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Strategies for Escape and Rescue from Underground Coal Mines

Department of Health and Human Services
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National Institute for Occupational Safety and Health

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RESEARCH REPORT ON STRATEGIES FOR ESCAPE AND RESCUE FROM UNDERGROUND COAL MINES

By Danrick W. Alexander, Susan B. Bealko, Michael J. Brnich, Kathleen M. Kowalski-Trakofler, Robert H. Peters

DEPARTMENT OF HEALTH AND HUMAN SERVICES
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ACRONYMS AND ABBREVIATIONS USED IN THIS REPORT

ABET	Accreditation Board for Engineering and Technology
CABA	Compressed Air Breathing Apparatus
CDC	Centers for Disease Control
COPE	Care of Pressurized Employees
CPR	Cardiopulmonary resuscitation
DHHS	Department of Health and Human Services
DHS	Department of Homeland Security
EMT	Emergency Medical Technician
ERP	Emergency Response Plan
FEMA	Federal Emergency Management Agency
GAO	General Accountability Office
H&S	Health and Safety
IASC	Inter-Agency Standing Committee
ICS	Incident Command System
ISO	International Organization for Standardization
MECS	Mine Emergency Command System
MER	Mine Emergency Response
MERD	Management Emergency Response Development
MERITS	Mine Emergency Response Interactive Training Simulation
MHRA	Major Hazard Risk Analysis
MINER Act	Mine Improvement and New Emergency Response Act of 2006
MSHA	Mine Safety and Health Administration
MST&TC	The Mine Safety Technology and Training Commission
NIMS	National Incident Management System
NIOSH	National Institute for Occupational Safety and Health
NTSB	National Transportation Safety Board
PTSD	Post-Traumatic Stress Disorder
RA/RM	Risk Assessment/Risk Management
SCSR	Self-Contained Self-Rescuer
SAMHSA	Substance Abuse and Mental Health Services Administration
UMWA	United Mine Workers of America

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot
lb	pound

RESEARCH REPORT ON STRATEGIES FOR ESCAPE AND RESCUE FROM UNDERGROUND COAL MINES

By Danrick W. Alexander, Ph.D.,[1] Susan B. Bealko,[2] Michael J. Brnich,[1] Kathleen M. Kowalski-Trakofler, Ph.D.,[3] Robert H. Peters[4]

1.0 Purpose and Scope

Section 2 of the Mine Improvement and New Emergency Response Act of 2006 (2006 MINER Act), Public Law 109-236, [MINER Act 2006] directed operators of underground coal mines to improve accident preparedness and response. This report summarizes the findings of research conducted by the National Institute for Occupational Safety and Health (NIOSH) between December 2007 and March 2009 to identify the attributes of an improved escape and rescue system. This report focuses on specific guidelines for escape and rescue from underground coal mines during fire and explosion incidents and contains an investigation of United States and worldwide mine practices. The basic elements of a mine emergency response system (escape, rescue, and incident command) are addressed. Further, knowledge gaps, training, human behavior, and technology challenges are also identified. This report presents a strategy of self-escape and safe-rescue[5] including incident command as an integrated system with consideration given to U.S. underground coal mine demographics. The findings are intended to facilitate the evolution of all miners' capabilities and support institutions so that they will have a greater chance of successfully managing abnormal incidents without injury or fatalities.

2.0 Escape and Rescue Introduction

A systematic self-escape and safe-rescue strategy is necessary when mine emergency incidents such as fires or explosions occur and lives are in danger. Miners have not always escaped U.S. coal mine accidents and rescuers have not always reached trapped or barricaded miners in time to save their lives. Therefore, continued research and efforts need to be made to improve mine emergency response including improvements in training, behavior, and technology. Human behavioral health factors and training penetrate every aspect of mine escape and rescue. The mining industry is lagging behind the rest of the U.S. emergency response community in the incorporation of behavioral research into pre-event, event, and post-event interventions. In particular, the training delivery mechanisms and assessment tools need to be improved. The objective is to have a better training and preparation system that results in the following outcomes:

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[4] Team Leader, Office of Mine Safety and Health Research, National Institute for Occupational Safety and Health, Pittsburgh, PA.
[5] Note that "self" is added to escape to emphasize that successful escape is dependent on the individual skills and resiliency of each miner. Likewise "safe" rescue is used to stress that the safety of the rescue team is the first priority. By extension, incident command contributes to maintaining safe conditions.

a) **Self-Escape:** Resilient[6] miners who are equipped and capable of timely self-escape under adverse conditions and hazardous atmospheres and who can act as first responders that can safely and knowledgably assist others to escape and can mitigate limited hazardous conditions until help arrives;

b) **Safe-Rescue:** Mine rescue teams who are equipped and capable of rapid, state-of-the-art safe-rescue in irrespirable mine environments and are ready to respond quickly;

c) **Incident Command:** Incident command centers and emergency response systems, under the direction of a single professional with qualified advisors, who are prepared and competent to manage a rapid, dynamic decision-making process and to direct a multi-faceted response team.

Figure 1 gives a visual illustration of both the current status and the vision for the future of these three outcomes of coal mine emergency response supported by training, preparation, and positive human behavior. Current status is shown on the left and can be characterized by the following description of what is needed:

Self-Escape skills are improving, but the emphasis on developing individual miner evacuation skills has not received the resources nor the attention needed (extend the short leg of the stool).

Safe-Rescue is functional but has wide variations between individual team capabilities. Rescue would benefit from better prioritization, combining of resources, and a focus on real-life training and rapid response methods rather than contests, while maintaining the safety of rescuers (strengthen the weak part of the leg).

Incident Command is broken; it is neither well-defined, consistent with non-mining national practice, nor are managers and technical advisors taught thoroughly or drilled regularly throughout the industry as is needed to be effective during an incident. Incident command requires renewed commitment (fix the broken leg).

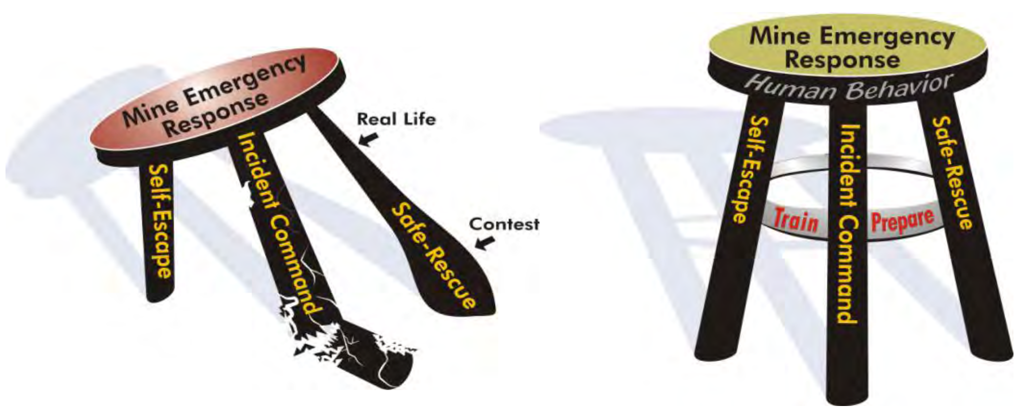

Figure 1--Coal mine emergency response is conceptually shown as a broken or weakened three-legged stool on the left to represent current status and a well-balanced solid stool on the right depicting the long term goal for the U.S. emergency management system.

[6] **Resilience** – the ability of an individual or organization to both withstand significant adversity and to "bounce back" after a trauma. Resilience has been described as a dynamic process of healthy adaptation in adversity.

The NIOSH vision for mine emergency response (shown as the stool on the right of Figure 1) requires a foundation of training and preparation using effective human behavior principles so that all three components will be effective, functional, and strongly supported by the coal mining operators, labor, regulatory agencies, and research. The overarching goal is a robust, resilient emergency response system that best meets the survival needs of injured, trapped, or endangered miners.

3.0 Research Activities

A literature survey was performed to identify past research findings on escape and rescue and topics related to emergency response, confined space rescue, mine refuge, mine disasters, escape behaviors, psychological issues, and escape and rescue practices outside of the mining industry. Visits were made to mines, nationally and internationally, and meetings were held with mining experts from labor, industry, and government in the United States, Australia, and South Africa to collect information on escape and rescue procedures. The Mine Safety Technology and Training Commission report [MST&TC 2006] and the Mine Rescue Handbook [NMA 2007] were also valuable benchmarks.

Based on the above work, we found that research on current mining practices and the results of changes brought about by enactment of the 2006 MINER Act are lacking. Therefore, to accurately assess current U.S. stakeholder needs, issues, and concerns, stakeholder meetings were conducted across the country from December 2007 through March 2008 and a report on mine rescue practices was contracted [Lazzara 2008]. A total of 70 emergency response experts including personnel from 51 large and small mining companies and five state agencies were represented at seven regional meetings, followed by multiple individual interviews and 10 training facility visits. Fourteen of the 17 underground coal mining states were visited. Table 1 shows the U.S. meeting locations, mining entities and states represented during this investigation. The emergency response experts included mine rescue team trainers, mine operators, state agencies, mine rescue team members, corporate personnel, safety and fire prevention officers and responsible persons, who in combination have experience in mine rescue, incident command, and mine emergency response.

Table 1-- Listing of meeting locations, mining entities, and states represented at the seven emergency response expert stakeholder meetings.

