource.

Chemistry, Analysis and Interpretation of Mine Atmospheres	Gases	IG-69	Yes	Book	MSHA - 1998	Instructors guide for teaching mine gases, sampling of mine fires, gas sampling methods, hand-held detection devices and mathematical calculations of mine gases as a result of mine fires. (108 pg.)	Somewhat dated but very comprehensive instructional guide to mine atmospheres, gases, combustion, sampling, formulas, etc. Very good advanced resource.
Evaluation of Gases from Mine Explosions	Gases	IR-1231	Yes	Book	MSHA - 1996	Introduces a new index, called the (H/C) index, used in investigations of fire and explosions to determine fuel composition. (31 pg.)	Technical and detailed breakdown of mine combustion events. Hydrocarbon molecule index is explained and demonstrated through several real world mine explosions / fires. Extremely valuable information for dealing with atmosphere readings from mine fires. Limited applicability to miners and non-mine rescue personnel.
Mine Gases	Gases	SM-2	Yes	Book	MSHA - rev1999	A complete reference on the sources and properties of mine gases(including explosive and toxic effects). Discusses means of detection, identification, analysis and legal requirements for each gas found in mine air. Also includes mine gas control methods. (42 pg.)	Small, somewhat dated handbook on mine gases, ventilation, atmosphere components, etc.. Thorough and detailed, would make a good reference tool during retraining / new miner training.
Mine Gases	Gases	PI-2	Yes	Book	MESA - 1977	Examines the various atmospheric components found in UG mines and describes the hazards of CH_4, CO, SO_2, H_2S, etc. (207 pg.)	Dated program of instruction on mine atmospheres and components. Covers the fundamentals of ventilating & monitoring UG mines. Contains several good program tests that could be effectively integrated into new miner training / retraining.

Inundation of Water and Ignition - Eyewitness Account	Inundations	VC-823	Yes	Video	MSHA - 1994	A miner describes his involvement in a coal mine inundation and explosion. Video stresses the importance of test drilling / examinations of abandoned areas. (12 min.)	Current video, standard interview w/ mine maps and footage. Good content. Wade Hinkle details experience and importance of safety near old UG works. Short & to the point. Could be good at retraining.
Advanced Mine Emergency Operations	Mine Emergencies & Rescue	CI-4	Yes	Book	MSHA - 1992	Materials designed for use in the Mine Simulation Laboratory to conduct emergency response disaster exercises. Materials can be modified to be used in other simulated settings. Incorporates principles of mine rescue. (51 pg.)	Somewhat dated, covers development and use of mine emergency response plans. Highlights importance of an effective immediate response, coordination and communication. Incorporates good MERD scenario problems at work. Good initail resource for mine management.
Another Sunrise: Close Call on a Surge Pile	Mine Emergencies & Rescue	VC-104	Yes	Video	MSHA 2002	Video recounts the rescue of a dozer operator from a coal surge pile accident. Emphasis is placed on reinforcing dozer cabs to withstand burial pressure, the role of advanced technologies in surge pile safety, and good safety practices and training. (9 min.)	MLCC Black Bear Prep Plant dozer operator recounts stockpile feeder hole & dozer burial. Interview with management & MSHA as well as still photos. Highlights life saving equipment and stockpile safety. Very informative, short and effective. Good for mechanics and equipment operators.
Emergency Response Planning (who needs it)	Mine Emergencies & Rescue	VC-838	Yes	Video	BuM - 1995	Video describes the importance of small mine operations to have an Emergency Response Plan(ERP), and discusses the planning, development, and proper use of the ERP. (17 min.)	Older, interview w/ good footage. Stresses worker & management apathy towards emergency planning(focus small operations). Low probability events compared to production & daily needs. Details importance & basic components of developing mine specific ERPs. Good source for foremen + management at operations to jump start planning and

							development of ERPs.
I Can't Get Enough Air: Proper SCSR Usage	Mine Emergencies & Rescue	NI-32	Yes	Workbook	NIOSH - 1999	Problem solving workbook for a section foreman reacting to an UG mine fire. Deals with escape strategies/procedures, use and transfer of SCSRs, and sensations/difficulties experienced when wearing an emergency breathing apparatus.	Good scenario, great workbook/answer discussion points w/information&facts about SCSR usage and difficulties. Highlights: proper donning & use of SCSRs, importance of TIME reference, expected difficulties breathing/wearing units, & problems reasonably expected to take place during an emergency. Somewhat lengthy exercise, great foundation for effective&interactive SCSR training. Excellent resource.
Lingering Smoke Exercise	Mine Emergencies & Rescue	NI-36	Yes	Workbook	NIOSH	Problem solving workbook for an outby scoop operator reacting to smoke and CO intoxication and two unconscious miners. Covers: ventilation, CO detection & symptoms, first aid & communication.	Somewhat dated scenario, incorporates UG explosives hazards. Deals with potential dangers that exist from smoke after shots has been fired, rapid and safe methods for emergency ventilation, safe rescue & assistance of victims in bad air, and the importance of proper pre-shift examinations. Good discussion points. Less applicable scenario to modern mining methods and likely emergencies.

Low Coal Fire	Mine Emergencies & Rescue	NI-37	Yes	Workbook	NIOSH	Problem solving workbook for outby worker reacting to an UG fire in 28 inch coal. Covers: escape route selection, communication w/ other miners and surface, location of missing miners in an emergency.	Somewhat dated, low coal scenario. Excellent discussion points on firefighting and searching for missing miners on the section prior to evacuation of the area. Good choice of escapeway exercise. Narrow scope of training due to conditions and mining practices of scenario.
Locating & Rescue of Trapped Miners	Mine Emergencies & Rescue	VC-927	Yes	Video	MSHA - 1998	Video describes the equipment and methods used to locate trapped miners in an underground coal mine. (8 min.)	Video covers dated MSHA method of locating trapped UG miners with an acoustic and seismic tracking system developed in the late 1990s. Very little current value. No training / decision making.
Man in the Bin	Mine Emergencies & Rescue	NI-39	Yes	Workbook	NIOSH	Problem solving workbook for a weigh master at a truck dumping bin reacting to a fellow worker being trapped in the bin following a collapse.	Not Reviewed.
MERD - Mock Disaster	Mine Emergencies & Rescue	VC-926	Yes	Video	MSHA - 1998	Video documents a Simulated Mine Emergency held in an active mine w/ 7 participating mine rescue teams. Company, state and federal inspectors, state and local police representatives, and local emergency personnel. Discusses the lessons learned from the exercise.	Robin Hood #9 - Peabody. Ex. footage, current material. Details realistic problems and difficulties encountered during emergencies. Stresses the need for realistic & coordinated mine emergency training. Training needs to extend beyond mine rescue team members: mine + company management, internal + external coordination, other companies, state + fed. assistance, media, medical assistance, command center SOP, family support, etc. An informative tool for mine & company management.

Mine Emergency Ventilation	Mine Emergencies & Rescue	CI-9	Yes	Book	MSHA - 1992	Designed for use by mine rescue team members, managers and supervisors responsible for mine rescue efforts. Lessons include instruction on making decisions on ventilating or sealing emergency areas and building ventilation controls and seals. (33 pg.)	Somewhat dated, very comprehensive guide to building/altering ventilation controls, sealing, and air sampling. Great resource. Limited use to non mine rescue miners.
Mine Escapeways	Mine Emergencies & Rescue	SM-11	Yes	Book	MSHA - rev1997	An introduction to mine escapeways and evacuation. Stresses the importance of having clear escapeways in case of an emergency. (24 pg.)	Small and dated handbook on the basics of mine emergency escapeways; necessity, ventilation, markings, etc. Could be used to augment new miner training. Not terribly useful.
Mine Rescue Training Modules (Coal)	Mine Emergencies & Rescue	IG-7	Yes	Books	MSHA - rev1999	Modules are designed to train experience or inexperienced mine rescue team members. Each self-contained unit covers a separate subject and includes suggested handouts and visual aids. (869 pg.)	Comprehensive guide details mine rescue techniques and principles: Surface organization, gases&ventilation, firefighting, explosions, rescue&recovery, effective training activities. Good resource for new mine rescue team members & company management.
Principles of Mine Rescue	Mine Emergencies & Rescue	IG-16	Yes	Book	MSHA - rev2002	Designed to instruct mining personnel in the principles involved in mine rescue operations and to increase miners' awareness of the necessity of a thorough knowledge of mine rescue techniques. (94 pg.)	Thorough and detailed. Covers fundamentals of mine rescue procedures, regulations, ventilation, fire, explosions, etc. Well laid out and easily understandable, would make a good resource for new mine rescue personnel & miners looking to increase their knowledge.

Recovery of Farmington #9 -	Mine Emergencies & Rescue	VC-958	Yes	Video	NIOSH - 2000	Danny Kuhn, midnight shift employee at the Farmington #9 mine describes his account of the destruction he witnessed and the recovery process used for finding his coworkers.	WV mine disaster 20 Nov 1968. Standard, dry interview with some footage and diagrams. Slow but interesting. Personal story of recovering coworkers over 10 year period following explosion. 78 dead, 19 unfound. Little training value.
Safety Talk: The Emergency Communication Triangle	Mine Emergencies & Rescue	NI-57	Yes	Workbook	NIOSH - 1999	Training guide focuses on the content of emergency communications and the importance of accurate & appropriate information.	Brief & comprehensive training guide. Details the "Who, Where & What" triangle of "Event, Miners, Response." Highlights importance of effective comm. during an emergency. Could be used effectively during scenario training, new miner training & retraining. Good resource.
Smoke on the Section	Mine Emergencies & Rescue	NI-60	Yes	Workbook	NIOSH - 1999	Problem solving workbook for UG miners who must evacuate through heavy smoke. Covers: basic ventilation, the selection of good evacuation routes&procedures, fire fighting, and first aid.	Good scenario buts should be modified to specific mine conditions & emergency equipment(FSR/SCSR). Lots of focus on dealing with a miner w/out an emergency breathing apparatus on hand. Great discussion points. Good resource.
Vulcan Mine Ignition	Mine Emergencies & Rescue	NI-72	Yes	Workbook	NIOSH	Problem solving workbook for a SC operator reacting to a methane ignition at the mouth of the section. Covers: recovering injured miners, providing and placing in order priorities of first aid, restoring ventilation & comm. with the surface, also movement & transporting of injured miners.	Good scenario but very first aid focused. Excellent discussion points could be used as a foundation for mine specific scenario training. Stresses the likelihood of a local emergency at the section/face and the importance of communication and leadership training.

Water Line Repair	Mine Emergencies & Rescue	NI-74	Yes	Workbook	NIOSH	Problem solving workbook for outby workers in a belt entry. Covers: signs&symptoms of CO intoxication, selecting escape routes, sources of CO(disabling&fatal amounts), solo response to an unconscious coworker.	Interesting scenario, first aid & CO poisoning focused. Could be effective for outby and belt personnel training although should be adjusted to mine specific conditions (belt air & SCSRs/FSR). Covers coal/belt fires and effects. Good resource but not as broadly applicable to majority of UG workers and situations as other NIOSH exercises.

C

Training for Preparedness Opinion Survey

May 7, 2006

Survey Participants:

This opinion survey is being distributed by The Mine Safety Technology and Training Commission (Commission). The Commission was formed in January of 2006 following two mine disasters in West Virginia. The Commission includes members of Academia, the United Mine Workers of America, NIOSH, technology specialists, public safety officials and company safety experts.

The Commission's objective is to identify significant policy changes needed to expedite the transfer of mine rescue and safety-related technology to operational use in the mining industry. Our particular focus is on those technologies and training methods that can improve the ability of miners to escape and survive in a mine emergency.

This opinion survey focuses on key behavioral and training issues related to self-escape and mine rescue. The survey is in three parts:

- Part I: Escape/Rescue Competency Levels
- Part II: Evaluation of Escape/Rescue Competency Levels
- Part III: Escape/Rescue Training Needs Assessment

The Commission is distributing this survey to three subgroups of mine safety professionals (UMWA, MSHA, and NMA) who are knowledgeable in the areas of mine rescue, emergency response, and safety training. The survey is designed to get your input in these key areas:

- What do miners need to know in order to escape/survive a mine emergency?
- What escape/rescue competencies should be evaluated?
- What "best practice" escape/rescue training materials are currently being used?
- What new escape/rescue training materials need to be developed?

Please return your completed survey by May 24, 2006 to the subgroup contact person who sent you this survey. The survey contact persons are Tim Baker (UMWA), Alan Dupree (MSHA), and Bruce Watzman (NMA).

Your input on this critical subject is needed by the Commission to develop our final recommendations. We value your opinion. Your assistance is appreciated. Please contact me at 314/994-2837 if you have any questions.

Tony Bumbico
Vice President of Safety
Arch Coal, Inc.

MST&T COMMISSION
TRAINING SURVEY

Please provide the general background information requested by checking the appropriate spaces. Information on your mine and company should only be completed by UMWA and NMA survey participants. Information on your MSHA District should only be completed by MSHA survey participants. This background information is needed to help analyze the survey results.