Meeting	Location	Entities Represented	States
1	Southwestern PA	Large Coal Mine Operators	WV, MD, PA, OH
2	Southwestern PA	Small Coal Mine Operators	WV, PA, OH
3	Southwestern PA	State Mine Regulators	PA
4	Southern WV	Large & Small Mine Operators, Academia, Safety Trainer	KY, VA, WV, AL
5	Western US	Large & Small Coal Mine Operators, State Regulators, N/NM Mine Operators	CO, UT, NM, WY
6	Midwest US	Large & Small Coal Mine Operators	IN, IL
7	Midwest US	State Regulators	IN, IL

Concurrently, contract research studies to identify existing international practices, regulations, and technology were conducted for Australia [Galvin 2008], South Africa [Marx et al. 2008], China [Wu and Gray 2008], and Eastern Europe (Ukraine, Poland, and Russia) [Pavlovich 2008]. These countries represent nearly 75% of global coal production.[7]

In addition, NIOSH researchers contracted for two academic research reports that highlighted the lack of applied human behavior principles in mining. The first was prepared by Johns Hopkins' Center for Public Health Preparedness [Everly et al. 2008] on the psychological aspects of escape and rescue strategies. The second drew on research experience at The Institute of Crisis, Disaster, and Risk Management at The George Washington University on human escape and rescue outside of the mining industry [Harrald et al. 2008]. Five special topic reports on refuge, intrinsic safety, risk, air monitoring, and communications were provided by NIOSH researchers. Overall, NIOSH researchers studied a range of practical issues associated with mine emergency response, alternative methods for training, and procedures used in actual emergency incidents.

3.1 Report Format

The remainder of this report summarizes the findings of the research, and it is organized into the categories of mine emergency preparedness, escape strategy, rescue strategy, incident command, and training. Human behavioral health factors have been integrated into each section because they affect all aspects of human interaction and performance and are critical to a successful "no harm" outcome. Detailed supporting information and key references are included in the NIOSH Docket #154. The docket can be accessed at http://www.cdc.gov/niosh/docket.

4.0 Mine Emergency Preparedness: Non-Mining, International, and U.S. Practices

When the U.S. Bureau of Mines was created in 1910 because of the regular occurrence of catastrophic disasters, miners were not well-prepared to escape in an emergency. They were not trained in escape methods; designated escapeways were not identified and were not isolated; long-term respiratory protection equipment was not available to protect miners from "black damp," explosive gases, or lack of oxygen commonly found in underground coal mines. Miners escaped by finding their own way out and if trapped by a fire or explosion, were told to "barricade" – i.e., to isolate themselves from the potentially poisonous environment and await rescue. Fortunately, great progress has been made in the last century in emergency preparedness, including mine planning, basic escape training, and technology components such as breathing apparatus, communications systems, zone tracking, multi-gas detectors, and directional escapeway lifelines. Along with these advances, non-mining and international practices offer a number of lessons about emergency preparedness that are worth describing here.

4.1 Non-Mining Practices

Research or technology transfer into the overall U.S. mine emergency response system[8] has been found to be lacking in comparison to non-mining industries and the mining practices in some other countries. A NIOSH academic contract with The George Washington University

[7] Based on data from BP Statistical Review of World Energy June 2008. www.bp.com/statsticalreview
[8] This research includes collaborative planning organizations that determine the best procedures and the application and dissemination of existing knowledge and awareness of non-mining or international best practices.

examined current strategies and practices used in the United States in other industries and in the military [Harrald et al. 2008]. Issues studied included: 1) personnel/human behavior; 2) command center and control room; 3) rescue team and first responders; and 4) standardization of emergency language, symbols, and training practices. In brief, the relevant findings are as follows:

a) The literature strongly argues that attention must be given to organizational and behavioral issues such as team resource management, inter- and intra-organizational communication, organizational improvisation, stress management, personal leadership, and emotional intelligence.

b) Progress is being made in the development of technology to support confined space evacuation and search and rescue operations. These advances include innovative methods of combining sensors with intelligent technology, development of remotely operated vehicles, guiding evacuees using sound, and improved communication technology. Unfortunately, few of these technologies are usable in U.S. coal mines. Non-mining technology is often unable to be incorporated into the underground mining environment because these newer technologies are not approved for use in underground coal mines.

c) The development of standards has become a critical part of the evolution of emergency and safety management. Standardization can greatly improve communications, inter-agency interaction and decision-making.

d) Adoption of a consistent model for working with the community or emergency response personnel has been found to benefit the non-mining industry by drawing on resources and expertise not always available during an emergency, e.g. at a remote mine site. Some mining states, such as Pennsylvania with its Mine Families First legislation[9], are looking into ways to address the needs of mine families and community during a mine disaster.[10]

Mining emergency preparedness, in regards to these findings, is lacking in many areas including organizational and behavioral issues, technology, alternative compliance practices, and a standard mine emergency response model. The logistics and environment of coal mines differs from those in other industries, creating unique and complicated challenges to overcome. Most underground work areas are remote, confined, dark, dusty, and perhaps wet, humid, or cold. They are also subject to changing conditions as the rock and coal deteriorate, seasons change, and new openings are mined. Because of this, a higher level of prevention and response skill is required within the mine workforce. According to Conti et al. [2005], miners must be prepared to respond quickly because early stage decisions and actions greatly influence the outcome. A well-prepared workforce can limit the consequences of an incident and return the operation back to normal faster than an unprepared group.

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9 The Pennsylvania Department of Environmental Protection, Bureau of Mine Safety with assistance from the Mine Families First Response and Communications Advisory Council issued a *Response and Communications Implementation Plan* on November 5, 2008 as required under the October 4, 2007 „Mine Families First Act' to provide assistance to family members of persons who are trapped or awaiting rescue during an underground emergency.

10 The MINER Act requires MSHA to serve as the primary communicator with the operator, miners' families, the press, and the public for mine tragedies involving multiple deaths. In addition the Response and Preparedness Plan must have a local coordination component that sets out procedures for coordination and communication between the operator, mine rescue teams, and local emergency response personnel.

4.2 International Practices

International practices, regulations, and technology identified by contract research studies and visits reveal significant contrasts with U.S. practices and response philosophies related to:

a) The systematic application of risk management for emergency response to identify hazards, assess their consequences and likelihoods, and mitigate their impacts rather than, or in addition to, prescriptive compliance-based enforcement.

b) regional mine rescue training centers with standardized emergency response skills requirements.

c) Competency-based training.

d) Alternative incident command lines of authority and responsibility used during underground coal mine emergencies.

e) Level of stakeholder involvement and cooperation.

As background, the 1995 Leon Commission in South Africa, the 1972 Robens report in the UK, and the 1996 Wardens Inquiry in Australia were conducted following major incidents and loss of life. These reports concluded that prescriptive style legislation and regulation does not provide a concise, up-to-date, proactive, or integrated safety system [Galvin 2008, Marx et al. 2008]. With regard to escape and rescue, a decade ago Australia and South Africa decided to change their emergency response approach to emphasize strong prevention cultures, competency-based training, integrated centrally trained mine rescue teams, and the application of risk management to develop systematic evacuation and response plans.

Based on a 40-year review of emergency incidents, Australia concluded that "survivors of major incidents usually rescue themselves" [Galvin 2008], hence the current emphasis on self-escape, in-seam aided escape, and in-seam response.[11] Workplace health and safety legislation requires an employee be protected from unacceptable risk through the "Duty of Care" obligations of the mine operator. Detailed codes of practice are developed by the mine operators in consultation with all stakeholders to incorporate best practices. Self-escape training and in-mine drills are provided regularly as an outgrowth of effective risk management. The mine's rescue employees are not only trained in rescue methods but are also working in the mine where they can respond directly to an emerging problem or assist others.

China and Eastern Europe use well-trained and capable, professional mine rescue teams and do much less individual escape planning or training. They respond to many incidents each year and report saving hundreds to thousands of miners annually.

4.3 U.S. Practices

The coal mining industry does not agree upon a standard mine emergency response model and therefore there are differences in practice and in regular training of emergency response personnel. One of the initial tasks in preparing for an emergency is to understand how an integrated response will evolve. Mine emergency response involves more than just escape or

[11] In-seam response includes any group of miners who are inside the mine at the time the incident is discovered and who are directed or choose to render assistance to mitigate the problem.

rescue; it is a continuous effort to prevent harm and save lives. The complete mine emergency response process includes training and planning, preparation, self-escape, assisted-escape, safe-rescue, incident command, assessment, feedback, and improvement. Each of these issues will be discussed in more detail later in the report with specific emphasis on self-escape, safe-rescue, incident command, and training.

The Mine Emergency Command System (MECS)[12] divides emergency response into three stages. It is assumed that all participants are trained in the MECS system and that the mine is prepared for MECS to be conducted successfully in an emergency. Section 7 of this report discusses current incident command deficiencies identified in this research. The MECS Stage I follows an event from detection through first responders' early decisions and actions. The Responsible Person or alternate must quickly identify the problem, provide operational awareness to first responders, and decide what assistance is required or mandated. Stage II begins with evacuation, if needed, and initiation of the mine emergency response plan and notification plan. A local command center is set up and second responders from within the mine may be dispatched. If the first and second responders are not able to provide assisted-escape or control the situation, Stage III is initiated with a fully staffed command center and callout of multiple mine rescue teams.

The assessment, feedback, and improvement processes are critical so that standard operations and training protocols may be improved and the lessons learned incorporated. Following an emergency in a U.S. mine, reports are generated with recommendations, but effective and timely application of those ideas is not apparent. During stakeholder meetings, researchers heard many comments questioning whether or not suggested improvements would be implemented. At present it is unclear whether or not a process is in place to ensure that recommendations are beneficially applied to mine emergency response. A possible model for the assessment of recommendations and incorporation of the best ideas into future training and procedures is demonstrated by the continuous improvement requirement that businesses (e.g. ISO 9000) and educational institutions (ABET EC2000) have adopted.

There is a growing realization that compliance with regulations alone is not sufficient to reach a goal of zero harm in the United States. [Kohler 2008, Harvey 2008]. Escape and rescue regulations alone are believed to be insufficient and it is argued that behavioral health factors have a significant influence on outcomes. More detailed discussions of international and U.S. escape, rescue, and incident command practices are contained in the remainder of this report and the Docket #154-items.

5.0 Escape Strategy and Behavioral Health Factors

5.1 Introduction

The basic premise of escaping an underground coal mine in an emergency has changed little in the past century. In short, miners have been taught to make every attempt to escape if

[12] MECS was adapted for mine use by MSHA Mine Emergency Operations (MEO) in 1994 from the national Incident Control System (ICS) and published by the National Mine Rescue Association and the Mine Rescue Veterans of the Pittsburgh District (Issue #3, September 1994, Issues Committee Report, National Mine Rescue Association). MECS is used today by MSHA in IG 110 and in the mandated training of responsible persons. See Section 7: Incident Command for more detail.

there is an emergency such as a mine fire or explosion, following the designated escapeways to safety. If escape is impossible, miners have been trained to seek temporary safety by erecting a barricade and awaiting rescue.

The need to escape an underground coal mine in case of a fire or explosion is a prospect miners have faced since the beginning of underground mining. Previous research has shown that a substantial number of miners may face the need to escape a mine fire at some point in their career. A 1996 study conducted at seven U.S. underground coal mines, focusing on underground miners' preparedness to respond to a fire, revealed that 38% of 180 miners interviewed had needed to evacuate from a mine because of a fire. In addition, 21% said they had donned either a self-contained self-rescuer (SCSR) or filter self-rescuer sometime in their career because of a fire [Vaught et al. 1996].

The 2006 incidents at the Sago, Alma, and Darby mines raised a number of issues about mine emergency preparedness and response, particularly as they relate to: 1) miners' donning of and expectations when wearing an SCSR and the need to switch to additional SCSR units for escape; 2) miners' judgment and decision-making processes under the stress and uncertainty of a mine escape; 3) emergency communications, including equipment, and the transmission of appropriate important information; 4) the layout and marking of emergency escapeways in mines (recently addressed by regulation) and miners' familiarity with escape procedures; 5) wayfinding and navigation in smoke; 6) the psycho-social aspects of mine emergency escape and response; and 7) evaluation of mine emergency training programs [Gates et al. 2007, Light et al. 2007, Murray et al. 2007]. Ironically, many of these issues, or subsets of them, are not new and have been identified in previous research on self-rescue and escape [Vaught et al. 2000, 1993], including those related to human response such as individual and group behavior, judgment and decision-making skills, warnings and communication, and wayfinding and leadership in escape. Previous research has also looked at judgment and decision-making under stress in the context of a variety of emergencies [Kowalski et al. 2003]. It is only within the context of the 2006 mine incidents that these concerns have once again been brought to the forefront.

5.2 Current U.S. Approach to Mine Escape Strategy

For decades the U.S. underground coal mining industry approach to escape has largely focused on the individual components that make up the broad concept of mine escape. These include, but are not limited to, elements such as recognition of the hazard, emergency communications, SCSR training, escapeway markings and routes, wayfinding, and the use of refuge or safe havens. In the aftermath of a major mine fire or explosion, in which miners failed to escape or had difficulty escaping, new regulations were enacted to address specific escape-related issues.

The overall response to the mine incidents of 2006 reflects this component-based approach. New legislation encompassed in the 2006 MINER Act and related regulations required quarterly hands-on SCSR and escape training; caches of additional SCSRs located along escapeways; availability of gas detectors; installation of directional lifelines; installation of refuge chambers/alternatives; creation of mine Emergency Response Plans (ERP); and development and installation of wireless communication and tracking systems [MINER Act 2006]. To this end, mining companies have been pursuing training and technologies focusing on meeting these regulatory requirements. This incremental approach has also been supported by the manner in which mine research projects have been conducted. While the individual changes are often grounded in findings from previous mine escape research [Vaught et al. 2000, 1993; Conti 2001; Kowalski et al. 2003; Conti et al. 2005], the concept of an overall, integrated approach to escape and evaluation of escape as a system has not been thoroughly investigated. Although mines are required to have ERPs, NIOSH found no evidence that identifies how well mine personnel can utilize the information contained in the ERPs. The Mine Safety and Health Administration (MSHA) reviews the ERPs regularly and miners complete quarterly evacuations, but further investigation and training is needed to see how well ERPs are utilized during a mine emergency response drill. Verifying that the parts of the plan exist is only the first step.

5.2.1 Self-Escape Training

Presently very little data exists about the methods used or how U.S. underground coal mines are complying with the 2006 MINER Act regulations with regard to SCSR and escape training and the use of refuge alternatives. Previous research has demonstrated that quality, performance-based training is key to successful self-escape [Vaught et al. 1993, 2000]. However, the authors are unaware of any research studies that have assessed how mines are complying with the new regulations, particularly regarding how operators are assessing trainee competency in self-escape and the use of refuge alternatives.

NIOSH stakeholder meetings conducted in all major coal mining areas of the United States identified that most operator efforts were dedicated to complying with the new regulations. Thousands of new SCSRs with a shelf life of at least 10 years were purchased to meet the requirements of the Act. However, there has not been sufficient time to evaluate the effectiveness of these efforts or to standardize best practices. Training will be discussed in more detail in Section 8.

Self-Contained Self-Rescuers and Compressed Air Breathing Apparatus

In an emergency situation, miners are instructed to don SCSRs completely when smoke is seen, smelled, or combustion gases are detected. However, miners have been known to remove their mouthpieces to talk and even breathe if they believed they were not getting enough air from their SCSR. A study of worker behavior in mine fires revealed that 29 of 48 miners (60.4%) reported difficulty breathing while wearing their apparatus. Of this group, 27 of the 29 (93%) partially removed the mouthpiece in the presence of smoke to get more air [Vaught et al. 2000]. The fact that more than 50% of miners endangered themselves during real emergencies suggests that adequate training was not accomplished and that there were fundamental human behavior problems with past application of SCSR technology.

On the positive side, qualitative evidence collected from more than 70 coal industry emergency response stakeholders across the United States revealed the mandatory quarterly SCSR donning and expectations training are having a positive effect on miners. Mines are using live SCSRs, SCSR training mouthpieces, standard SCSR training units, or realistic training simulators which provide several minutes of oxygen, present breathing resistance, and generate heat. Data collected from stakeholders indicates that miners are now more confident in their abilities to don SCSRs and escape in an emergency.

Discussions with stakeholders indicated that miners are still having difficulty switching from one SCSR to another. Stakeholders reported that this issue is particularly a problem at mines that have different models of SCSRs. A new generation hybrid/dockable SCSR that will allow miners to switch out oxygen sources without having to remove the SCSR mouthpiece is being investigated by NIOSH. Yet, with any SCSR, the problem of verbally communicating still exists for the miner while wearing a mouthpiece. Communication is a critical function during escape that is not now being supported while the SCSR is being worn.

The use of a compressed air breathing apparatus (CABA) for escape is a relatively new approach for U.S. mines, although it is clearly described and supported in the 2006 MST&TC report [MST&TC 2006]. Several underground mines in Australia have installed CABA systems to aid escaping miners and enhance the capability of in-seam responders [Galvin 2008]. The San Juan Mine in New Mexico has a combined SCSR and CABA plan approved by MSHA in 2007, but no guidance has been issued for other mines to use CABA instead of SCSRs. Compared to SCSRs, which have a one-hour duration and require the user to breathe through a mouthpiece, CABAs can be recharged at outby refill locations without breaking the mask seal, provide air on demand without resistance, and utilize full-face masks that allow wearers to verbally communicate while under air. NIOSH is conducting research to assess and adapt CABAs and other technologies that allow high quality 2-way communications and to determine how they can be integrated into mine escape systems.

Escape Drills

Generally, stakeholders believe that mine escape training is better than it has ever been in the past. Some, however, expressed concern that the mandated quarterly escape drills are time consuming to plan and conduct, especially if mines are to simulate actual conditions. This same concern was borne out in a U.S. General Accountability Office (GAO) report on a survey of 342 underground coal mines in the United States regarding mine emergency response issues [GAO 2007]. Many stakeholders also said they struggle with developing acceptable and appropriate content for quarterly escape training. Quarterly training on SCSRs and escape is essential for miners to maintain adequate skills. To this end, instructional materials and competency evaluation instruments should be developed to assist mine operators.

Some mine stakeholders have reported to NIOSH that required escape training is also physically difficult, especially for miners who are not in the best physical condition and/or who have to escape in low coal. The present U.S. strategy for the location of SCSR caches is based on the average distance miners can travel in 30 minutes as estimated by MSHA using a one-hour rated SCSR. Australian practice is to locate caches the maximum distance the slowest miner on the crew can travel in a specified period of time. South African mines determine distances based on detailed calculations which account for SCSR capacity, seam height and pitch, and the inhalation volume needed by the SCSR wearer. All approaches allow a safety factor to be built in to ensure that miners will not run out of oxygen before reaching safety.