<u>Participant Background Information</u>

Survey Subgroup: _____ UMWA _____ MSHA ______ NMA

General Mining Experience: _____ years

Mine Rescue/Emergency Response Experience: _____ years

Safety/Training Related Experience: _____ years

Location (State) of Current Mine: ____________ (UMWA & NMA)

MSHA District: ___________ (MSHA)

Size of Mine: _____ tons/year ______ employees (UMWA & NMA)

Size of Company _____ tons/year _____ employees (UMWA & NMA)

Have you been involved in a mine-wide emergency? _____ Yes _____ No

Have you been involved in a mine rescue/recovery operation? _____ Yes _____ No

MST&T COMMISSION
TRAINING SURVEY

PART I

As you respond to the questions in this survey, please consider only those currently employed coal miners whom you know well enough to be able to confidently answer the question. If you are not reasonably sure of the proportion of miners who possess the knowledge/capability, please circle the "Don't know" option.

I. SELF RESCUER

Please circle the number of the response option that most closely matches your estimate of the proportion of miners who possess sufficient knowledge/capability with respect to each of the following aspects of using SCSRs.

A. PROPORTION RESPONSE OPTIONS

1) Almost all
2) More than half
3) Half
4) Less than half
5) Almost none
6) Don't know

What proportion of miners …

are proficient in donning an SCSR?

1 2 3 4 5 6

are capable of transferring from one SCSR to another SCSR in a toxic environment?

1 2 3 4 5 6

know the location of their SCSR caches?

1 2 3 4 5 6

understand the need to slow their pace when they encounter resistance breathing through an SCSR?

1 2 3 4 5 6

What proportion of miners …

Understand they may experience stress while using an SCSR?

1 2 3 4 5 6

Using these six response options, please indicate the extent to which you agree or disagree with each of the following statements.

B. AGREE-DISAGREE RESPONSE OPTIONS

1) Strongly Agree
2) Agree
3) Slightly Agree
4) Slightly Disagree
5) Disagree
6) Strongly Disagree

SCSR training should require miners to breath through the device.

1 2 3 4 5 6

The 3+3 method is an effective way to train miners to don an SCSR.

1 2 3 4 5 6

Hands-on training is the best way to train miners to don an SCSR.

1 2 3 4 5 6

SCSR training should be repeated frequently so miners don't forget how to use them.

1 2 3 4 5 6

II. ESCAPE WAYS

Please estimate the proportion of miners who possess sufficient knowledge and capabilities with respect to each of the following aspects of emergency escape.

A. What proportion of miners …

are familiar with their escape ways?

1 2 3 4 5 6

know how to locate and use life lines?

1 2 3 4 5 6

are physically capable of walking their escape way in an emergency?

1 2 3 4 5 6

understand how stress can affect their behavior during an emergency escape?

1 2 3 4 5 6

understand how stress can affect their co-workers behavior during an emergency escape?

1 2 3 4 5 6

B. Please indicate the extent to which you agree or disagree with each of the following statements.

Miners should receive additional training in "way finding" (i.e., the use of alternative means of finding your way around in a specific mine, such as track, belt lines, etc.).

1 2 3 4 5 6

Miners should be required to walk their escape way in emergency drills.

1 2 3 4 5 6

Well-designed job aids and directional signs enhance the ability of miners to escape in an emergency.

1 2 3 4 5 6

III. EMERGENCY PROCEDURES/MINERS

A. What proportion of miners are sufficiently familiar with their mine's …

emergency escape/evacuation plan?

1 2 3 4 5 6

communication systems?

1 2 3 4 5 6

protocol for notifying the Responsible Person on the Surface of an emergency?

1 2 3 4 5 6

protocol they should follow if notified of an emergency?

1 2 3 4 5 6

B. What proportion of miners should receive additional training in …

critical facts to remember to communicate during an emergency?

1 2 3 4 5 6

general mine rescue procedures?

1 2 3 4 5 6

fire fighting procedures ?

1 2 3 4 5 6

how to deal with stress in a mine emergency ?

1 2 3 4 5 6

IV. EMERGENCY PROCEDURES/SURFACE

A. What proportion of Responsible Persons on the Surface …

are well trained in mine monitoring and communication systems?

1 2 3 4 5 6

are familiar with their emergency/evacuation communication protocol?

1 2 3 4 5 6

What proportion of Responsible Persons on the Surface …

know how to effectively warn miners of an emergency?

1 2 3 4 5 6

B. What proportion of Mine Managers (i.e., top position at the mine) …

are sufficiently familiar with emergency/evacuation response procedures?

1 2 3 4 5 6

are sufficiently familiar with their Mine Rescue Response Command Center protocol?

1 2 3 4 5 6

should receive additional training in Mine Rescue Response Command Center protocol?

1 2 3 4 5 6

C. Considering mining operations with which you are familiar, what proportion…

have a comprehensive emergency/evacuation response plan in place?

1 2 3 4 5 6

review and revise their emergency/evacuation response plan regularly?

1 2 3 4 5 6

have Responsible Persons on the Surface who are well trained on the emergency/evacuation response plan?

1 2 3 4 5 6

have Mine Managers who are well trained on the emergency/evacuation plan?

1 2 3 4 5 6

include post-incident counseling in their emergency/evacuation response plan?

1 2 3 4 5 6

V. VENTILATION

A. What proportion of miners…

are familiar with the mine's ventilation system and understand the ventilation in their work area?

1 2 3 4 5 6

understand the effects of Carbon Monoxide (CO) and other mine gases?

1 2 3 4 5 6

are familiar with the concept of ventilation leakage?

1 2 3 4 5 6

VI. BARRICADING

A. What proportion of miners…

know that escaping the mine in an emergency is their first priority?

1 2 3 4 5 6

have sufficient quantities of materials for barricading on their working section?

1 2 3 4 5 6

know that barricading is the last resort?

1 2 3 4 5 6

know how to erect an effective barricade?

1 2 3 4 5 6

know the location of refuge chambers (where applicable)?

1 2 3 4 5 6

know how to use a refuge chamber (where applicable)?

1 2 3 4 5 6

undertand the psychological aspects of barricading?

1 2 3 4 5 6

VII. DECISION-MAKING/MINERS

A. What proportion of miners…

are capable of identifying alternative escape routes (other than designated escape ways) in an emergency?

1 2 3 4 5 6

are capable of escaping the mine if smoke is present?

1 2 3 4 5 6

B. Please indicate the extent to which you agree or disagree with each of the following statements.

Miners need more training on escaping the mine in a smoke-filled environment.

1 2 3 4 5 6

Miners should be trained in how to make decisions during emergencies.

1 2 3 4 5 6

VIII. DECISION-MAKING/SURFACE

A. Please indicate the extent to which you agree or disagree with each of the following statements.

Mine Managers should be trained in how to make decisions during emergencies.

1 2 3 4 5 6

Responsible Persons on the surface should be trained in how to make decisions during emergencies.

1 2 3 4 5 6

IX. LEADERSHIP/TEAM BUILDING

A. Please indicate the extent to which you agree or disagree with each of the following statements.

Leadership is a key factor in a successful escape during a mine emergency.

1 2 3 4 5 6

Leadership training would improve the ability of Supervisors to respond during a mine emergency.

1 2 3 4 5 6

Leadership skills should be a factor in determining the composition of work groups.

1 2 3 4 5 6

Effective team work is a key factor in a successful escape during a mine emergency.

1 2 3 4 5 6

Team building training would improve miners' ability to escape during an emergency.

1 2 3 4 5 6

X. What other types of new training materials/exercise should be developed to improve miners' ability to escape during a mine emergency?

____
____
____
____
____
____

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PART II

Evaluation of Emergency Response Capabilities/Competencies

The items listed below are capabilities or competencies that may need to be evaluated. For each one, please indicate which of the following four options you agree with. You may circle more than one option.

RESPONSE OPTIONS:

1) Suitable methods for evaluating this capability/competency already exist.

2) Better information is needed with respect to evaluation of this capability/competency.

3) This competency does not need to be evaluated.

4) I don't know if suitable evaluation methods are available.

1. **Miners' knowledge of escape ways, life lines and way finding.**

   1 2 3 4

2. **Miners' knowledge of emergency/evacuation response procedures.**

   1 2 3 4

3. **Miners' knowledge of their ventilation plan and mine gases.**

   1 2 3 4

4. **Miners' ability to escape in a smoke-filled environment.**

   1 2 3 4

5. **Miners' ability to make decisions during emergencies.**

   1 2 3 4

6. **Responsible Persons' (on the Surface) knowledge of emergency/evacuation response procedures.**

   1 2 3 4

7. **Responsible Persons' (on the Surface) knowledge of mine monitoring systems.**

   1 2 3 4

8. **Responsible Persons' (on the Surface) knowledge of Mine Rescue Response Command Center Protocols.**

   1 2 3 4

9. **Responsible Persons' (on the Surface) ability to make decisions during emergencies.**

   1 2 3 4

If you are familiar with good methods or materials for evaluating any of the above competencies, please provide a copy or write the title and explain how we can obtain a copy.

Title	**Source (Person, Organization, Website, etc.)**

THANK YOU!

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PART III (A)

Need for New or Better Training for Miners

Here is a list of mine emergency training topics for which new or improved materials/programs may be needed. For each topic, please circle the one response option you agree with the most.

RESPONSE OPTIONS:

1) Training materials do not exist
2) Training materials exist, but need improvement, extension, or updating
3) Suitable training materials are available
4) Don't know

1. **Donning SCSRs**

   1 2 3 4

2. **Using SCSRs during an escape**

   1 2 3 4

3. **Using escape ways**

   1 2 3 4

4. **"Way finding" (i.e., the use of alternative mine specific directional devices such as track, belt lines, etc.)**

   1 2 3 4

5. **Location and use of life lines**

   1 2 3 4

6. **Emergency escape plan**

   1 2 3 4

7. **Communication systems at the mine**

   1 2 3 4

8. **Protocol for notifying the Responsible Person on the Surface of an emergency**

   1 2 3 4

9. **Protocol that miners should follow if notified of an emergency**

   1 2 3 4

10. **General mine rescue procedures**

    1 2 3 4

11. **Fire fighting procedures**

    1 2 3 4

12. **When/how to barricade**

    1 2 3 4

13. **Using a refuge chamber (where applicable)**

    1 2 3 4

14. **Mine ventilation system**

    1 2 3 4

15. **Carbon Monoxide (CO) and other mine gases**

    1 2 3 4

16. **Ventilation leakage**

    1 2 3 4

17. **Escaping the mine in a smoke-filled environment**

    1 2 3 4

18. **How to make decisions during emergencies**

    1 2 3 4

19. **Team building training (small group behavior during emergencies)**

    1 2 3 4

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PART III (B)

Need for New or Better Training for Mine Managers and Responsible Person(s) on the Surface

The next few questions are concerned with the need for materials/programs to train Mine Managers and Responsible Persons on the Surface. Again, please circle the one response option you agree with the most.

RESPONSE OPTIONS:

1) Training materials do not exist
2) Training materials exist, but need improvement, extension, or updating
3) Suitable training materials are available
4) Don't know

1. **Decision making during emergencies**

   1 2 3 4

2. **Mine monitoring**

   1 2 3 4

3. **Mine communication systems**

   1 2 3 4

4. **Emergency communication protocol**

   1 2 3 4

5. **Emergency response procedures**

   1 2 3 4

6. **Mine Rescue Command Center protocol**

   1 2 3 4

If you are familiar with good training on any facet of mine emergency training, please provide a copy or write the title and explain how we can obtain a copy.

Title	**Source (Person, Organization, Website, etc.)**

THANK YOU!