U.S. stakeholders feel that the mandated quarterly escape drills are effective in helping miners learn their escapeways but may not help them decide when to escape, how to safely assemble and find the escapeway entrance in limited visibility, or to learn the skill of wayfinding. As with SCSR training, there is a clear need to audit whether or not regulatory mandates on escape and evacuation are sufficient to adequately prepare miners for emergencies.

Refuge Alternatives

The introduction of refuge alternatives into the mine escape equation as mandated by the 2006 MINER Act has been controversial and raises the issue of how refuge alternatives should be incorporated into mine escape strategy. A recent NIOSH study [NIOSH 2007] of refuge alternatives assessed a number of issues associated with implementing them in underground coal mines. NIOSH concluded that refuge alternatives, to facilitate escape and serve as a last resort for refuge, are practical for use in most underground coal mines. The study also looked at training for refuge alternatives. NIOSH concluded that mandatory training in the use of refuge alternatives should be given quarterly and integrated with mandatory evacuation drills. Researchers also concluded that miners must receive expectations training on refuge alternatives to address panic, anxiety, behavior in confined spaces, physical reactions to confined space, and to suggest interventions such as breathing techniques and limited space exercises.

In meetings, mine visits, and interviews conducted across the United States, stakeholders were asked how they plan to implement refuge chambers in their mines. Overall, operators want miners to escape rather than choose refuge alternatives. Stakeholders said they are training miners to use refuge chambers as a last resort during escape, or as a temporary stop-off point to change SCSRs, re-hydrate, rest, and try to obtain more information about the situation. Some stakeholders expressed concern that refuge alternatives may give miners a false sense of security in the event of a mine fire or explosion. Some also felt that having refuge alternatives available may cause miners to erroneously choose to wait for rescue when they could have escaped. In response, NIOSH researchers have completed a training exercise to aid miners in the judgment and decision-making process when deciding whether to seek refuge [Vaught et al. 2009].

The introduction of refuge chambers into underground coal mines has created important psychological considerations for the safety and health of the mining population, raising the following questions: 1) What supplies are important for maintaining physical and emotional health of the miner while in the chamber? 2) How will the miners interact over a 96-hour period in the confined space? and 3) Under what conditions might miners leave the refuge alternative given conditions both internal and external to the unit?

If miners elect to stay in a refuge chamber, they must have confidence that someone will rescue them or that they have no other alternative for escape. Mine rescue practice has not been changed to accommodate large numbers of trapped miners. Similarly, airlocks are not designed for stretchers or rescuers wearing breathing apparatus. South African practice is to use strata[13] chambers first, because their flat-lying shallow seams allow large diameter drills to be used during a rescue mission. A drill and escape capsule was successfully used at Quecreek in 2002; however, many U.S. underground mines have less favorable access according to a NIOSH evaluation of surface seismic array sites at three mines that have experienced disasters [Lowe et al. 2009]. Therefore, in many circumstances mine rescue teams must be prepared to enter the mine to assist groups of miners who choose to remain in chambers.

[13] Strata chambers are constructed in one location in a mined opening and isolated from the mine atmosphere with airlock seals.

As described above, there are circumstances where it may be desirable to use a refuge chamber first. Immediate escape to the outside may not be the best philosophy for all mines in the United States since there is tremendous variability in mine size, depth of cover, seam height, and topography. A combination escape/rescue philosophy may have a lower overall risk level than escape only, and different solutions may be needed at different mines. This is an example of a question that could be answered by a comprehensive risk assessment.

5.2.2 Integration of Communications and Tracking Systems

Recent mine disasters underscored the need for robust two-way communications between underground miners, outside personnel, rescuers, and emergency command centers. The 2006 MINER Act required that all underground coal mines, by June 2009, designate revisions to the Emergency Response Plan to incorporate wireless two-way communication systems that provide post-accident communications between the underground and the surface, and tracking systems to aid in locating miners at all times while underground [MINER Act 2006]. These systems must be capable of surviving an explosion, fire, or roof fall, and remain operational for a period of time following such an incident.

There are a number of technical issues with communications and tracking systems which are beyond the scope of this report [Gürtunca 2008, Kohler 2007]. However, there is clearly a need to understand how miners behave during emergencies and what information and communication functions are necessary to support their rapid evacuation. It is also important to understand how communication systems will affect miners' self-escape efforts. Therefore, certain information useful to help miners make informed escape decisions must be readily available and deliverable to the miners. As such, miners should demonstrate competency in giving and receiving emergency warning messages. One demonstrated method is the "Emergency Communication Triangle" discussed in Mallett et al. [1999].

In addition, responsible persons or their delegates, who are in a position to provide this timely information, must focus on the proper use of communication and tracking systems. Observations of miners using hand-held two-way radios, who seldom if ever used a radio, suggest the need for basic training in radio use. Miners, supervisors, communication and/or control room attendants, and others must be competent in how to properly locate, operate, and maintain in-place communication and tracking systems and to convey the appropriate content in an emergency message. Utilizing the same system in an emergency as in day-to-day operations would provide an obvious advantage of familiarity.

Finally, there is still the issue of how miners are to effectively communicate using new communication technologies while wearing an SCSR with a mouthpiece. Unless a solution for talking while wearing an SCSR mouthpiece is found, communications will be severely compromised during an evacuation. Once the SCSR is donned, miners are not able to verbally communicate with each other, let alone engage in two-way communications with outside personnel or emergency responders. Substitutes for speech such as using hand signals and written notes between miners or Morse code taps on a microphone are not sufficient to adequately interact with others, to inform a group of the situation, or to determine an optimum escape process. NIOSH is researching methods of non-verbal communication in the interim. Several venders have added pre-determined text messages to their communication or tracking devices. One offers a QWERTY keyboard so any message may be sent. Only CABA units, with a full-face mask, allow two-way conversation between miners or when using a communication device such as a hand-held radio.

5.3 Behavioral Health Factors

There has been extensive research on behavior in escape and rescue, especially since the attack on the New York World Trade Center, 9/11/01. Earlier in this section the authors mentioned expectations training, the judgment decision-making process, communication, and the need for attention to the psycho-social consequences of mine disasters. These are all behavioral health factors, as are issues of leadership, decision-making, and fatigue referred to in the sections on rescue and incident command. The mining industry is lagging behind the rest of the U.S. emergency response community in the incorporation of behavioral research into pre-event, event, and post event interventions.

Humans are efficient survival machines, individually and in groups. Survival is accomplished, not by brute strength or avoidance, but by the ability to cope with a potentially hostile environment by recognizing and solving problems. Today's terminology sometimes refers to this construct as *resilience* – defined earlier as the ability of an individual or organization to both withstand significant adversity and to "bounce back" after a trauma. Resilience is multidimensional and involves personal, organizational, and environmental factors including hardiness, flexibility, optimism, and availability of social resources, sense of connectedness and support, and overall intelligence. Resilience is emerging as an umbrella concept for positive behavioral emergency response, with identifiable factors that are applicable to improved escape and rescue strategies [Reissman et al. 2004]. Developing resilient miners able to self-escape is one of the three components this research project has determined is needed to improve emergency response in the U.S. underground coal industry. Non-mining research is defining the components of resilience with the premise that resilience can be taught.

5.3.1 NIOSH 2008 International Contract Reports

The reports on South Africa, China, Poland, the Ukraine, and Russia produced under contract for NIOSH for this project offered little in the way of further information on behavioral strategies for escape and rescue. The Australian report, on the other hand, offered an empirically based behavioral intervention that has been in practice for a number of years, that of *self-escape*. In a mine emergency, self-escape places the emphasis on the skills of the individual miner, providing each miner with sophisticated training, strategies, and practice in escape. Emphasis on enhancing the escape skills of every miner has been successful in other countries, specifically Australia. It has been introduced in South Africa and now, as required by the MINER Act, the United States is moving in the same direction.

South Africa has a trauma management program ("COPE," for Care of Pressurized Employees) developed by the employee assistance program at the Chamber of Mines to respond to mining workplace accidents. The guiding principles of the program include the belief that psychological trauma should be given the same consideration as physical trauma and that the program must be voluntary and confidential such that participation cannot affect promotion potential. The program also provides supervisor training to help identify potential post-traumatic stress disorder (PTSD) cases based on changes in work performance. The program identifies three levels of intervention: individual major incident, individual minor incident, and widespread incident. Each of these types has a particular methodology associated with it [Maiden 2005].

5.3.2 Previous NIOSH Studies

NIOSH research on behavior in mine escapes includes interviews with miners who escaped from fires while wearing emergency breathing apparatus. Researchers examined individual and group behavior, judgment and decision-making skills, warnings and communication, wayfinding, and leadership in escape. The psychological effects of trauma outside mining were studied and the findings applied to various mining investigations and training. Analysis of the present status of programs in the industry, reflected by this research, indicates that the dissemination of behavioral health information is definitely limited and not well-represented in training and policies in the U.S. mining industry.

The conclusion in the 2000 NIOSH publication *Behavioral and Organizational Dimensions of Underground Mine Fires* [Vaught et al. 2000] was that "There seems to be too much dependence on engineering hardware solutions without a concomitant understanding of how miners will use these systems." After Sago in 2006, researchers were quick to analyze the root cause of the explosion, but without trying to understand the behavior of the miners reflected in their decisions to barricade and to remove and/or share some of the self-contained self-rescuers (SCSR). The sole survivor reported that four of the units did not work, yet NIOSH tests indicated the SCSRs were functional and had not been used to capacity. This data supports the hypothesis that the miners may have removed their SCSRs thinking the units did not work. In addition, it is important to continue random field tests of SCSR units for defects.