D

Summary of Training for Preparedness Survey Results

MST&T Commission Training Survey

Participants Background Information

Survey Subgroup	UMWA: 0	MSHA: 39	NMA : 40	Total = 79
General Mining Experience	Avg: 29.8 yrs			
Mine Rescue/Emergency Response Experience	Avg: 18.4 yrs			
Safety/Training Related Experience	Avg: 22.3 yrs			
States	West Virginia, Pennsylvania, Utah, Kentucky, Illinois, Ohio, Virginia, Indiana, Colorado, Alabama & Wyoming.			
MSHA Districts	2, 3, 4, 5, 6, 7, 9, 10, 11			
Involved in a mine-wide emergency	Yes: 87%	No: 13%		
Involved in a mine rescue/recovery operation	Yes: 88%	No:12%		

Part I. Escape/Rescue Competency Levels

I. Self Rescuer (A)

What proportion of miners…	Almost All	More than Half	Half	Less than Half	Almost None	Don't Know	Na	Total	Less All	50% less
are proficient in donning an SCSR?	34	21	9	12	0	3		79		
	43%	**27%**	**11%**	**15%**	**0%**	**4%**			**57%**	**15%**
are capable of transfering from one scsr to another in a toxic environment?	14	14	9	11	14	17		79		
	18%	**18%**	**11%**	**14%**	**18%**	**22%**			**82%**	**32%**
know the location of their SCSR caches?	42	16	5	5	1	6	4	79		
	53%	**20%**	**6%**	**6%**	**1%**	**8%**	**5%**		**47%**	**7%**
understand the need to slow their pace when they encounter resistance	20	17	14	13	11	4		79		

breathing through an SCSR?										
	25%	**22%**	**18%**	**16%**	**14%**	**5%**			**75%**	**30%**
understand they may experience stress while using an SCSR?	23	20	10	14	8	4		79		
	30%	**25%**	**13%**	**18%**	**10%**	**5%**			**70%**	**28%**

<u>I. Self Rescuer (B)</u> *Agree-Disagree Response Options*	**Strongly** **<u>Agree</u>**	**<u>Agree</u>**	**Slightly** **<u>Agree</u>**	**Slightly** **<u>Diagree</u>**	**<u>Disagree</u>**	**Strongly** **<u>Disagree</u>**			**<u>Agree</u>**	**<u>Disagree</u>**
SCSR training should require miners to breath through the device.	32	17	13	4	6	7		79		
	40%	**22%**	**16%**	**5%**	**8%**	**9%**			**78%**	**22%**
The 3+3 method is an effective way to train miners to don an SCSR	27	36	12	2	1	0		78		
	35%	**46%**	**15%**	**3%**	**1%**				**96%**	**4%**
Hands-on training is the best way to train miners to don an SCSR	62	16	0	0	1	0		79		
	78%	**20%**	**0%**	**0%**	**1%**	**0%**			**99%**	**1%**
SCSR training should be repeated frequently so miners don't forget how to use them.	48	23	6	0	1	1		79		
	60%	**29%**	**8%**	**0%**	**1%**	**1%**			**98%**	**2%**

<u>II. Escapeways (A)</u> *What proportion of miners…*	**<u>Almost All</u>**	**<u>More than half</u>**	**<u>Half</u>**	**<u>Less than Half</u>**	**<u>Almost None</u>**	**<u>Don't know</u>**	**<u>Na</u>**		**<u>Less All</u>**	**<u>50% Less</u>**
are familiar with their escapeways?	29	22	16	8	2	2		79		
	36%	**28%**	**20%**	**10%**	**3%**	**3%**			**64%**	**36%**
know how to locate and use lifelines?	27	14	16	6	8	5	3	79		
	34%	**18%**	**20%**	**7%**	**10%**	**6%**	**4%**		**66%**	**37%**
are physically capable of walking their escapeway in an emergency?	23	19	23	9	0	5		79		
	29%	**24%**	**29%**	**11%**	**0%**	**6%**			**71%**	**40%**
understand how stress can affect their behavior during an emergency escape?	13	16	13	17	11	9		79		
	16%	**20%**	**16%**	**22%**	**14%**	**11%**			**84%**	**52%**
understand how stress can affect their co-workers behavior during an emergency escape?	12	15	15	14	16	7		79		
	15%	**19%**	**19%**	**18%**	**20%**	**9%**			**85%**	**57%**

II. Escapeways (B)

Agree-Disagree Response Options	Strongly Agree	Agree	slightly Agree	Slightly Disagree	Disagree	Strongly Disagree		Agee	Disagree
Miners should receive additional training in "way finding" (i.e., the use of alternative means of finding your way around in a specific mine, such as track, belt lines, etc.).	39	29	8	2	1	0	79		
	49%	**37%**	**10%**	**3%**	**1%**	**0%**		**96%**	**4%**
Miners should be required to walk their escapeway in emergency drills.	27	11	13	6	8	14	79		
	34%	**14%**	**16%**	**8%**	**10%**	**18%**		**74%**	**26%**
Well-designed job aids and directional signs enhance the ability of miners to escape in an emergency.	37	32	5	4	1	0	79		
	47%	**41%**	**6%**	**5%**	**1%**	**0%**		**94%**	**6%**

III. Emergency Procedures/Miners (A)

What proportion of miners are sufficiently familiar with their mine's…	Almost All	More than half	Half	Less than Half	Almost None	Don't know	Na		Less All	50% Less
emergency escape/evacuation plan?	14	27	19	14	3	2		79		
	18%	**34%**	**24%**	**18%**	**4%**	**3%**			**82%**	**46%**
communication systems?	42	17	12	4	2	2		79		
	53%	**22%**	**15%**	**5%**	**3%**	**3%**			**47%**	**23%**
protocol for notifying the Responsible Person on the Surface of an emergency?	26	19	17	8	6	2		78		
	33%	**24%**	**22%**	**10%**	**8%**	**3%**			**67%**	**40%**
protocol they should follow if notified of an emergency?	18	24	17	11	5	3		78		
	23%	**30%**	**22%**	**14%**	**6%**	**4%**			**77%**	**42%**

III. Emergency Procedures/Miners (B)

What proportion of miners should receive additional training in…	Almost All	More than half	Half	Less than Half	Almost None	Don't know	Na		Less All	50% Less
critical facts to remember to communicate during an emergency?	50	14	9	2	4	0		79		
	63%	**18%**	**11%**	**2%**	**5%**	**0%**			**37%**	**18%**

general mine rescue procedures?	38	14	17	3	5	2		79		
	48%	**18%**	**22%**	**4%**	**6%**	**2%**			**52%**	**31%**
fire fighting procedures?	54	13	4	2	4	2		79		
	68%	**16%**	**5%**	**2%**	**5%**	**2%**			**32%**	**12%**
how to deal with stress in a mine emergency?	52	16	2	4	1	4		79		
	66%	**20%**	**2%**	**5%**	**1%**	**5%**			**34%**	**8%**

IV. Emergency Procedures/Surface (A)

What proportion of Responsible Persons on the surface…	Almost All	More than half	Half	Less than Half	Almost None	Don't know	Na		Less All	50% Less
are well trained in mine monitoring and communication systems?	40	14	14	7	1	3		79		
	50%	**18%**	**18%**	**9%**	**1%**	**4%**			**50%**	**28%**
are familiar with their emergency/evacuation communication protocol?	39	13	16	5	3	3		79		
	49%	**16%**	**20%**	**6%**	**4%**	**4%**			**51%**	**30%**
know how to effectively warn miners of an emergency?	39	16	11	7	2	3		78		
	50%	**21%**	**14%**	**9%**	**3%**	**4%**			**50%**	**25%**

IV. Emergency Procedures/Surface (B)

What proportion of mine managers…	Almost All	More than half	Half	Less than Half	Almost None	Don't know	Na		Less All	50% Less
are sufficiently familiar with emergency/evacuation response procedures?	33	25	11	4	3	3		79		
	42%	**32%**	**14%**	**5%**	**4%**	**4%**			**58%**	**23%**
are sufficiently familiar with their Mine Rescue Command Center protocol?	21	16	15	9	9	8		78		
	27%	**21%**	**19%**	**12%**	**12%**	**10%**			**73%**	**43%**
should receive additional training in Mine Rescue Response Command Center Protocol?	46	16	5	3	6	3		79		
	58%	**20%**	**6%**	**4%**	**8%**	**4%**			**42%**	**18%**

IV. Emergency Procedures/Surface ©

Considering mining operations with which you are familiar, what proportion…	Almost All	More than half	Half	Less than Half	Almost None	Don't know	Na		Less All	50% Less
have a comprehensive emergency/evacuation response plan in place?	52	14	6	4	0	3		79		
	66%	**18%**	**8%**	**5%**	**0%**	**4%**			**34%**	**13%**
review and revise their emergency/evacuation response plan regularly?	27	18	11	11	7	5		79		
	34%	**23%**	**14%**	**14%**	**9%**	**6%**			**66%**	**37%**
have Responsible Persons on the Surface who are well trained on the emergency/evacuation response plan?	30	20	10	9	4	6		79		
	38%	**25%**	**13%**	**11%**	**5%**	**7%**			**62%**	**29%**
have Mine Managers who are well trained on the emergency/evacuation plan?	28	23	9	7	5	6		78		
	36%	**29%**	**12%**	**9%**	**6%**	**7%**			**64%**	**26%**
include post-incident counseling in their emergency/evacuation response plan?	12	15	6	3	23	20		79		
	15%	**19%**	**7%**	**4%**	**29%**	**25%**			**85%**	**40%**

V. Ventilation (A)

What proportion of miners…	Almost All	More than half	Half	Less than Half	Almost None	Don't know	Na		Less All	50% Less
are familiar with the mine's ventilation system and understand the ventilation in their work area?	12	24	26	13	1	3		79		
	15%	**30%**	**33%**	**16%**	**1%**	**4%**			**85%**	**50%**
understand the effects on Carbon Monoxide(CO) and other mine gases?	21	17	14	14	9	3		78		
	27%	**22%**	**18%**	**18%**	**12%**	**4%**			**73%**	**48%**
are familiar witht the concept of ventilation leakage?	15	16	21	10	12	4		78		
	19%	**21%**	**27%**	**13%**	**15%**	**5%**			**81%**	**55%**

VI. Barricading (A)

What proportion of miners…	Almost All	More than half	Half	Less than Half	Almost None	Don't know	Na		Less All	50% Less
know that escaping the mine in an emergency is their first priority?	46	15	6	6	2	4		79		

	58%	**19%**	**7%**	**7%**	**3%**	**5%**			**42%**	**17%**
have sufficient quantities of materials for barricading on their working section?	22	19	9	14	7	6		77		
	29%	**25%**	**12%**	**18%**	**9%**	**8%**			**71%**	**39%**
know that barricading is the last resort?	44	14	11	3	2	5		79		
	56%	**18%**	**14%**	**4%**	**3%**	**6%**			**44%**	**21%**
know how to erect an effective barricade?	11	22	13	9	17	7		79		
	14%	**28%**	**16%**	**11%**	**22%**	**9%**			**86%**	**49%**
know the location of refuge chambers(where applicable)?	3	2	0	2	3	30	39	79		
	4%	**3%**	**0%**	**3%**	**4%**	**38%**	**49%**		**96%**	**2%**
know how to use a refuge chamber(where applicable)?	4	1	1	0	4	31	38	79		
	5%	**1%**	**1%**	**0%**	**5%**	**39%**	**48%**		**95%**	**6%**
understand the psychological aspects of barricading?	6	6	7	7	25	24	2	77		
	8%	**8%**	**9%**	**9%**	**32%**	**31%**			**92%**	**50%**

VII. Decision-Making/Miners (A)

What proportion of miners…	Almost All	More than half	Half	Less than Half	Almost None	Don't know	Na		Less All	50% Less
are capable of identifying alternative escape routes(other then designated escapeways) in an emergency?	10	18	24	15	9	3		79		
	13%	**23%**	**30%**	**19%**	**11%**	**4%**			**87%**	**60%**
are capable of escaping the mine if smoke is present?	14	15	18	14	9	9		79		
	18%	**19%**	**23%**	**18%**	**11%**	**11%**			**82%**	**52%**

VII. Decision-Making Miners (B)

Agree-Disagree Response Options	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree			Agree	Disagree
Miners need more training on escaping the mine in a smoke-filled environment.	53	22	2	0	1	1		79		
	67%	**28%**	**3%**	**0%**	**1%**	**1%**			**98%**	**2%**
Miners should be trained in how to make decisions during emergencies.	55	20	2	1	0	1		79		
	70%	**25%**	**3%**	**1%**	**0%**	**1%**			**98%**	**2%**

VIII. Decision-Making/Surface (A)

Agree-Disagree Response Options	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree			Agree	Disagree

Mine managers should be trained in how to make decisions during emergencies.	63 **80%**	15 **19%**	0 **0%**	0 **0%**	0 **0%**	1 **1%**	79	**99%**	**1%**
Responsible Persons on the surface should be trained in how to make decisions during emergencies.	60 **78%**	14 **18%**	1 **1%**	0 **0%**	1 **1%**	1 **1%**	77	**97%**	**2%**

<u>IX. Leadership/Team Building (A)</u>

Agree-Disagree Response Options	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree		Agree	Disagree
Leadership is a key factor in a successful escape during a mine emergency.	55 **70%**	20 **25%**	2 **3%**	0 **0%**	2 **3%**	0 **0%**	79	**97%**	**3%**
Leadership training would impove the ability of Supervisors to respond during a mine emergency.	42 **53%**	28 **35%**	8 **10%**	0 **0%**	1 **1%**	0 **0%**	79	**98%**	**1%**
Leadership skills should be a factor in determining the compostion of work groups.	39 **50%**	26 **33%**	10 **13%**	1 **1%**	1 **1%**	1 **1%**	78	**96%**	**3%**
Effective team work is a key factor in a successful escape during a mine emergency.	49 **62%**	28 **35%**	2 **3%**	0 **0%**	1 **1%**	0 **0%**	79	**99%**	**1%**
Team building training would improve miners' ability to escape during an emergency.	42 **53%**	21 **27%**	14 **18%**	2 **3%**	0 **0%**	0 **0%**	79	**97%**	**3%**

Part II. Evaluation of Emergency Response Capabilities/Competencies

	Suitable methods for evaluating this capability/competency already exist.	Better information is needed with respect to evaluation of this capability/competency.	This competency does not need to be evaluated.	I don't know if suitable evaluation methods are available.	Total

Miners' knowledge of escapeways, lifelines and way finding.	34	43	0	1	78
	44%	**55%**	**0%**	**1%**	
Miners' knowledge of emergency/evacuation response procedures.	32	46	0	1	79
	41%	**58%**	**0%**	**1%**	
Miners' knowledge of their ventilation plan and mine gases.	35	42	1	1	79
	44%	**53%**	**1%**	**1%**	
Miners' ability to escape in a smoke-filled environment.	17	51	4	7	79
	22%	**65%**	**5%**	**8%**	
Miners' ability to make decisions during emergencies.	9	54	3	13	79
	11%	**68%**	**4%**	**16%**	
Responsible Persons'(on the surface) knowledge of emergency/evacuation response procedures.	36	34	4	5	79
	46%	**43%**	**5%**	**6%**	
Responsible Persons'(on the surface) knowledge of mine monitoring systems.	46	30	1	2	79
	58%	**38%**	**1%**	**3%**	
Responsible Persons' (on the surface) ability to make decisions during emergencies.	17	52	3	7	79
	22%	**66%**	**4%**	**8%**	

Part III(A) Need for New or Better Training for Miners

	Training materials do NOT exist	Training materials exist, but need improvement, extension, or updating	Suitable training materials are available	Don't know	Total	Develop/Improve
Donning SCSRs	2	42	34	1	79	
	3%	**53%**	**43%**	**1%**		**56%**
Using SCSRs during an escape	8	50	18	3	79	
	10%	**63%**	**23%**	**4%**		**73%**

Using escapeways	3	44	30	2	79	
	4%	**56%**	**38%**	**3%**		**60%**
"Way Finding" (i.e. the use of alternative mine specific directional devices such as track, belt lines, etc.)	17	31	19	12	79	
	22%	**39%**	**24%**	**15%**		**59%**
Location and use of lifelines	12	30	30	5	77	
	16%	**39%**	**39%**	**6%**		**55%**
Emergency escape plan	2	41	34	2	79	
	3%	**52%**	**43%**	**3%**		**55%**
Communication systems at the mine	2	37	38	2	79	
	3%	**47%**	**48%**	**3%**		**50%**
Protocol for notifying the Repsonsible Person on the Surface on an emergency	5	38	34	2	79	
	6%	**48%**	**43%**	**3%**		**54%**
Protocol that miners should follow if notified of an emergency	3	41	32	3	79	
	3%	**52%**	**41%**	**3%**		**55%**
General mine rescue procedures	2	47	25	5	79	
	3%	**59%**	**32%**	**6%**		**62%**
Fire fighting procedures	1	48	27	3	79	
	1%	**61%**	**34%**	**4%**		**62%**
When/how to barricade	4	44	24	7	79	

	5%	**56%**	**30%**	**9%**		**61%**
Using a refuge chamber (where applicable)	17	9	5	36	67	
	25%	**13%**	**7%**	**54%**		**38%**
Mine ventilation system	2	43	30	4	79	
	3%	**54%**	**38%**	**5%**		**55%**
Carbon Monoxide (CO) and other mine gases	2	43	33	1	79	
	3%	**54%**	**42%**	**1%**		**57%**
Ventilation leakage	8	41	27	3	79	
	10%	**52%**	**34%**	**4%**		**62%**
Escaping the mine in a smoke-filled environment	11	51	15	1	78	
	14%	**65%**	**19%**	**1%**		**79%**
How to make decisions during emergencies	16	44	8	11	79	
	20%	**56%**	**10%**	**14%**		**76%**
Team building training (small group behavior during emergencies)	18	41	5	15	79	
	23%	**52%**	**6%**	**19%**		**75%**

Part III(B) Need for New or Better Training for Mine Managers & Responsible Person(s) on the Surface

	Training materials do NOT exist	Training materials exist, but need improvement, extension, or updating	Suitable training materials are available	Don't know		Develop/Improve
Decision making during emergencies	15	41	17	5	78	
	19%	**53%**	**22%**	**6%**		**72%**
Mine monitoring	5	42	26	5	78	
	6%	**54%**	**33%**	**6%**		**60%**
Mine communication systems	3	38	32	5	78	
	4%	**49%**	**41%**	**6%**		**53%**
Emergency Communication Protocol	4	51	21	2	78	
	5%	**65%**	**27%**	**3%**		**70%**
Emergency Response procedures	0	49	27	2	78	
	0%	**63%**	**35%**	**3%**		**63%**
Mine Rescue Command Center protocol	7	50	16	5	78	
	9%	**64%**	**21%**	**6%**		**73%**

Comments

"What other types of new training materials/exercises should be developed to improve miner's ability to escape during a mine emergency?"

NMA:

Smoke training and breathing through rescue devices that provide resistance.

Follow through on mine scenario - "We do this when!!"

Mandatory training in simulators such as the WV University fire and smoke van.

Decision making training during evacution drills. Take their planned route away drom them at various points. Make them come up with alternative routes and choices.

Expectations training. Wear training devices that simulate self-rescuers. Travel through smoke, shut off cap lamps or otherwise obstruct visibility. Use lifelines, linklines and carry a stretcher.

Emergency communications drills. Require miners to actually practice making emergency situation reports over the communication systems at the mine.

Train miners on the importance of prevention. The element at least so far has been left out of the national debate. All the legislation and media attention has been on after the fact systems. The real fertile ground is to improve the prevention capabilities of the mine and the knowledge of the miners. If miners had a better understanding of the components in the fire/explosion prevention systems maybe the industry would see less of the accumulations violations, mandoors would get closed. Damaged stoppings would always be reported and immediately repaired. There are many more examples too.

Get MSHA on development of new material in DVD's & Powerpoint formats. Hand-outs, flyers.

Smoke rooms utilizing SCSRs.

Mock fire drills have proven to be a very valuable training tool. Especially if it is unannounced and unexpected. Crews experience the real thing. A mock drill involves the employee with emergency communication, organization, evacuation, SCSR "hands-on" training, training in smoke, training to evacuate as a team, with a leader, decision making, etc. The cost of such "hands-on" actual training is expensive. If you utilize old expired SCSRs you can pull it off(if you can convince the individual to use the stored unit "mantrip" instead of their belt wearable unit), without them knowing that something is up. The expired SCSR could be substituted minutes prior to the drill. We have pulled this off in the past with great success. Not a single employee (19 total) suspected that this was a moch drill.

MSHA:

Hands-on SCSR & mine rescue training.

The donning of SCSRs should include inserting the mouthpiece. Disposable mouthpieces should be developed to allow the miners to experience the fell of the mouth piece between their cheeks & gums. The more real it is training, the more likely the success in the event of an emergency.

The ETS has provided for many changes in training and required exercices.

Each person on or in the mine should know how to conduct the crew if responsible person is not present or has been injured. TAKE CONTOL.

Training: 1-Mine specific ventilation system Blowing/Exhausting, air directions, and how this could be evaluated when a decision is made to travel out of the mine or barricade.

Trainig: 2-The affects of CO when encountered in small amounts.

Trainig: 3-SCSRs should have some visual device to show when they are working, also there could be an audible alarm when the device is in an environment of say 50 or 100 PPM of CO.

Taining: 4-The after affects of an explosion/fire, what to expect, what you will encounter and what you must do to survive.

Training videos of actual miners who have escaped a mine emergency.

SCSRs that have less resistence during breathing to help reduce the stress of escape.

Escapeway signs/reflectors nearer to the mine floor to allow persons to see them in a smoky environment.

Emergency strobes that automatically alarm, green in color, directing persons to and alongs escapeway routes.

Requirement of CO detectors for all U/G supervisors.

MSHA/State/NIOSH conducted smoke training.

Revised SCSRs that have a nose clip that would allow those persons who may be unconcious to be fitted with an SCSR until help arrives.

A 3-4 hour rescue device to allow persons to escape. Considering the cost escalations of SCSRs this may be the most effective means.

MERD problems are developed for mine rescue teams and command centers. A similar MERD type program should be developed for miners in how to respond to these emergencies. Miners need to be updated constantly on problems with the SCSR units. There is information that these miners need in order to have confidence in these units. Information that says maybe the unit does not appear to be functioning properly but it is. Information on the difficulties that breathing through these units miners might experience. Total information on gases that may be encountered and how to protect themselves. Also persons need to know and practice how to communicate when they have a mouth piece in or they can not see.

Computer training modules of the mine that can simulate a mine fire at any location in the mine that will test all workmens' (management and non-management) ability to escape and make decisions based on the information and knowledge of the mine. Take the MERD programs to the next level.

Cheap training SCSR units that workmen can take home that simulates the donning of the unit, and breathing resisitance that results from using the SCSR. I believe that is a person need to think about donning the SCSR then he needs more training on the unit.

Develop a cheap meterial or device that covers the eyes of workmen to simulate the different stages or degrees of smole to be encountered when walking the escapeways during a mine fire. This material can be worn during the required escapeway drills on the section or when traveling the section and main escapeways. With the eyes covered have workmen do the SCSR and walk on the section and through the escapeway. Require all workmen to participate in walking main escapeways on each shift, from all sections, using a blindfold and a training SCSR unit simulating the breathing resistance at least once a year, including outby persons. Have a unit on the surface to simulate the heating of the unit that a person would expect to feel when wearing the unit.

MSHA and State agencies should develop and provide the mining industry with more detailed programs aof the accident investigations of mine fires and mine explosions including workmen's testimony, results of workmen's (management and non-management) failure to comply with mining laws. The destruction caused by the mine fire or mine explosion, information including pictures taken at the emergency during the investigation. This information can be presented at the mine or on the national television networks.

Develop a new program for all miners to report unsafe work conditions.

Revise the training regulations to require more detailed training concerning mine fires and mine explosions. Causes and results.

MERD type esercises.

Independent scenarios.

Hands on training, on site, in simulated conditions.

More frequent training

Improved and up-to-date training plans.

The miners should be trained in how to effectively barricade and the fire fighting and barricading material should be required to be stored at each working section.

Traveling smoke rooms (Classroom).

Develop a refillable SCSR training unit miners can wear in smoke.

Physiological training in adverse conditions that could be simulated hypobaric chambers for CO symptoms as pilots train in hypoxia symptoms. Smoke filled areas to demonstrate difficulty traveling.

Hands on training w/fire extinguishers. Fire fighting procedures UG + SU.

Develop a training SCSR that will provide the restricted breathing that a person will actually experience if used.

Should have a lifeline and be hooked together when traveling in smoke.

Situation training + Discussion. Each miner should be required to don & wear an SCSR for 1 hour on a treadmill as part of new miner training and any miner who has no done this at least once for each type of device used at their mine. If they fail this test or exercise, NOT employable for UG work. This would be a fitness for duty requirement. Could also be done annually. Stay fit or no work.

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Preliminary Assessment of Communication Systems For Underground Mines

D R A F T

Preliminary Assessment of Communication Systems For Underground Mines

by

William H. Schiffbauer and Gary L. Mowrey

1.0.0 Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the view of the National Institute for Occupational Safety and Health. Before decisions are made based on the information provided in this report, NIOSH suggests the reader contact the vendor or manufacturer in question for the latest information. There may be other vendors or manufacturers that were not discovered during the creation of this report. Additions and comments should be directed to either author for inclusion. Inclusion in this report does not constitute endorsement by NIOSH.

2.0.0 Background

Recent tragic events and mine emergencies at the Alma, Sago, Quecreek and No. 5 mines have highlighted the need for reliable communications between the miners inside the mine and outside. Present wired and wireless communication systems may fail due to exposure to fires, roof falls or explosions tearing down wires, power failure or battery failure. Coal mine communications research goes back as far as 1922 (Colburn, 1922) when the U.S. Bureau of Mines (USBM) performed experiments to detect radio signals from inside their mine in Bruceton, PA. Coal mine communications research has been conducted generally in response to major accidents such as those mentioned. It is the intention of this report to identify and document previously developed significant research as well as new and emerging technologies which can benefit and improve the safety and health of today's underground (UG) coal miners.

Communication systems used in today's UG coal mines generally employ a hard-wired system or a special cable called a "Leaky Feeder". Fiber optic cables are also used in some applications. Through-the-earth (TTE) and wireless radio systems are less common.

Hardware includes dedicated telephones, walkie-talkies, paging devices, and similar technologies. While hardwired and leaky feeder systems perform well under normal mining conditions, they may fail during disasters as cable breakage interrupts communications. Armored, buried borehole, loop-around and redundant cabling could improve reliability, but would add to the maintenance and complexity of the system (Moussa and Lagace, 1982).

Coal mines are a particularly unique environment for radio signals. Radio signals require a clear path or open air for signal propagation. Stoppings or roof falls halt or impede conventional radio signal propagation. It is also believed that ionized air that can result from a mine fire could be a problem. Some radio-based systems employ repeaters or leaky feeders within the mine that permit a radio signal to cover a larger area. However, not all radio signals will propagate down a coal mine entry due to the electrical properties of the coal and the surrounding strata.

Frequency selection has a great impact on signal propagation. Some frequencies which utilize the coal mine entry as a waveguide, enhancing signal propagation, while other frequencies will not travel more than 50 feet. Unaided radio signals in a certain frequency range may propagate line-of-sight up to 1000 feet, but typically will not turn corners for more than two crosscuts. Parasitic propagation in the proximity of wires, conductors, pipes, and rails can enhance the propagation of signals at certain frequencies (medium frequencies).