Previous NIOSH research clearly indicates that donning and using SCSRs has been problematic for miners who escaped mine fires [Vaught et al. 1993, 2000]. An important finding from this research is the notion that miners felt their SCSRs were not properly functioning during escape. As such it is imperative that miners receive quality, hands-on training in donning the apparatus coupled with expectations training to aid them in understanding what it is like to breathe from a unit. MSHA, based on NIOSH research, addressed these two important issues in its final rule on escape and evacuation.

NIOSH completed one study after Sago to determine realistic miner expectations while donning and wearing these units, identifying nine key areas representing issues that might influence a miner to remove his/her breathing apparatus. This study resulted in a new NIOSH training program focusing on expectations training [Kowalski-Trakofler et al. 2008].

NIOSH research and other research in this area suggest four human factor themes of importance to consider in mine disasters. First, the literature asserts that *human decision-making processes must be taken into consideration*. In 2001 at the Jim Walter Resources No. 5 mine, after the first explosion, a number of miners decided to head to the area where they thought their buddies were down, only to be killed in a second explosion. Their judgments were based on misinformation or lack of information. In this case, miners made judgments and decisions that affected their safety. In the Sago event, it is believed that miners were exposed to high CO before donning their SCSRs. The effects of high levels of CO may have affected miners' judgments and decisions. Studying the human aspects of incidents provides data for prevention, strategies for escape and rescue, and identifies skills and interventions for training.

A second theme is the issue of *communication behavior*. Experts in mine emergency response and miners who had experienced escape under duress were interviewed concerning the critical first moments of a mine fire. The number one issue mentioned was communication. Earlier the authors discussed the importance of human communication and cited examples of situations when miners took their mouthpieces out to talk. The miners noted that technology was important, but issues of trust, leadership, pre-planning, and training on how to communicate facts about the "who, where, what" of the incident were mentioned repeatedly. The development of non-verbal communication must be a consideration in an escape strategy until better SCSRs are developed. Currently the SCSR mouthpiece prevents verbal communication when it is most needed.

The third behavioral theme is that of people's *reactions once an emergency situation has been identified*. NIOSH work confirms other research in the field of emergency response – i.e. that people in these circumstances tend *not* to panic and they tend to behave as if things are "normal". However, they do have a stress reaction, implying that high stress situations may lead to confusion and poor decision-making, affecting an escape plan and execution. In addition, unofficial leaders emerge from escaping groups. Leadership skills are an important component in escape that can be taught.

It is a common mistake to think that people panic in an emergency, but the data shows that panic happens in a limited number of individuals. The routine roles of individuals tend to be extended in a crisis and thus the social order is maintained. [Johnston and Johnson 1988] "The social behavior and cognitive processing of individuals stays remarkably close to what can be seen in ordinary, daily behavior." [Canter 1990 p. 3] As an example, the "Miracle on the Hudson" River in New York City in 2009 validated the orderly egress of passengers after an emergency aircraft landing in the river. This does not mean individuals are not afraid and may exhibit erratic behavior, but that the tendency in such a situation is to maintain normal behavior and, some research has shown, to help one another. [Sime 1983]

Fourth, *the behavior of people once they reach safety* has been studied. From a psychological perspective, many times the trauma is just beginning when individuals reach safety. In mining, interventions after-the-fact and educational programs begun as part of mine emergency planning on the expected human response in crisis are generally addressed with a referral to the local county mental health office. Unfortunately, local, rural mental health facilities rarely have training in disaster mental health. In some communities, the local Red Cross is available to provide qualified emergency mental health support, but is not present for follow-up. Research in this area has shown that such interventions may mitigate serious emotional, behavioral, physical, and cognitive consequences to personnel. Rescue workers, co-workers, and family members are also subject to the psychological after-effects of a traumatic incident as exemplified by the suicides after the Blacksville No. 1 shaft explosion, Quecreek rescue, and the Sago disaster. Some mining states, such as Pennsylvania with its earlier-mentioned Mine Families First legislation, are looking into ways to address the needs of mine families, recognizing the needs of family and community during a mine disaster.

Suicides and depression can be the result of inadequate psychological support during and after an emergency response. It has been suggested that the most vulnerable time emotionally is from 6 months to one year after the event. There is increased fear of rages, self-destructive behavior, and even suicide. “The despair, the helplessness gets so intense… it bursts out” [Lagnado 2002]. There were suicides in the aftermath of both the Quecreek and Sago events. Two West Virginia miners who were at the site of the Sago Mine disaster committed suicide within about six months of the event. Neither man was blamed in the tragedy nor was it clear why they committed suicide. However, family members claimed that these men were continually bothered by the event. Another suicide victim was the man who surveyed the location to drill at Quecreek, but it is not clear if this played a role in his suicide. These cases support the need for specially trained counselors in disaster mental health. Their services would be beneficial before, during, and after a mine disaster.

5.4 Alternative Approach to Mine Escape

As mentioned earlier, the U.S. underground coal mining industry has approached self-escape in a piecemeal reactionary fashion. A systems approach is necessary for a complete emergency escape program that integrates self-escape, behavioral issues, rescue, and training. Below, Australia is used as an example of a systems based approach.

Before 1980, Australia followed a “prescriptive” model of mine safety legislation which sought to specify measures to prevent the reoccurrence of a particular incident or disaster. The 2008 Galvin Report states that this “prescriptive” style of legislation incorporated a number of core provisions for underground coal mining. Some of these have stood the test of time; for example, the requirements for a second means of egress. However, others have become obsolete due to changed circumstances and new technology. Following the Robens’ report [1972] from the UK, the Australian state governments began implementing “enabling” Occupational Health & Safety Legislation for standards of health and safety to be achieved in all workplaces and mandating that risk assessment be used. They introduced “duty of care” legislation and tested it at a few mines in the early 1990s [Poplin 2008]. Beginning in the late 1990s, following 15 fatalities at the 1994 Moura mine explosion and the 1996 Gretley Mine flood, the Australian underground coal industry studied options for managing safety, published in the form of the 1996 Warden’s Inquiry. This changed their emergency response philosophies to include a risk-based system [Galvin 2008] while still keeping an underlying backbone of prescriptive measures that may not be overridden by a risk analysis. As a result of this tripartite review (government, industry, and labor) coal mining legislation was changed (1999 in Queensland and 2001, through 2009 in New South Wales).

Broadly, the leading practice in Australian legislation requires operators not to expose employees to unacceptable levels of health and safety risks. The legislation stipulates that “duty of care” must be satisfied by companies by providing: 1) a safe workplace; 2) a safe system of work; 3) fit-for-purpose equipment; and 4) adequate training, instruction, and supervision [Galvin 2008]. Under this legislation, mine operators are required to consult with employees and conduct risk assessments to identify hazards, rank risks, and implement control strategies. This approach, which places responsibility on the operator, appears to have been extremely effective in reducing the number of mine disasters in Australia.[14]

[14] Australia has experienced no disasters since the 1994 Moura Mine explosion. Australia produces about 20% as much as U.S. underground coal mines and has fewer than 50 large underground coal mines. The U.S. underground coal industry comprises over 600 mines with a wide range of sizes and types, continues to use a command and

The Australian model advocates a limited risk, systems approach to mine health and safety. All mines are required to have a safety and health management system, which includes dedicated personnel to administer it. Australian mines identify potential emergency scenarios and work to minimize probabilities of occurrence as well as severity of the consequences. In terms of self-escape, the risk-based approach aids mines in defining their optimal escape system. This includes such elements as numbers and locations of changeover bays or refuge stations; selection and marking of escapeways; communications equipment and its use; mine environmental monitoring and alarm conditions, training of miners in self-escape and first responders in incident management; and determining the numbers and locations of SCSRs and/or CABA units.

Because the Australian self-escape approach is based on risk assessment/risk management (RA/RM), operators have determined that rapid escape poses the least risk to miners and mine rescue teams because it offers the greatest chance for survival. Therefore, escape is stressed and miners are taught to seek refuge only as a last resort. According to Galvin [2008], there are a limited number of refuge chambers in use in Australian mines. To this end, refuge alternatives may be incorporated into the overall escape system at some mines because they reduce risk; while at others chambers might not be used. They are largely seen as SCSR changeover and way stations for escaping miners. Depending on the location of the mine, standardized mine escape training is provided by mine rescue services personnel (mines in New South Wales) and by mine operators for mines in Queensland. An interesting element of the Australian model is legislation mandating that 5% of the workforce, including contractors, at each mine be trained in mine rescue. As such, miners with this advanced training serve as in-seam responders who can aid escaping miners should they need assistance. They also function as in-mine mentors and escape leaders.

As part of their overall mine emergency response model, all Queensland Australia coal mines conduct annual mine-wide emergency response exercises, known as a Level 2 exercise. One mine is selected annually for a Level 1 mine emergency preparedness exercise. Level 1 drills are unannounced, comprehensive, mine-wide exercises including all external responders that focus on a mine's ability to manage a complex mine emergency. The entire exercise is evaluated by third parties who produce a report and recommendations for improving emergency response, including escape and rescue [Galvin 2008].

South African mines also use a systems approach to self-escape [Marx et al. 2008]. South African mines utilize risk assessment and develop their escape systems based on the outcomes of the risk analysis. Unlike Australian mines, operations in South Africa integrate both escape and refuge into their self-escape system. Miners evacuate to refuge chambers which have pre-drilled 6-in diameter boreholes to the surface. Here they await rescue, which is designed to occur within 24 hours. South African officials feel this approach poses the least risk to escaping miners. Eastern Europe depends mostly on professional rescue teams because miners have few opportunities for escape in mines designed for single-entry development, and rapid response is critical to successful rescues. Chinese practices for escape were not verifiable for this report.

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control, prescriptive regulatory mine safety system, and has had 6 multi-fatality incidents during the same time period (Willow Creek, JWR No. 5, Sago, Alma, Darby, Crandall Canyon). (Data taken from Galvin [2008] and http://www.eia.doe.gov/cneaf/coal/page/acr/table2.html) A study by Poplin et al. [2008] compared rates of change of injury incident rate ratios and found that Queensland and New South Wales improved several times more than the US over the study time from 1996 to 2003.

International practice and recent research suggests that risk assessment/risk management is a tool that can provide benefits during systematic analysis of the individual emergency response needs of each mine. Recent NIOSH research, by means of a case study approach, investigated the utility of using Major Hazard Risk Analysis (MHRA). The study demonstrated that most U.S. mines have the capability to successfully implement MHRA to identify additional prevention controls and recovery methods to lessen the risk of major mining hazards, including those associated with mine escape [Iannacchione et al. 2008]. One case study focused on primary and secondary escapeway integrity at an underground limestone mine that was in compliance with all applicable regulations. The risk analysis team identified and ranked 28 potential hazards along the escapeways. Besides the prevention controls already in place, the team identified 15 new prevention ideas.

5.5 Psychological Aspects

As a result of 9/11 and the Iraq War, the empirical investigations of the consequences of crisis and disaster to personnel, organizations, families, and communities have increased in the past 10 years. Previous studies have documented the nature of the human stress response and the short-term and long-term consequences of exposure to a disaster, usually referred to as a traumatic incident. More recent studies have examined the psychological impact of crisis and disasters on leadership, incident management, families, and communities. Increasingly, behavioral health is part of planning and response in the nation's emergency response system (FEMA, SAMHSA, CDC, DHS) and internationally. The Inter-Agency Standing Committee (IASC) was established in 1992 in response to the United Nations General Assembly Resolution 46/182. The IASC is the primary mechanism for international inter-agency coordination of humanitarian assistance, and in 2008 published *Guidelines for Mental Health and Psychosocial Support in Emergency Settings* [IASC 2008].

The mining industry is just beginning to recognize the need to conceptualize a safety management system incorporating engineering controls; administrative interventions with behavioral health issues including attention to safety culture, judgment and decision-making under duress; command center dynamics; fatigue; community response and pre-, during, and post-psychological support [NMA 2008]. In 2002, two crews of nine miners were inundated in the Quecreek, PA, underground coal mine when the first crew broke through into an adjacent old sealed and flooded mine. The first crew had to be rescued after a three-day ordeal. The second crew barely escaped with their lives. This second crew took part in a critical incident stress de-briefing with trained professionals within several weeks of the incident. Previous data has supported such early intervention in the mitigation of serious psychological side effects after a trauma. Follow-up a year later indicated that eight of the nine miners on the second crew had returned to work at the mine. A number of the miners credited the intervention with helping them resume working in the mining industry.

Although the term "stress" was coined in the 1930s by Dr. Hans Selye and further defined by Nobel Laureate Walter Cannon as the "fight or flight response," the field of disaster mental health has developed within the past 20 years. The severity of the experienced stress response is a function of the interpretation of the event. This understanding supports the need for expectations training to mitigate potential negative cognitive and behavioral reactions such as anxiety, confusion, fear, difficulty in making decisions, sleep disturbance, depression, post traumatic stress disorder (PTSD) or compassion fatigue, which may develop in those helping or rescuing victims.

Data suggests that, for the most part, emergency workers have learned to deal with traumatic events and take them in stride. However, there are certain circumstances when rescuers develop an emotional connection to the victim or the victim's family, in which case the rescuers have reported increased symptoms of traumatic stress. This is especially relevant in the small mining community, where "everyone knows everyone else" and many times everyone knows the families and relatives also.

Presently MSHA, in response to the 2006 MINER ACT, has been working toward incorporating the National Transportation Safety Board (NTSB) response for families after a mining incident. The efficacy of the NTSB program for mining has not been shown, and there are a number of immediate issues needing evaluation before such a program is implemented, including a review of the IASC international guidelines and the behavioral disaster mental health programs recommended in this country by the Departments of Health and Human Services (DHHS) and Homeland Security (DHS). The NTSB responds to major incidents such as plane crashes, train wrecks, etc. where victims are unrelated, family members are geographically separate, and the incident is considered over a period within days or weeks of its occurrence.

In contrast, mining incidents take place in rural communities where many people know each other, the families of victims, and mine management, and thus the effect on the community is long-term. Recently, national experts have suggested utilizing Psychological First Aid, a program providing professional support and training community members to help each other, as a possibility for the mining industry.

5.6 Escape Recommendations

Underground coal miners in the United States will continue to be faced with the prospect of having to escape a mine fire, explosion, or other emergency incident. While appropriate assessment and prevention strategies play an important role in reducing miners' exposure to the dangers of such incidents, miners must be adequately prepared for self-escape. Based on analysis of stakeholder data, incident reports, pertinent literature, and contract reports, the following recommendations are made for self-escape:

a) Risk minimization - Risk assessment should be integrated into the self-escape process.
b) Escape system integration - The U.S. underground coal mining industry should adopt an integrated systems approach to mine escape, and a model of such a system should be developed for mines to select components that work best for their local circumstances and maximize the likelihood of successful escape.
c) Escape system validation - The development of new escape scenarios, which include judgment and decision-making components, is necessary to aid mine operators in conducting quarterly escape training and verifying that the escape system works well. These drills must be audited to ensure that deficiencies are corrected in a continuous improvement process.

d) Proper communication, tracking, and data system usage - The development of protocols and related training materials is essential to teach miners, supervisors, communication or control room attendants, and others how to properly locate, operate, and maintain in-place communication, tracking, and data systems, and how to use them to their full potential during a mine emergency.

e) Two-way communications during escape - Once the SCSR is donned, high quality two-way communications presently are not possible between escapees and responders. Therefore NIOSH recommends, in the short-term, development of a method for miners to use non-verbal communication while wearing an SCSR mouthpiece. In the long-term, a new solution is needed to fully utilize the recent technological progress made in mine-wide wireless communications systems[15].

5.7 Behavioral Health Recommendations

The behavioral health needs of the mining community pre-event, during, and post-event are not being addressed, and information from behavior research in emergency response, including the concept of worker resilience, is not reaching the mining industry. Interventions can decrease exposure to risks and/or increase the number of protective factors. Research in this area has shown that such interventions may mitigate serious emotional, behavioral, physical, and cognitive consequences to personnel. Based on these observations, the following recommendations regarding the behavioral health needs of the mining community are made:

a) Behavioral health knowledge integration - Introducing behavioral health concepts, skills for self-escape, expectations escape training, and application of universal incident command center principles are needed to improve mine escape and rescue to the U.S. mining industry. Behavioral health must be part of a systems approach to emergency management in the mining industry, including the development of pre-event, during, and post-event protocols.

b) Resilience - The U.S. mining industry must develop programs that focus on resilience for all miners, mine management, and industry organizations.

c) Psychological First Aid - Psychological First Aid should be evaluated as a program to provide professional support and training for community members to help one another in the event of a disaster.

6.0 Rescue Strategy

6.1 Introduction

When miners' lives are in danger, mine emergency response systems must function rapidly and competently. The hierarchy of response actions begins with self-escape, then first responders and/or fire brigades, and last of all mine rescue teams. If there is a breakdown in self-escape and initial responders are not successful, then the deployment of mine rescue teams is necessary. Just as in fire fighting, team members accept some personal risk to save the lives of others. Hence, it is essential that mine rescue teams are fully equipped with state-of-the-art

[15] NIOSH has initiated research to assess and adapt for mine use breathing apparatus technologies that allow high quality 2-way communications and to determine how they can be integrated into mine escape systems.

technology, are professionally trained, and receive guidance from the best available mine emergency response experts.

Emergency situations requiring mine rescue teams are high-consequence, low-probability events. The mining industry's goal has always been to reduce the number of emergency situations to zero. However, until this goal is accomplished, mine rescue teams will be required. Over the past decade, mine rescuers have experienced a combination of successful rescues, saddening recoveries, and even the loss of team members.

Mine rescue teams have consistently performed well during mine emergency responses. NIOSH has found no evidence in reports of investigations that mine rescue teams that were deployed at mine emergencies were unable to do what the command center asked of them or displayed poor performance. However, not all teams are at the same level of readiness and some do not have the resources to be fully prepared for all types of responses. This report seeks to address these issues and provide guidance to achieve the highest performance possible for all mine rescue teams. Growing evidence from international practices shows that integrating a well-trained mine rescue component into underground coal mines will not only improve rescue operations' success, but also increase prevention efforts. The impact of strengthened mine rescue will also improve self-escape of all coal miners through their association with these highly skilled mine rescuers and will aid in the development of emergency leaders.

6.2 Mine Rescue Issues and Concerns

NIOSH conducted a comprehensive investigation to determine the present status of underground coal mine rescue as well as the issues, concerns, barriers, and suggestions for improvement. NIOSH also conducted an inventory of the U.S. and international coal mine rescue training practices, contest procedures, technologies, and training facilities. Finally, NIOSH created a list of U.S. facilities where coal mine rescue training is being offered or planned, with attention to training capabilities at each facility and creative ideas that could enhance coal mine rescue training. The research purpose was to develop a clear understanding of each issue, identify inadequacies, then finally to make logical recommendations for improvement. Below is a discussion of each major mine rescue issue identified.