In the mid 1970's the USBM conducted extensive research on this and many other phenomena associated with radio signals propagation at coal mines (Appendix A). This research and other development work was done in response to the Coal Mine Health and Safety Act of 1969 and aimed at increasing the survivability of coal miners trapped UG during disasters. It included the determination of the optimum frequencies for reliable communications especially during disasters. Frequencies investigated ranged from extremely low frequencies to a few GHz. Propagation measurements were conducted both within the mine as well as through-the-earth.

Extensive electrical noise measurements were performed both in and on the surface at a representative sample of mines throughout the coal fields. Electrical noise measurements are important to the success or failure to convey voice or data. To be heard or detected, the signal generally must exceed the noise. Modern signal processing techniques, such as spread-spectrum and ultra-wide-band (UWB) have changed that paradigm, but still the signal-to-noise ratio is a critical factor to communication success.

In UG coal mines within the United States, regulations require that electrical communications devices be approved by the Mine Safety and Health Administration (MSHA) as "permissible." Permissibility can be achieved through explosion-proof (XP) or intrinsically safe (IS) design.

3.0.0 UG Coal Mine Communication System Design

Before any new communication system is installed in a mine the electrical noise environment, both surface and UG should be measured, documented, and analyzed. Next, signal propagation measurements should be performed, documented, and analyzed. Candidate technology should be reviewed, tested, and evaluated. A heavy emphasis should be placed on interoperability. A "Risk Assessment" should also be done to determine the possibility of a system operating under emergencies conditions. Only then should a specific system be installed. Older mine communications systems should be technically reviewed and updated accordingly. Methods and devices should be added to the older systems to provide for interoperability and redundancy which will improve the odds that communications will be available during disasters.

3.1.0 Electromagnetic Interference (EMI)/Noise

Analysis and design of radio-communication systems requires knowledge of atmospheric-noise models. Also the performance of any electronic communication system is highly dependent on the electromagnetic (EM) noise of the environment in which it will be used. The selection of candidate operational/emergency EM mine communication and location systems should therefore only occur after EMI measurements are made.

If there were no natural or man-made electrical noise interference, TTE receivers could be extremely sensitive and transmitters could be very low power. Unfortunately, nature has imposed barriers and fixed limits which current technology and as yet has been unable to circumvent.

Clouds contain electrical charges with respect to each other and also the earth. Under storm conditions theses charges reach tremendous voltages which cause violent discharges evidenced as lightning strokes which may be between clouds, or clouds and the earth. This flow of current, often in the thousands of amperes, causes EM radio waves to be produced which may travel for hundreds of miles with sufficient intensity to interfere with radio communications in distant undisturbed areas. Other sources of EMI include galactic, cosmic, and even the earth's aurora magnetosphere. Much of this noise ends up in the extremely low frequencies (ELF), voice frequencies (VF), and very low frequencies (VLF) frequency bands. All have a negative impact on the operation of a TTE receiver.

The amplitude of man-made EMI decreases with increasing frequencies and varies considerably with location. It is typically due to electric motors, power lines, appliances, etc. Unfortunately most of the noise is in the frequency bands which are most appropriate for UG coal mine communications.

In receiver design, thermal noise is caused by the agitation of electrons in resistances. Selection of low-noise components for a TTE receiver can make a big difference in whether a signal is detected or not. Some receiver concepts have been built around high-temperature superconducting devices (SQUID - Superconducting QUantum Interference Device – See Appendix F) to minimize this problem. A precise evaluation of the quality of a receiver as far as noise is concerned is obtained by a determination of its noise factor.

The measurement of EMI outside of the receiver is done in the same way as radio-wave field strengths with the exception that peak, rather than average values of noise are usually of interest, and that the overall band-pass action of the measuring apparatus must be accurately known in measuring noise. Fortunately, for the UG TTE case, much data has been taken by and under contract with the former U.S. Bureau of Mines (Aidala et al, 1974).

3.2.0 Signal Paths/Signal Propagation

In an underground coal mine, the options for communications signaling include: Through-the-Wire (TTW), Through-the-Air (TTA), and Through-the-Earth (TTE). Each of these will be briefly addressed.

3.2.1 TTW

TTW communications signals in a coal mine can travel over twisted pair, coax, CAT5, trolley, leaky feeders, and fiber optic cables. Each of these cable types have unique properties which generally are selected to suit the characteristics of the signals being conveyed. Twisted pair is typically used for telephones and pager phones carrying only voice signals. Coax cables are used to convey higher frequency signals and are generally modulated with voice and/or data signals. CAT5 cables are specially constructed twisted pair cables that handle advanced digital protocols for computer networking. Fiber optic cables are in many cases used in place of CAT5 cables for the relay of computer networking protocols over longer distances. Trolley cables are normally used to provide power to mine locomotives, but can also act as a conveyor of medium frequency (MF) type signals. A leaky feeder cable is a specialized cable that enhances the propagation of certain radio frequencies underground. The signal characteristics of this cable require a more detailed description which is provided at the end of this section.

Fires, explosions, and roof falls do destroy cables in UG coal mines. Cables are not reliable. Some of the measures that can be taken to address the problems include using armor cable or conduit, burying the cable, creating redundancies by having multiple cables feeding the same portion of a system, providing loop-around, and providing borehole connections to main lines. Various software techniques have also been employed using sophisticated algorithms (such as the "spanning-tree algorithm") to direct signals when cable failures occur. Using armored cable or putting the cable in conduit is expensive. Providing redundancy by using multiple cables and loop-arounds can be complicated to design and manage as well as being expensive. Feeding cables through boreholes can protect the cables, but boreholes have their own unique set of problems such as, impede radio signals, water getting into the cable, etc. Also, cased boreholes can cost upwards of $30 a foot or so. In summary all of theses methods are vulnerable to complete failure when a fire, explosion, or roof falls in a mine occur.

Leaky feeder cable is designed to "leak" signal, which allows radio transmissions to both leak from the cable and also to enter the cable. Leaky feeder cable can be either a twin-core, coaxial cable in which the sheath (outer conductor) is pierced by a series of apertures: loose-weave cables, cables with holes or continuous lengthwise slots in the sheath. The cables radiate over their entire length. The increase in signal range is due to the lower degree of attenuation by the cable than by free-space propagation in the mine (Delogne and Liegeois, 1975). Leaky feeder cables commonly require specially placed line amplifiers and repeaters to compensate for signal loss. Each of these devices requires power and battery backups for operation when power fails. Transmission range can exceed 100 feet and receive range can exceed 300 feet in line-of-sight of the leaky feeder. There are four leaky feeder systems presently approved by MSHA:

- Mine Radio System, Flexcom, MSHA approval number 9B-219
- Varis Mine Technology, SmartCom IS, MSHA approval number 23-A050001
- DAC, RFM 2000, MSHA approval number 9B-201
- El-Equip Inc., Model VHF-1, MSHA approval number 9B-196

Advantages:

- The listed systems are currently available and are MSHA approved
- Provide clear two-way voice communications and low data rate signals
- Offer mine-wide coverage
- Portable radios that are small and efficient

Disadvantages:

- Radio signals in the VHF and UHF bands which are used on leaky feeder cables cannot penetrate rock
- Signal propagation is limited to line-of-sight-and within 300 or so feet of the leaky feeder cable
- Leaky feeder cables are subject to damage during a disaster and will most likely fail when most needed
- Leaky feeder cables are relatively expensive to install
- Repeaters must be installed at intervals to boost signal loss
- Maintenance and installation require skilled technicians
- Require battery backups

Further information can be obtained by contacting the cited vendors.

3.2.2 Through-the-Air

Much research has been conducted in UG coal mines. As far back as 1922, the USBM and the Westinghouse Electric Company (Westinghouse, 1979) conducted signal propagation tests towards the application of radio for mine rescue operations (Jakosky, 1924A). UG coal mines present unique challenges to radio signal propagation. The electrical properties of coal attenuate certain frequencies more than others. The propagation of some frequencies is enhanced by a waveguide effect due to the sandwiching of radio signals between layers of strata with varying electrical properties. The viability of wireless radio transmission in coal mines can only be determined through thorough testing in the UG mine environment. Many such tests have been performed at a large collection of coal mines. A partial listing is provided below:

- Propagation of EM Signals in Underground Mines, Terry Cory, Rockwell International USBM Contract No. HO366028 1977
- Communications/Location Subsystem, Westinghouse NTIS PB 208-267, Open File Report OFR 9(20-72)
- Preliminary Performance Predictions, for EM Through-the-Earth Mine Communications, Arthur D. Little, OFR 16-73
- EM Location System Prototype and Communication Station, Westinghouse, NTIS PB 226 600/AS
- Electromagnetic Location Experiments in a Deep Hardrock Mine, Continental Oil, NTIS PB 232 880/AS
- Electromagnetic Guided Waves in Mine Environments, Department of Commerce, James R. Wait, USBM Contract No. HO155008, 1978
- Electromagnetic Propagation in Low Mines At Medium Frequencies, Collins Radio, USBM Contract no. HO377053.

Research has shown that medium frequencies (MF) offer a viable approach to UG communications in both coal and metal/non-metal mines under certain circumstances. MF transmission is feasible for both personnel and vehicular communications. It does not suffer the attenuation characteristics and severe corner losses of UHF communications; nor does it require the use of expensive leaky feeder cable. Furthermore, it does not experience the high noise levels of ELF, VLF and LF communications. Research has demonstrated ranges of 1000 – 1500 feet in conductor-free areas, and much greater ranges in conductor-filled areas.

UG tests have shown that MF band EM signals couple into, and reradiate from, continuous electrical conductors in such a way that these conductors become the transmission lines and antenna system for the signals. The existence of electrical conductors in the entryway provides the means for what is has been called the "tunnel mode" or "parasitic propagation mode" of radio signal propagation in an UG mine. Testing has shown that MF signals propagating on one conductor would, by magnetic induction, induce signal current flow on other nearby conductor. Thus all of the entryway conductors and the magnetic coupling mechanism between conductors provide a means of mine-wide signal distribution. The method emulates the general properties of a leaky feeder without requirement of the specialized cable. USBM testing has also shown that MF radio signal propagation was possible in "natural waveguides" (coal, trona, and potash seams that are surrounded by more conductive rock) existing in certain layered formations (A.R.F, 1986). There have been a few commercially developed walkie-talkie systems that take advantage of this property. One vendor (Conspec) has a permissible system available. The range depends on a number of factors which include conductivity of the surrounding strata, type of floor and roof, distance to conductors, type of conductors, etc. The size of the antenna can also be cumbersome.

Some of the higher frequencies (VHF, UHF) propagate in a line-of-sight mode down a mine entry which can be upwards of 1000 feet. However, it is unlikely that an unaided (i.e., no leaky feeder) VHF or UHF signal would be able to travel around more than about two crosscuts.

The selection of frequencies for use in an UG coal mine has been well researched, though more should be done. A few of the more significant highlights are 600 to 3000 Hz (voice frequencies – VF) is the best frequency for TTE signal propagation, 300 kHz to 600 kHz (MF) frequencies exhibit excellent parasitic propagation effects when in the presence of any conductive medium (e.g., wires, cables, tracks, etc.). The U.S. Coast Guard has developed a system (NAVTEX – http://www.navcen.uscg.gov/marcomms/gmdss/NAVTEX.htm) which operates at 518 kHz and is used for emergency signaling. This system should be investigated for potential adaptation to coal mines. Radio signals in the 27 MHz range are a poor choice for coal mine use. Radio signals in the 150, 500, 900 MHz and 2.5 GHz provide good line-of-sight propagation but typically won't turn more than a few cross cuts.

3.2.3 TTE

TTE communications can take on a few different forms. They include ground conduction, seismic, and wireless. Each type has unique characteristics which may be beneficial under certain emergency situations. Each will be discussed and references are provided for further information.

3.2.3.1 TTE Ground Conduction Signaling

Ground conduction signaling, called "the TPS method" by the U.S. Army Signal Corps (Jakosky, 1924B); consists of injecting and receiving signals through the ground via ground-stake connections. Using this method, as expected, the signals in the VF range propagate the best. However experimental results proved the distance that the ground terminals must be separated are two to four times the vertical distance through which the signals are to propagate. A 1000-ft deep mine would be a challenge for this method. Water tables, conductive strata, and other factors reduce the operational distance.

3.2.3.2 TTE Seismic Signaling

Seismic signaling consists of using special sensors called geophones, to pick up rhythmic vibrations signatures created by a miner who pounds on roof bolts, the roof, or floor of the mine. A more in-depth description of this method follows in section IVA2 of this document.

3.2.3.3 TTE Wireless Signaling

A portable TTE system will likely have the best chance of providing contact with miners since it offers the best resistance to damage from roof falls, fires, and explosions. Part of the reason is the miner can keep the system on his/her person. Also, there is not necessarily a need for a pre-existing antenna infrastructure. However, in this type of system frequency, geology, noise, and depth will influence the probability of successfully communicating with the surface. A series of studies (Emslie et al, 1974) resulted in feasibility calculations to establish first-order estimates of the magnitude and variability of transmitter power requirements under different noise, overburden conductivity, and mine depth conditions; to identify relationships, conditions, or frequencies that are likely to limit or enhance system performance; to reveal items requiring further investigation and data required; and to suggest practical methods for optimizing system performance. Simple experiments to support these calculations were carried out along with detailed investigations of specific modulation, coding, noise-suppression, voice-compression and signal-conditioning techniques, aimed at producing TTE operational/emergency mine-communications systems that were not only effective, but also practical and economical. Today only a very few systems incorporate the results of those studies, and typically they only operate from surface-to-UG. More details on TTE wireless communication are provided later.

4.0.0 Emergency Communications

Though any communication system used in a mine can be termed an emergency communication system, it is statistically unlikely that a conventional or normal everyday-use hardwired or wireless system will survive and/or operate after a major roof fall, fire, or explosion in a mine. On the other hand, a TTE communication system which does not require a preexisting cable or open-air signal path for the signal to propagate, would most probably be capable of providing communications from the miners to the outside world during a disaster. Therefore TTE systems will be the major focus of this portion of this document. Also, rescue team communication systems are only used during mine emergencies and they will be discussed at the end of section IV.

4.1.0 Presently Available TTE Systems

There are several companies who now offer TTE systems. Most are limited to communication from surface-to-UG. Only one system (TransTek) provides a communication system for both surface-to-UG and UG-to-surface. However, it is not a portable system. Recently a few companies have appeared which expect to be providing a TTE system in the near future. A brief description of each vendor's product is provided below. See Appendix C for additional information.

4.1.1 GLON-GLOP – Faser - Poland

This system consists of Personal Mining Location Transmitter (GLON), and Measurement Mining Location Receiver (GLOP) PAM-G3/1.

The GLON transmitter is contained in a Light Emitting Diode (LED) based miners cap lamp. The GLON generates a 4000 Hz to 6000 Hz EM signal on 1 of 8 distinct channels. Range of the signal through solid rock is projected to be 75 to 150 feet.

The GLOP receiver can determine the distance and direction to a GLON transmitter. The GLOP features manual or automatic tuning. Its liquid crystal display (LCD) indicates the frequency, signal level, and the projected distance to a GLON. The GLOP features a three-axis antenna design which minimizes signal source directional anomalies. The system has European ATEX M1 certification.

Advantages:

- Useful for rescue teams trying to find miners within the mine
- Will transmit through the earth.
- Compact
- A portable cap-lamp battery operated system.

Disadvantages:

- Range is limited
- Not yet available in the US
- Not yet MSHA approved

4.1.2 Seismic Communications

Though not what may generally be thought of as a communication system, a seismic location system can locate a miner and can tell a miner his signal has been located. Research performed in the 1970's by the USBM produced a system and a method which could provide locations of miners to a depth of 1500 feet. This system is presently used by MSHA when disasters occur. Signals have been detected to a depth of 2000 feet. The seismic location system is truck mounted and is capable of detecting and locating the source of seismic vibrations produced by trapped miners. Miners may generate seismic signals by pounding on mine surfaces such as the roof, floor, ribs, but preferably roof bolts. These signals are detected by sensors called geophones installed either on the surface or underground. The system can monitor approximately 1 square mile over most mines (depending upon terrain). The system is highly mobile, and can be air lifted. The general procedures when escape is cut off are:

- Barricade
- Listen for 3 surface shots
- Pound hard 10 times on roof bolt or floor
- Rest 15 minutes then repeat pounding
- You hear 5 surface shots which means you are located and help is on the way

An attractive feature of this approach is that no special equipment need be carried by the miner to provide the seismic signal.

4.1.3 PED – Mine Site Technologies - Australia

The Personal Emergency Device (PED) communication system is a one-way TTE text messaging transmission system that enables communication of specific text messages to individuals. It features a belt-wearable receiving unit for individual miners. It does not provide UG-to-surface TTE communications, but communications to the surface is facilitated via a separate Tag based system.

The PED system operates at a frequency of 400 Hz, and transmits digital messages to miners. The system utilizes either a surface or underground antenna loop which radiates a radio frequency signal enabling one way communication to the underground workings. The power generated from the antenna is about 1200 watts. Presently there is only one US mine using a surface antenna. Use of surface antennas is limited due to problems with undulating terrain and obstructions. The maximum amount of cover for a surface antenna to be effective is about 2500 to 3000 feet. Underground antennas can be compromised in fires and explosions. Messages can be directed to an individual, to a group, or to all the UG personnel. When a message is received, the cap lamp dims and flashes for about 10 seconds and a message is displayed on a liquid crystal display (LCD) on top of the miner's cap lamp battery. Individual, group or broadcast messages can be sent. The first demonstration of the system in the United States was in 1990.

There are currently about 18 permissible PED systems installed in U.S. coal mines and one in a metal/nonmetal mine. There are 9 systems installed in Utah, 3 in West Virginia, 2 in Indiana, 1 in New Mexico, 1 in Colorado, 1 in Virginia, and 1 in New York, There are reportedly 140 systems in use worldwide, including; Australia, Canada, China, and Sweden. Mining companies that are using PED systems include Consol, Peabody, Centennial Coal, BHP, Adalux, and IGC. The first successful evacuation of miners attributed to the PED system occurred during the Willow Creek mine fire, in Helper, Utah, on November 25, 1998.

Advantages:

- Can contact one person with a message
- Can provide messages to all miners during the early stages of a mine fire including evaluation instructions

- Can be retrofitted with existing cap lamp manufacturers lamps such as Koehler, NLT, and MSA
- Can be deployed with an antenna on the surface enabling one-way communication from the surface

Disadvantages:

- Installations incorporating underground antenna loops may be compromised in the event of a fire or explosion preventing communications
- Mines using the systems in both the US and Australia, have reported reliability issues including shadow zones within the mine where communications are not possible, miners in "same locations" underground not all getting messages
- Communication is only one way with no way of verifying reception of the signal
- Systems employing underground antenna loops are not intrinsically safe and power must be removed in the event of a fan outage or other incidents such as mine fires and explosions, which disrupts communication
- Conditions are different at each mine, the systems don't work well in every mine

4.1.4 TeleMag - Transtek – United States

TeleMag is a wireless through-the-earth two-way voice and data communication system. It operates between 3000 Hz and 8000 Hz. It employs a single sideband modulated carrier technique. It uses a Digital Signal Processor (DSP) based tracking comb filter for attenuating harmonic-induced noise, which improves the signal-to-noise ratio thus improving the range of the system. It is a fixed, station-to-station system. It is not portable. The UG and surface antennae consist of a wire loop. It has been tested to depths of 300 feet. Extended communications from the surface and underground fixed stations using wireless handsets is possible. Calculations indicate that 1000 feet of ground penetration is possible. The first demonstration of the system was in August of 2000 (Conti, 2000) at the NIOSH Lake Lynn Laboratory mine. However, it is not permissible. Other mine installations are not known at this time.

Advantages:

- Provide clear two-way voice communications TTE
- Interfaces to other Transtek communication systems in the mine and above the mine which enables extended voice communications through the earth

Disadvantages:

- System is not MSHA permissible and is not portable
- System is restrained by not having a portable loop antenna. A fixed place loop antenna will be subject to destruction from a roof-fall, fire, or explosion

4.2.0 TTE Systems Under Development

In the past few months a number of different companies have decided to direct their efforts towards providing TTE systems for underground coal mines. The details follow.

4.2.1 Delta Electromagnetic (DeltaEM) Gradiometer Beacon Tracking System – Stolar – USA

A system consisting of a beacon transmitter and a DeltaEM wave gradiometer (receiver) has been developed. The DeltaEM receiver is portable and is used on the surface of the mine to locate the beacon transmitter. The beacon transmitter generates a 2000 kHz EM signal. The system is a prototype and is not yet MSHA approved. The DeltaEM receiver antenna consists of 3 ferrite-core antennas. There are three beacon antennas; 30 inch diameter loop, 6 inch ferrite-rod antenna, and large loop antenna.

4.2.2 TramGuardMinerTrack - GeoSteering-Gamma Services International – USA

GeoSteering presently markets an MSHA-approved proximity warning system called TramGuard for continuous mining machines. Information from the system is continually archived in the system and can be locally accessed with appropriate hardware and software. GeoSteering has been engineering a method to provide the data via a TTE connection with the surface. The data includes the identification of all miners local to the system, their distance from the system, and other useful data. This part of the system will be called TramGuardMinerTrack. The system is portable and includes a backup battery. In-mine tests are now being conducted; however at this time details are proprietary.

4.2.3 Subterranean Wireless Electric Communication System (SWECS) – Kutta Consulting – USA

This system is being developed under an SBIR contract to the U. S. Army CERDEC program. It is expected to be a fully portable system with TTE capability. The relative location of the underground device can be determined. Connections to other underground communication systems are planned.

The U.S. Army originally commissioned the project for wartime use in such places as Afghanistan or to communicate with soldiers who may be in a collapsed building. But in response to the 14 miners who died in West Virginia coal mines in the recent past, government officials recently directed Kutta to adapt the device for commercial use in the mining industry.

The patent-pending SWECS, consists of a PDA-type device with a screen and keypad, an 8-ounce radio and a foot-long antenna. It has push-to-talk capability similar to a walkie-talkie and fits into a small backpack. The device has been tested in caverns and Arizona mines, and can send voice communication through 800 feet of solid rock, and a digital photo through at least 400 feet of rock.
The SWECS has not yet been tested by MSHA for permissibility conformance.

4.2.4 Canary 2 - Vita Alert - Canada

Vital Alert has created an emergency broadcast network (EBN), called Canary 2, which is a two-way, through-the-earth, voice and text messaging technology for use in urban, subterranean and ocean environments. The technology was developed with Government support under Contract No. W-7405-ENG-36 awarded by the US Department of Energy. The technology was licensed to Vital Alert. The network's 2-way voice system has the ability to penetrate the earth to depths of up to a thousand feet. Vital Alert claims that its EBN's text messaging system can penetrate to 9000 feet.

The equipment consists of mobile surface units which employs a ferrite-rod as an antenna. Each surface mobile unit can communicate with several underground base units. Preliminary tests suggest the system can penetrate up to 400 feet of overburden.

4.3.0 Research on TTE

Research on TTE has been conducted by a wide variety of universities and government agencies around the world and has resulted in a few commercially available products. Some of the more significant developments are provided as follows.

4.3.1 CSIR Miningtek – South Africa

Miningtek developed a trapped miner-locating device. A prototype was successfully tested UG where it provided detection and location of a trapped miner at the distance of more than 100 feet through rock. It consisted of a uniquely coded belt wearable miner's tag and portable search unit. The tag is built into a metal buckle and includes an LED and buzzer (Kononov, 1999). It is not known if this development ever resulted in a commercial product.

4.3.2 Institute for Advanced Physics, University of Innsbruck - Austria

Research at the University of Innsbruck (Nessler, 2000) resulted in the development of a system which was composed of a beacon contained in a miner's cap lamp, and a hand-held location receiver which could search for the trapped miners beacon. Field tests at the Schwaz/Tirol mine demonstrated a detection accuracy of about 20 inches. The paper does not mention the distance from the beacon to the receiver. It is not known if the system ever became a commercial product.

4.3.3 U.S. Bureau of Mines – United States

In the mid 70's to the early 80's the U.S. Bureau of Mines conducted extensive electronic communications research over a broad spectrum of frequencies and system types. Most significantly was their TTE research at frequencies between 600 Hz to 3000 Hz. The promise of the research resulted in the development of an extensive collection of system hardware. The miner-carried part of the system was a compact belt-worn device with a wire-loop antenna. The surface part of the system consisted of a transmitter and long wire loop antenna, and a handheld receiver with a 15-inch loop antenna (Lagace et al, 1980). Two varieties of the miner-carried devices were developed. One version provided a beacon signal to the surface. The second version was a transceiver composed of a beacon and a voice receiver. More than 100 miner-carried beacons were built. About a dozen or so contained a voice receiver. A collection of surface systems were created. Tests were performed at 94 UG coal mines which were a representative sampling of all coal mines in the U.S. Depths ranged to 1500 feet. Resulting data showed a 68 % probability of detection of the miner's beacon at a depth of 750 feet (Lagace et al, 1980).

4.4.0 Rescue Team Communication Systems

Life lines are a standard part of mine rescue and recovery operations, and their use is mandated by law (30 CFG 49.6). The wires or cables that make up the life line must be strong enough to be used as a manual communications system. The life line must be at least 1,000 feet in length. An approved sound-powered rescue team telephone system was developed using this cable in 1946 by the USBM (Forbes et al, 1946). Many of today's teams use a system that hasn't changed much since that date, although there has been a number of advances in the technology. In 1991, the National Mine Rescue Association and the Mine Rescue Veterans conducted a membership survey on the problems associated with the use of life lines during mine rescue, as well as practical ways of improving life line procedure. One of the recommendations was to use radios which allow all team members to communicate with each other, as well as the fresh air base. Radio-based systems have been developed and have improved communications. A sampling of vendors and equipment for coal mine rescue team communications systems include:

- Con-space Communications
- Conspec Controls, RimTech
- Draeger, Soundpowered Rescue Team Communications
- TransTek, ResQCom
- Rock Mechanics Technology, MComm

Further vendor information can be obtained from the complete vendor list in appendix C.