6.2.1 Coal Mine Rescue Skills

Standardization

NIOSH has identified that the 170 underground coal mine rescue teams across the United States possess highly variable mine rescue contest and emergency preparedness skills (fire fighting, navigation in smoke, advanced first aid, etc). The link between teams that perform well at contests and the best prepared teams for a mine emergency has not been established. This investigation has identified a skills disparity (both in contest performance and emergency response skills preparedness) among teams due to high variability in financial resources, educational opportunities, turnover and available manpower, training expertise, and available local training facilities. Smaller mines typically have fewer resources per team member than larger mines. Stakeholder reports suggest that when an emergency requires multiple teams to respond, teams may not share sufficient common practices and basic skill sets to safely and efficiently work together. Building trust between teams is important and may be another reason to standardize skill sets, provide more equal opportunities to learn, and conduct exercises for multiple teams and contests so that teams meet each other and see that each is competent.

Verbal content for radio communications is a skill area in which standardization should be considered for mine rescue teams. However, no current standard nomenclature for pronunciation, standard vocabulary, or established verbal content for relaying messages, numbers, or names currently exists for mine rescue. The military and the aviation industry impose mandatory standard nomenclature to reduce misunderstandings. This practice helps to prevent confusion between similar sounding letters, such as “m” and “n,” for instance, and to clarify communications that may be garbled during transmission. In the case of mine rescue, rescuers wearing face pieces have even more difficulty maintaining clear communications.

During this investigation, NIOSH researchers observed mine rescue teams (from both the Western and Eastern United States) during smoke training sessions and found tremendous variability in radio communication responses and protocols. For instance, during just two days of training (4 teams), NIOSH researchers documented as many as 14 different responses in which all of the responses meant “yes.” These responses include: yes, yes followed by a sentence, a sentence, absolutely, yeah, yep, affirmative, that’s right, positive, got it, ok, right, copy that, right. These responses were often repeated, but the same response for “yes” was not always given by the same party. High variability was also observed for the verbal content when communicating the response “no” or citing gas readings, equipment names (e.g., “gas detector,” “spotter,” or “sniffer”), numbers, and location descriptors (e.g., “block,” “stopping,” or “wall,” and “bottom,” “fresh air base,” or “refuge area”). Stuttering, hollering, and accents made radio communication even more difficult for the briefing officer to ascertain the responses of the team members.

Mine rescue personnel in Queensland, Australia, are trained in radio communications and all teams receive the same standardized training. This training does not necessarily include specific verbal content, but identifies the proper use of the radio system, ensures clear and concise communications, requires confirmation of messages, and teaches alternative forms of communications including tapping, beeps, or banging sounds [Hartley 2009].

Real-life refuge chamber rescue is another skills area in which standardized protocols and procedures need to be developed and then practiced by all mine rescue teams. These procedures can be quite different from the historical procedures of rescuing miners located inside of a barricade because of the confined space and environmental systems. Some of the refuge chamber rescue skills that mine rescue team members need are how and when to breach the opening of a refuge chamber, how to maintain proper ventilation inside of the chamber, how to maneuver equipment and persons through refuge chamber openings, etc. They should also understand the necessity of un-tethering from a lifeline when going through the chamber door (for proper door sealing), the maximum number of team members that should enter the chamber, and the equipment that each rescuer should possess both inside and outside of the chamber.

Beyond mine rescue skills, a lack of standardization also exists with technology and equipment in the United States. Integrating different communication systems, breathing apparatus, gas detectors, and emergency response technologies (e.g., thermal imaging cameras) complicates logistics, team support, inter-operability, and the sharing of resources during a mine emergency response.

International coal-producing countries utilize regional mine rescue training facilities to provide standardized skills training to all mine rescue teams irrespective of mine size or resources. Some countries require that team members not only receive the training, but also demonstrate their skills competency. Other standardization includes map symbols, emergency response technologies, communication systems, and breathing apparatus as well as physical performance or age requirements.

This investigation, as well as the 2006 MST&TC report, supports the need for standardized skills training to better prepare all mine rescue team members for a real-life mine emergency response. Basic competencies in the following skills are necessary for teams to be prepared for mine-emergency situations arising from fire, explosion, inundation, or ground fall incidents:

Primary Skills

- Basic mine rescue skills and practices in relation to contest and real-life rules, first aid, map reading, mine gases, ignition sources, the importance of adequate rock dusting, electrical and equipment safety, dust and ventilation, roof and rib control, communications, breathing apparatus, rescue and firefighting equipment, gas sampling, ventilation control construction, etc.
- Verbal content for radio communications.
- Rapid exploration and navigation ability in reduced visibility (smoke or dust) while working under apparatus.
- Advanced first aid, life support systems, and multiple-casualty extrication (e.g., an EMT or paramedic on each team).
- Specialized fire fighting and knowledge of the ventilation effects of fires.
- Gas analysis, sampling, and trend analysis.
- Incident command, problem solving, and decision-making.
- Refuge chamber rescue

Non-typical Skills

- Heavy object lifting or removal.
- Vertical-rope rescue or repelling from structures or shafts and raises.
- Still and swift water rescue.

Cross-Training of Mine Rescue Skills

Coal mine rescue teams are made up of 6 team positions: the captain who leads the team; the number 1 gas person and back-up for the captain; a map man; the number 2 gas person who also pulls the stretcher; a tail person or co-captain who relays information to the fresh air base; and the briefing officer who remains at the fresh air base. Each position has responsibilities for specific tasks and duties, especially during mine rescue contests. It has been reported that cross-training mine rescue positions provides more flexibility and available skills during an emergency response, especially in cases where a composite team is formed. However, only a small percentage of teams adopt this practice.

In contrast to the U.S. practice, international teams typically consist of a captain and co-captain, and the rest of the team members are assigned no specific position. All members are cross-trained in a variety of skills and abilities including map reading, communications, first aid, gas detection, etc. Composite teams may be randomly chosen at mine rescue contests where highly experienced and novice team members are brought together to facilitate mentoring and to further the skills of new team members.

6.2.2 Coal Mine Rescue Training and Facilities

There are 170 underground U.S. coal mine rescue teams (MSHA database, August 2008) and adequate training for all of these teams is essential. NIOSH stakeholders concur that current coal mine rescue training facilities and capabilities are insufficient to handle the comprehensive needs of all the U.S. underground coal mine rescue teams. The 2006 MST&TC report also supports this finding.

The NIOSH training facility inventory describes ten publicly available facilities (5 large and 5 small) that offer some real-life mine rescue training activities (as of March 2009). There are a handful of other facilities including government research, academic, or privately owned resources that are frequently available to outside teams. Eleven basic features were evaluated at each facility, including: availability to public (no, yes, or limited); underground coal mine (real or simulated); classroom exercises (mine rescue rules, first aid, mine gases, ventilation, etc.); specialized fire fighting (burn galleries, fire pads, and foam training); navigation in smoke; incident command exercises; heavy object lifting; vertical rescue; water rescue; indoor contest practice field; and on-site lodging.

Figure 2 shows the location for each underground coal mine rescue team (red symbol) and the locations for the small (green symbol) and large (blue symbol) facilities used for coal mine rescue training. The total number of available coal mine rescue training facilities in the United States is ten as of March 2009. Also on the map are five locations of coal basins and the corresponding number of mine rescue teams in each. The Western U.S. coal basin includes San Juan, Raton, Uinta, and Piceance coal basins.[16]

Figure 2 also demonstrates that many teams located in Colorado/New Mexico, Kentucky, Tennessee, Virginia, and Oklahoma/Arkansas must travel long distances to the nearest facility. Large numbers and high densities of teams are found in the northern and central Appalachian coal fields (n=45 and n=60 teams, respectively). High densities are also found in Alabama, the southern Illinois region, and central Utah. Each region, except for the Alabama region, has at least two facilities that offer some kind of mine rescue training; however the smaller facilities have limited training capabilities and cannot handle a large number of teams. Table 2 identifies

[16] If all types of mine rescue teams from surface and underground, coal and metal/non-metal, and plants are combined for training support, a different spatial solution would be proposed that may require additional facilities. The Arkoma coal basin in Arkansas and Oklahoma is not included because only two underground coal teams cannot support a standalone training center. Two teams in Missouri are registered university contest-only teams and not counted in the assessment.

the number of coal mine rescue teams and lists the names of each facility in that particular coal basin region. Table 3 provides a listing of the training capabilities available at each training facility.