5.0.0 Normal Coal Mine Communication Systems

UG coal mining employs a diverse mix of communication devices (Kohler, 1992) and technologies including telephones, loud-speaking telephones, radios, trolley phones, shaft, and hoist phones. The more modern system can also deliver digital data, digital voice, and even video. Today's predominant systems however are conventional telephones, loud-speaking telephones, and radios. A quick sampling of all coal mine communication system types, both normal and emergency. The type of technology involved, a general description of their capabilities, a few of the vendors who can supply the technology, whether the technology is MSHA approved, and a brief list of the advantages and disadvantages of each technology type is provided in Appendix B (Existing Mine Communications and Tracking Technology). Other useful data is also provided.

Though recent events have shown that most normal communications systems can fail during disasters, they still can play a significant role for normal everyday use. Particular emphasis will be put on radios since this technology affords the miners the most flexibility and instantaneous communications. Radios can require an elaborate support structure to compensate for the poor radio signal propagation environment of a coal mine. The most predominant support structure is called a leaky feeder. One relatively new concept using radio in a mine is called

"WiFi." WiFi requires strategically placed wireless repeaters. Interestingly, these systems are digital, which opens up a new realm of possibilities, including simultaneous delivery of voice (VoIP), data, and video, over the link. There has also been a merging of technologies which combine leaky feeder, Ethernet, and WiFi. A few cell phone vendors now market a phone that combines standard cell phone communications protocols such as Code Division Multiple Access (CDMA) or Global System for Mobile communications (GSM) with WiFi. With the appropriate software installed in a PC at the mine office, and a WiFi network installed in the mine, a miner can walk into the mine and continue to use his cell phone. Reference information for all of the vendors and distributors of the equipment mentioned throughout this document can be found in Appendixes B, C, D, and E. Each appendix groups the contained data into tables or lists for easy access. Appendix B is a table of technology types. Appendix C is an alphabetical list of all vendors, manufacturers, distributors, and research organizations. Appendix D1 and D2 are tables of manufacturer information. Appendix E is a distributor list. Appendix F is a table of research organizations.

5.1.0 Telephones

Telephone communication links are required by law -- see 30 CFR, Part 75 Paragraph 75.1600. **75.1600 Communications**
The communication systems that are now in use at each mine will be acceptable at the present time. However, there must be at each mine an operative means of communications between each working section and the surface when the working section is more than 100 feet from the portal.

75.1600-1 Communication Facilities; Main Portals; Installation Requirements requires that a telephone or two-way communication facility be located on the surface within 500 feet of each main portal.

75.1600-2 requires that there be a telephone or equivalent two-way communication facility at each working section, located not more than 500 feet outby the last open crosscut and not more than 800 feet from the farthest point of penetration of the working face.

In 30 CRF Part 23, Telephones and Signaling Devices, must be explosion-proof or intrinsically safe. The telephones must be supplied with back-up power supply in the event of a power outage. The entire system must be XP or IS in the event of a loss of ventilation.

Telephones for UG mining are integrated into ruggedized housings to survive the environment. Battery operation is common. Versions of the phones include signaling lights. Operationally they are much like conventional surface-type phones. The telephones are interconnected through multiple pair cables and a private branch exchange (PBX - telephone switching system). Safe operation of the systems is due partially to barrier circuits installed at the entrance of the mine which limit the electrical energy of the signal to safe levels. Barrier circuits and lightning arrestors protect against sudden energy surges. A few phone systems have been developed which incorporate multiplexed voice channels over a common radio channel permitting single-pair wired operation.

Advantages:

- Relatively cheap and reliable
- Easy to use
- Doesn't require skilled maintenance

Disadvantages:

- Dependant of the electrical continuity of the line
- Prone to failure due to bad joints, moisture, corrosion, and damage from roof falls, explosions, and fires
- Require battery back-up systems

Several vendors can supply telephone systems for underground use. They include:

- AmpControl
- Austdac
- Conspec Controls
- FHF
- Gaitronics
- Hard-Line
- Marco

Other details can be obtained by contacting the vendors listed in Appendix C.

5.2.0 Page Phones – Loudspeaking Telephones

The pager phones used in many UG coal mines are battery-operated, party-line telephones with provisions for loudspeaker paging. The system is two-wire, non-polarized, and is operated by self-contained batteries. Paging phones were introduced during the later 1950's when a progression of new equipment came to the mining industry. Basically each paging phone unit is self-contained, consisting of a speaker, telephone handset, 12-V or 24-V battery power supply, and solid-state amplifier and associated circuitry. Power is drawn only while the unit is in operation. The majority of mines use party-line paging phones. The units are interconnected with twisted-pair cable to make a system for audio paging and semi-private calling. With this arrangement, a miner can page a person, a place, or the entire mine. System operation does not depend on one central interconnecting device.

Implementation of pager phone systems has resulted in two-wire phone lines being an integral part of the topology of all mines; interconnecting all operating areas with each other and with a central "dispatch" or supervisory location on a common bus. The implementation of these phone lines does not conform to any uniform or standard practice: that is, the phone lines are implemented using many kinds of wire, many differing splicing techniques, many wire termination techniques, and many different wire hanging/suspension techniques. Typical phone lines in a single mine may use twisted-pair line, house wire, multiple-pair cable, and sometimes single conductors individually attached to insulators.

For all practical purposes, noise on phone lines appearing in the usual transmission line (differential) mode results from mode conversion of monofilar (common) mode noise which is electromagnetically induced or coupled to the phone line from a multiplicity of discrete sources. The mode conversion is due to line imbalance. Thus, characterizing the excitation “source” of common-mode noise is of prime importance. Secondarily, the actual differential-mode noise (or ratio of common-mode to differential-mode noise) is important (Corey, 1981).

Advantages:

- Paging telephones provide two-way voice communications wherever phone lines are installed.
- They are battery backed up with replaceable batteries; batteries last for a very long period of time.
- They are relatively cheap and reliable
- They are easy to use

Disadvantages:

- A one-conversation party line may be inadequate for larger mines
- Voice paging can be easily ignored
- Mine-wide paging for all communications can be annoying

Several mine page phones are approved by MSHA. They include:

- Appalachian Electronics Instruments, 101 Page Phone – MSHA approval 9B-71, Midgi-Talker – MSHA approval 9B-71-1
- Comtrol Corporation, Loudmouth Page Phone, MSHA approval 9B-71
- Gai-Tronics, Mine Dial Page Phone, Model number 491-204, covered by MSHA approval 9B-221
- Gai-Tronics, Model numbers AM7011, AM7012, AM7021, and AM7022, covered by MSHA approval 9B-155
- Pyott Boone, Model numbers – 112-112P-118-119, covered by MSHA approvals 9B-102 and 9B-163
- Pyott Boone, Model 128 Mini Page Boss, covered by MSHA approval 9B-158
- Mine Safe Electonics, Model IIA Mine Phone, covered by MSHA approval 9B-164
- Mine Safety Appliances (MSA), Pager III, covered by MSHA approval 9B-85

Other details can be obtained by contacting the vendors which are listed in Appendix C.

5.3.0 Trolley Phone – Trolley Carrier Phones

Trolley carrier phones are relatively unsophisticated devices typically operating at carrier frequencies of about 60 to 190 kHz using narrow-band frequency modulation. The equipment is typically rated at 25 watts. Most mines use a few fixed-location trolley carrier phones and a large number of mobile trolley carrier phones on locomotives, jeeps, and portal buses.

The operating environment for trolley carrier phones is quite severe. The mobile units are subjected to constant vibration and shock, and suffer the extremes of temperature variations from season to season. The also operate in 100% relative humidity environments during much of the warm season. They are frequently exposed to acid vapors, dust, and dirt. The electrical environment in which the carrier phones must operate is harsh. The trolley wires are known to have voltage extremes running as high 12,000 volts for a few milliseconds, and to be subject to the ever-present AC ripple generated by power rectifiers.

The transmission line that interconnects the carrier sets represents the major difficulty in obtaining and maintaining good carrier phone performance. It is not the fundamental character of the transmission line that imposes this problem. Rather it is the many bridging loads necessarily placed across the trolley wire and the branches imposed on the trolley wire/rail by rail haulage requirements.

The attenuation rate for a typical trolley wire rail in a conductive medium in a tunnel is approximately 1 db/km. A typical trolley carrier phone can accommodate a 70 dB transmission loss (i.e., a loss from 25V rms to 8 mV rms). With an ideal antenna this would mean a range of 40 miles. However, the bridging loads such as mine motors, lightning arrestors, signal and illumination lights, vehicles, insulators, and borehole shorts, all greatly degrade the communication path.

Addressing the signal propagation issues, some mines have made use of auxiliary wires strung for the sole purpose of providing aided transmission. This line is free of the branches and other impediments to good propagation. Inductive-coupling loops and ferrite-bar couplers have shown improvements to some systems (Little, 1977).

Trolley carrier phones operate in a wide variety of mine topographical layouts – mines ranging from as small as a few miles to many miles in dimensions and encompassing many miles of trolley wire/rail, including switches, crossovers, sidings, and the usual configurations found in rail haulage systems. They also operate in the face of an ever-changing mine layout as the mining progresses. They operate in an environment that is generally detrimental to electronic equipment with a minimum of maintenance and a lack of good maintenance tools. There are frequent problems with performance. The problems are evidenced by lack of coverage of certain regions of the mine, breakdown of equipment, and noise-imposed performance limitations.

Several vendors can supply trolley phones. They include:

- Conspec Controls
- Comtrol Corporation
- Gaitronics
- Hughes Supply

Other details can be obtained by contacting the vendors listed in Appendix C.

Advantages:

- Provides communications to all rail haulage vehicles using trolley cables

Disadvantages:

- Noisy
- Coverage problems in large systems
- Usually single-channel operation

5.4.0 Hoist Phones

Hoist communications are necessary to permit communication between persons in the hoist cage and the surface or underground. Particularly in coal mines, a phone line directly connects the cage to the mine communication system. In deep hard-rock mines, it is difficult to maintain such a cable.

Earlier research identified that radio could be used to improve the hoist communications problem, based on the premise that it would be advantageous to use the hoist cable (rope) as a radio signal conduit. Signal propagation would be provided by means of coaxial mode of transmission in which the hoist cable serves as the inner conductor and the surrounding rock acts as the outer conductor of an envisioned coaxial cable. Since the rock/concrete of the shaft is a poor electrical conductor the current in the outer conductor of the coaxial line is not confined to a very thin surface layer as in a metal coaxial cable, but spreads radially to a distance that is generally many times the shaft diameter.

Research results indicated that the coaxial mode of transmission, showed that a broad minimum in overall signal loss would occur between 100 kHz and 1 MHz, possibly centered on 300 kHz. However, the most favorable frequency selection is highly dependent on determining the EM spectral noise data over that frequency range (Spencer, 1974).

To get a radio signal into the hoist cable the signals must be inductively coupled onto and off the hoist rope transmission line. One method that was developed involved the use of a ferrite or powdered iron toroidal core coupler which also provided signal reception. Several hoist phones are available. They include:

- Comtrol Corporation
- Conspec Controls

Other details can be obtained by contacting the vendors listed in Appendix C.

5.5.0 Walkie Talkies

A walkie-talkie is a portable, bi-directional radio transceiver. Major characteristics include a half-duplex (only one of receive or transmit at a time) channel and a push-to-talk switch that starts transmission. The typical physical format looks like a telephone handset, possibly slightly larger but still a single unit, with an antenna sticking out of the top. Generally walkie-talkies operate in the VHF and UHF bands. In coal mines they are commonly used with the support of a leaky feeder cable and line amplifiers. A few MF band walkie-talkie systems have been created. The antennas consisted of a bandolier type antenna which wrapped over one shoulder. They could be used without any existing antenna support structure. There presently are no walkie-talkies approved by MSHA. Kenwood may receive an MSHA approval in the near future. Other details can be obtained by contacting the vendors listed in Appendix C.

Advantages:

- Provides wireless portable communications
- Can provide wide areas of coverage
- Can be used on longwall sections

Disadvantages:

- Only works line-of-sight
- Requires a leaky feeder infrastructure to go around corners and to provide whole mine coverage
- Leaky feeder line amplifiers require battery backup systems.

5.6.0 Longwall Communications

Longwalls can advance as much as 200 feet a day. As with any part of the longwall system the communication link must also be continuously extended. There are many communication systems which have been developed for use on longwall. They include hard-wired and wireless systems. The wireless systems can employ MF, VHF, and UHF walkie-talkies. Several companies can provide longwall communications. They include:

- Ausdac
- Conspec Controls

Other details can be obtained by contacting the vendors which are listed in Appendix C.

5.7.0 RFID or Tag-Based Systems

Radio-frequency identification (RFID) refers to the technology that uses devices (called Tags) attached to objects that transmit data to an RFID receiver. RFID provides tracking and accountability of persons and other assets. RFID is provided by a combination of wireless readers interconnected via leaky feeder, WiFi, or other systems. RFID first appeared in tracking and access applications during the 1960s (Grayson and Unal, 1998). It consists of devices that can either be passive or active. Passive RFID is used in relatively short-range applications which do not contain a power source. Active RFID is used in longer range applications and can be read up to 300 feet away. Tag reading is localized to the vicinity in which the tag reader is installed. In mining RFID can provide improved response to downtime, identification of workers entering or leaving a mine, control of personnel traffic into hazardous areas, identification of vehicles entering or leaving production units or passing specific locations in the mine, tracking of supplies and materials, and maintenance scheduling. There presently is no real-time tracking system available for underground use. Operation is limited to the range of the Tag reader.

Several companies can provide RFID/Tag-Based systems. They include:

- Davis Derby
- El-Equip
- Grace Industries
- Impro
- Marco
- Mine Site Technologies
- Saco
- Sira
- VAK
- Varis

Advantages:

- Provides people or asset tracking and accounting
- Determines position of miners up to the point of a disaster by reviewing logged files.

Disadvantages:

- Range is limited
- Requires readers in area to be covered

6.0.0 Antenna Design for Coal Mine Appropriate Communication Systems

Though many mines use standard walkie-talkie style of radios for communications it does not necessarily mean that they are the best radio for the environment. Research as mentioned in the VLF and MF ranges has shown that alternative types of radio could be more useful. One problem with the use of these lower frequencies is the antennas required can be quite large and cumbersome and likely would be an inconvenience for the everyday miner. Addressing that concern some research has indicated that more compact designs are possible (Curtis et al, 1977). Integrating ferrite rods into antenna designs can make for more compact antennae with minimal effect on range performance. MSHA IS issues will have an impact on design types.

7.0.0 Interaction of Radio Transmissions on Mine Monitoring, Control Systems, Explosives

Many tests have been conducted to determine if control and monitoring equipment in the Nation's coal and metal/nonmetal miners were susceptible to radio-frequency interference (RFI) from communications sources. These tests were conducted to decrease the possibility of RFI causing monitoring systems to be unreliable, preventing RFI from causing malfunctions in mining equipment, providing the mining industry with information on EM compatibility (EMC) standards, developing a frequency coordination plan for use in UG mining, and to identify the need of manufacturers to adopt RFI suppression standards (A.R.F. 1986). A principal part of the work was to identify classes for mining equipment that could potentially be susceptible to RFI.

Though tightly controlled, explosives are used in underground mines. There are many factors which could lead to unplanned explosions and radio frequencies have been one of them. Addressing those issues the Institute of Makers of Explosives (www.ime.org) has created an information book (SLP – Safety Guide for The Prevention of Radio Frequency Radiation Hazards in the Use of Commercial Electric Detonators) to identify what frequencies and at what power levels could be cause for concern. Pilot check wire current sensors, ground fault detectors, and other current protection device could be adversely affected by RFI and even specific radio frequencies. Though little could be found on the subject, this is one area that definitely needs to be investigated.

8.0.0 Radio Remote Controlled Continuous Mining Machines and Others

Over the years there have been instances where one piece of radio-controlled equipment has interfered with the operation of other radio-controlled equipment. This has occurred when two or more radio systems from the same vendor are operated in close proximity. This problem has resulted in the generation of information bulletins from MSHA. Though the more modern radio systems have addressed the problem through special encoding schemes, it is prudent to be aware of the potential hazard. With the recent activity in the area of mine communications for coal mines, new technology will be introduced into the mines which may not account for the possibilities unless properly addressed.

9.0.0 Proximity Warning Systems

Proximity systems are not necessarily communication systems but they have many of the same features. They generally provide one or more wireless links between coal miners and their machines. In the underground mining environment there is presently only one MSHA approved system (GeoSteering -TramGuard). At least one other company has been developing a similar system (Nautilus). These systems may be adapted to interact with other communication systems in mines in the near future.

10.0.0 Data Networks in Coal Mines

There presently is a wide collection of different digital data networks being used in mines. They include a combination of computers, computer-like devices, monitoring and control systems, and communications devices that interoperate across common transmission mediums. The networks can take on a variety of forms. Local area networks (LANs), Personal Area Networks (PANs) wide area networks (WANs) and wireless local area networks (WLANs). TCP/IP and variants of it have generally been accepted as the common intercommunication protocol across these network types. The following sections of this paper provide a brief description of applicable information relative to data networks which are being or will be used in coal mines.

10.1.0 TCP/IP

Transport Control Protocol/Internet Protocol (TCP/IP) is a protocol system – a collection of protocols that support computer network communications. Basically it is a common set of rules that helps to define the complex process of transferring data (Casad, 2001). Present-day TCP/IP networking represents the synthesis of two developments that began in the 1970's; the Internet, and the LAN.

10.2.0 Ethernet

Ethernet is fundamentally a communications standard (IEEE 802.3) used on LANs. An Ethernet LAN typically uses coaxial cable, fiber-optic cables, or special grades of twisted-pair wires (CAT5 or better). The most commonly installed Ethernet systems are called 10BASE-T or 100Base-T and provide transmission speeds up to 100 Mbps. Devices are connected to the cable and compete for access using a Carrier Sense Multiple Access with Collision Detection (CSMA/CD) protocol. This is a system where each computer listens to the cable before sending anything through the network. If the network is clear, the computer will transmit. If some other node is already transmitting on the cable, the computer will wait and try again when the line is clear. Sometimes, two computers attempt to transmit at the same instant. When this happens a collision occurs. Each computer then backs off and waits a random amount of time before attempting to retransmit. With this access method, it is normal to have collisions. However, the delay caused by collisions and retransmitting is very small and does not normally affect the speed of transmission on the network. Ethernets can employ a version of TCP/IP and in some cases is even used on leaky feeder transmission lines. Newer versions of Ethernet can support 1000 Mbps or more. A few of the vendors who can supply Ethernet-based systems are:

- Mine Site Technologies
- Varis

10.3.0 WiFi

WiFi is short for 'wireless fidelity', a term for wireless local area networks conforming to a protocol specified in IEEE 802.11b,g. WiFi has gained acceptance in many environments as an alternative to a hard-wired LAN. Many airports, hotels, and other services offer public access to WiFi "hotspots" so people can log onto the Internet and receive emails on the move. Hotspot WiFi-based communications systems are also available for UG coal mines. The vendors who can supply WiFi technologies for mines include:

- Ekahau
- Ipackets
- Mine Site Technologies
- Northern Light Technologies

10.4.0 Wireless Mesh Networks

Another interesting and applicable technology to the needs of UG coal mining in the future is identified as a "Wireless Mesh Network. It's based on WiFi technology and employs special TCP/IP-based data protocols. Mesh networking with respect to WiFi types of systems is now being addressed by the Extended Service Set (ESS) Mesh Networking Task Group (802.11s). The new IEEE 802.11s standard will enable a collection of Wireless Access Points (WAP) to be interconnected with wireless links that enable automatic topology learning and dynamic path configuration. The group aims to release the standard by 2007. A form of mesh networking in lower data rate applications such as wireless sensor networks are generally addressed by IEEE 802.15.4 standard for wireless personal area networks. Multivendor operability of products using the IEEE 802.15.4 standard is contained in what is called the Zigbee specification set. Wireless modems (sometimes called "Hot Spots" or nodes) are strategically placed throughout a work area, and each unit can receive, transmit, or act a signal repeater. This multi-hop style network can be designed to be redundant and automatically configures itself and also has a "learning" and "self-healing" capability. There are no predefined signal pathways between the nodes. Failure of any one node or closure of any one signal path (due to loss of power or an event such as a fire or a roof fall) has little impact on the whole network. The application of this type of network could greatly enhance the reliability of a wireless coal mine network. Still, if all possible radio signal paths are closed or if too many nodes fail, communications will stop. Note that wireless mess networks are currently used under mandate by NFPA (http://www.nfpa.org/) for structural fire response and commercially available Underwriters Laboratory (UL - http://www.ul.com/) IS devices but do not currently have voice capability.

A few of the vendors who may soon supply wireless mesh networks for mining are:

- Grace Industries
- Rajant

10.5.0 VoIP

Ethernet networks support internet protocol (IP) telephones, also known as voice over IP (VoIP) telephones. VoIP telephones are used in many of today enterprises. Typically VoIP telephones are hardwired to a wall socket, Ethernet hub or switch. There are also wireless systems. There are international standards (H.323), and they are compatible with public networks. A few VoIP based systems are now available to the mining industry. These phones can work in combination with leaky feeder systems which incorporate Ethernet protocols, fiber-optic networks, and WLAN systems. Each of these network types are now being used in UG mines.

10.6.0 Network security/firewalls/Viruses

Any connections made to outside networks are vulnerable to any number of security breaches, not to mention outright attacks. It is only prudent to provide the proper protection, especially when the lives of miners could be at risk should any of the control, monitoring, or communication systems fail. A firewall is a set of related programs, located at a network gateway server that protects the resources of a private network, such as the outside office area for an underground mine, from users from other networks. The firewall will prevent outsiders from accessing the mine's private data, communications, and control resources and will also control access to outside. A firewall, working closely with a router program will filter all network packets to determine whether to forward them toward their destination. A firewall is often installed in a specially designated computer separate from the rest of the network so that no incoming request can get directly at private network resources.

Anyone working with computers connected to the Internet must have virus protection software even if they have a firewall installed. Viruses can be embedded in emails, in software applications, and in virtually any data they may be received through an Internet connection. Whether any mine has yet had a major data or communication network failure due to a virus is unknown, but that possibility does exist. All computers and computer-based systems should, of course, include automatic virus detection. Regular updates to that software should be performed.

11.0.0 Cell Phone Technology

Cell phone technology can be used in a coal mine. First the mine must have a WiFi infrastructure; secondly the phones must be WiFi-enabled, and thirdly the cell phones and infrastructure must meet MSHA permissibility requirements. Recently at least two present cell phone manufacturers provide the combined normal operation and WiFi ability (Motorola, and Nokia). At least one company (ECOM) sells an IS cell phone, but it is not yet WiFi-enabled.

12.0.0 Interoperability

Today there is very diverse group of control, communication, and monitoring systems being used in UG coal mines. Many of these systems work independently, especially legacy systems. What may be a perfectly stable system today could fail as soon as a new device is added to the environment. Some efforts should be made to ensure compatibility not only from an interoperability standpoint, but also from the potential interference standpoint. Interoperability and interference can be an issue for all system types including control, communications, and monitoring systems. The UG coal mine environment is rich with potential interference sources including DC trolley power, AC and DC machinery power, stray currents, high-voltage cables, and variable-frequency drives. Any one of these sources could terminate a critical life-support system.

Wireless networking in any environment today involves many often non-interoperable systems working on different carrier frequencies, and protocols. What is needed is some interpreter that accepts multiple frequencies and protocols from various devices – no matter which vendor or application, and converts them to a common data model, regardless of heritage. Some of the protocols include Ethernet, IEEE 802.11 (WiFi), 802.16 (WiMAX), 802.15.4 (Zigbee), plus RFID, VoIP, and other proprietary/vendor specific protocols, along with associated network security issues.

The same interoperability issues are also challenging traditional emergency response and noted in the 9-11 commission (http://www.gpoaccess.gov/911/index.html) and Rand studies (http://vivisimo.rand.org/vivisimo/cgi-bin/query-meta?input-form=simple&query=9-

11+commission). The mining communications industry should work toward conformance to these standards.

From a coal miner survivability standpoint it only makes sense to enable all of the voice communication devices to interact with all other voice systems. This would be especially true during disaster situations. A properly designed system should be capable of providing this ability.

13.0.0 Training and Maintenance

It will take more than a few hand tools and a multimeter to maintain the types of systems being discussed. Technicians will require a broad background knowledge covering communications, control systems, and monitoring systems. Maintenance should be performed on regular intervals, and periodic drills should be conducted to verify the ability of the systems to perform when disasters occur.

14.0.0 Risk Assessment

Any safety system for use in coal mines should evaluated to determine if it posses any risk to miners. This particularly includes communication systems. It is doubtful that a properly conducted risk assessment has ever been conducted on a mine communication system. This reference provides at least preliminary information on safety system risk assessments (Sammarco, 2005).

In order to aide in risk assessments, guidance on the impact on wireless signals due to noise sources, geology, mine entry geometry, and mine infrastructure is needed. The many research projects completed by the USBM in the 70's did, identify, characterize, and document that kind of information. Future research could expand this knowledge base. NIOSH is presently creating a prototype web page containing the USBM information.

15.0.0 Summary

It is clear that much work needs to be done to improve the state of UG coal mine communication system design in the United States. Systems already in place in mines should be evaluated and brought up to an acceptable level of reliability. New mine designs should incorporate most, if not all, of the ideas highlighted in this document. Signal propagation measurements should be made both in mines and TTE to determine what signals best suit the given environment. EMI sources should be identified and eliminated or suppressed to an acceptable level. Systems should be designed and custom engineered, based on the unique character of the given mine environment. Interoperability should be stressed through all communication links whether they carry voice or other data. Previous and present technology should be reviewed and applied as defined by the system needs. Risk assessments and disaster scenarios should be performed to highlight any insufficiencies in the final system design. Training and maintenance should given priority status in order to keep mine communications systems functioning, especially during disasters.

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