Underground Coal Mine Rescue Teams and Facilities

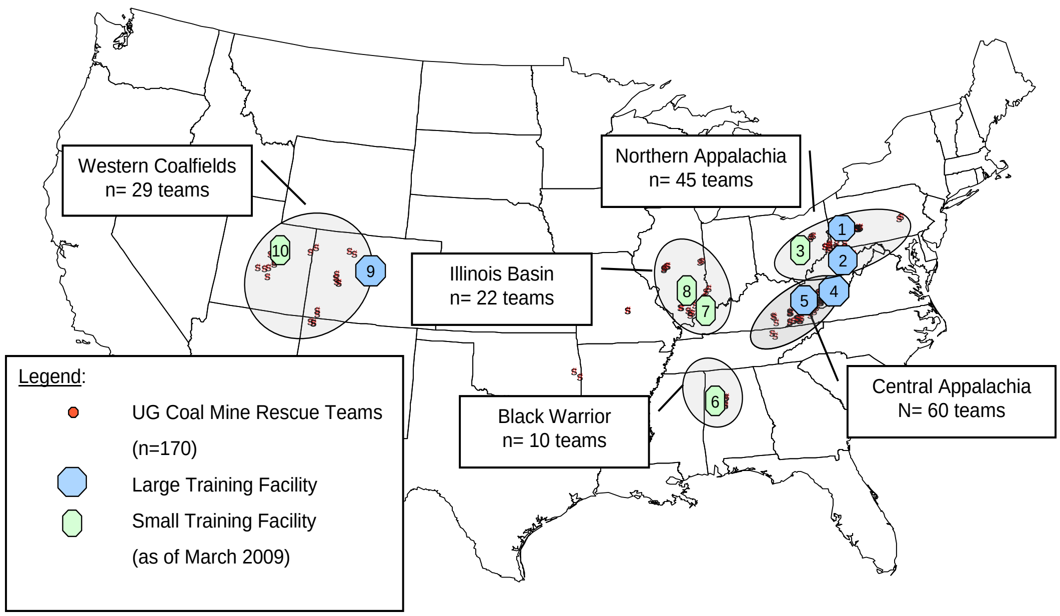

Figure 2--Map of the United States showing coalfields, coal mine rescue teams, and coal mine rescue training facilities as of March 2009 (Data Source: MSHA).

Table 2--UG Coal Mine Rescue Team Members and Facilities for Each Coal Basin (March 2009)

Coal Basin	# of UG coal mine rescue teams	Facilities with UG coal mine rescue training
Northern Appalachia	45	1. Mining technology and Training Center (MTTC) 2. WVU Mining Extension and Outreach (WV ME&O) 3. Ohio Mine Safety Training Center (OMSTC)
Central Appalachia	60	4. MSHA Academy Mine Simulation Lab (MSL) 5. Southern WV Community and Technical College (SWVCTC)
Black Warrior	10	6. Bevill State Alabama Mine Training Consortium (AMTC)
Illinois	22	7. RLC Mining Training Center (RLC) 8. Kentucky Coal Academy, Community and Technical College (KCA)
Western U.S.	29	9. CSM Edgar Mine Rescue Training Center (Edgar Mine) 10. Western Energy Technology Center (WETC)

NIOSH researchers conducted a needs assessment for U.S. underground coal mine rescue teams and a facility evaluation, determining that no coal mining region in the United States currently has sufficient group training capabilities to adequately train every mine rescue team in wide-ranging, simulated emergency conditions. However, an examination of Table 3 shows that every facility is in need of training enhancements in one area or another. Some facilities need specialized fire fighting capabilities where others need more advanced first aid training exercises or the capabilities for heavy object lifting or water rescue. Furthermore, larger mining companies with private training facilities, paid training time, and travel funding have an advantage in their level of preparedness and training opportunities over small mines with fewer resources.

Table 3--Current and projected capabilities of ten coal mine rescue training facilities (March 2009)

Facility Name	UG Mine Real or Simulated	Specialized Fire Fighting	Navigation in Smoke	Incident Command or MERD Exercises	Heavy Object Lifting	Vertical or Shaft Rescue	Water Rescue	Indoor Contest Practice Fields	On-site Lodging
MTTC	sim. 3rd.Qtr 2009	yes, 3rd Qtr 2009	yes	yes	yes	no	proposed	proposed	no
WVU ME&O	sim. 3rd.Qtr 2009,and at MSL	yes, off-site MSL	yes, mobile unit & MSL	yes	no	no	no	no	no
OMSTC	sim.	no	yes	proposed	no	no	no	no	no
MSHA MSL	sim.	yes	yes	yes	no	no	no	no	yes
SWVCTC	sim.	yes	yes	yes	yes	yes	yes	proposed	no
AMTC	sim.	no	yes	yes, 2nd Qtr 2009	no	no	no	no	no
RLC	sim. 3rd Qtr 2009	yes, 3rd Qtr 2009	yes 3rd Qtr 2009	no	no	no	no	no	no
KCA	sim.	yes, 2010	yes	yes	no	no	no	no	no
Edgar Mine	real	yes, off-site	yes	yes	pro-posed	yes	no	no	no
WETC	sim. 3rd Qtr 2009	yes, 2010	yes, 3rd Qtr 2009	yes	no	no	no	yes	proposed

MSHA's Mine Simulation Lab is the most heavily utilized facility and recently began offering services on the weekends to keep up with training demands. All facilities offer access to a real or simulated underground mine, classrooms exercises, and basic first aid classes; few offer EMT or paramedic training opportunities. Most offer specialized fire fighting and smoke exercises, but some must use off-site resources or utilize a mobile unit. Incident command or Management Emergency Response Development (MERD) training is provided by most facilities, except for the ones located in the Midwest. Heavy object removal and vertical-rope rescue is limited to only two centers and water rescue is only offered at one. Only one available facility has an indoor mine rescue contest field, and only one facility (the MSHA Academy) can provide lodging. Almost half of the facilities are in the construction or planning phase and will not be fully functioning until at least late 2009 or early 2010. For many, additional funding is needed to make much-needed enhancements.

Based on an Australian model (where facilities are used for mine rescue training as well as new miner, foremen, first responder, incident command, and escape training), if similar coal mine training facilities were adopted in the United States, NIOSH has concluded that 120 is the optimum number of mine rescue team members to be trained at each facility per year.[17] With the average number of mine rescue team members being eight, the number of coal mine rescue teams that should be serviced by each facility is approximately fifteen. Therefore, based on the number of mine rescue teams in Table 4, the number of fully equipped coal mine training facilities to meet the training needs of the U.S. underground coal industry is twelve.

Table 4--As of March 2009 the current number of teams and facilities per coal region as well as the projected number of facilities needed in each region (following the Australian model)

Coal Mining Region	No. of Underground Coal Mine Rescue Teams by Region	No. of Available Coal Training Facilities	Projected No. of Facilities per Region	Projected No. of New Facilities
Northern Appalachia	45	3	3	0
Central Appalachia	60	2	4	2
Black Warrior	10	1	1	0
Illinois	22	2	2	0
Western U.S.	29	2	2	0
Total	166	10	12	2

According to the model, there are sufficient numbers of U.S. facilities (assuming that enhancements are made) in each region except for Central Appalachia, where an additional two facilities may be needed. However, the existing two facilities in Central Appalachia have fairly large training capacities, potentially resulting in the need for only one more facility in that region. The best location for that facility would be in eastern Kentucky or western Virginia. Although there are two facilities (one large and one small) located in the Western United States, there is no centrally located facility. Enhancing local training centers will create an added benefit to small mines that have fewer resources for in-house training. Regional centers could provide opportunities to receive skills training that meet national standards, at an affordable cost.

This report only addresses facility and training needs for underground coal. If the needs for surface and metal/nonmetal mine rescue teams and travel times to the centers were taken into account, the number and capacities of training facilities would be increased. Furthermore, if the numbers of underground coal mines increased substantially in the Arkoma coal basin, the development of an additional training facility would be justified.

Unlike the United States, international coal-producing countries predominantly operate regional mine rescue training facilities. These centers exist in South Africa, Australia, China, India, United Kingdom, Germany, and Eastern Europe (Russia, Poland, and the Ukraine). They are centrally located in the middle of coal fields or between groups of mines to keep travel time

[17] This number is based on an Australian model (using both Queensland and NSW data) where an average of 120 mine rescue team members are trained at each mine rescue facility. These centers employ 4 to 6 full-time mine rescue training personnel and are not only used for mine rescue team training, but for new miner, foremen, first responder, and mine emergency management training for coal miners. They also provide audit, technical, and specialized services.

from each mine to a minimum. They provide physical, and sometimes rigorous, hands-on training in mines or simulated real-life environments as well as specialized training including multiple-casualty extrication, life support mine medics, rescue through boreholes, location of trapped miners, incident command, and emergency simulations using state-of-the-art virtual reality theaters. The full-time staff are emergency response specialists and provide expertise and leadership during mine emergencies. Some countries utilize full-time medical staff as trained team members. Medical testing (heat tolerance and fitness for duty), first-responder training, housing of specialized equipment, and technical expertise are other facility functions.

International mine rescue training facilities are funded, staffed, and legislated in diverse ways. Training centers in China and Eastern Europe employ full-time mine rescue team members (non coal miners), paid for by the state, who have the sole responsibility of responding to mine emergencies. However, South African and Australian centers train company-employed mine rescue team members who are part of the coal mining workforce. The South African mines rescue service is a private organization, and by law, every underground mine in South Africa must enter into a contract with a mine rescue service provider and pay a fee that is calculated using employee numbers and tonnages. Australia funds mine rescue training facilities by means of a government levy. The current levy amount is approximately equivalent to 1 cent per ton of underground coal production. Funding models for potential U.S. mine rescue training facilities are not addressed in this report. However, combining some team resources, in contrast to the current piecemeal system of individual team funding, may create a more efficient system, support regional centers of excellence, and better serve the needs of the industry.

6.2.3 U.S. Mine Rescue Contests and Contest Rules

Mine rescue contests are intended to force teams to learn a common rescue procedure, to evaluate and showcase mine rescue team knowledge and skills, and create camaraderie within and among teams and regulatory agencies. It is the "basic training" of mine rescue. Specific protocols are followed including the use of national rules and trained judges, competing under apparatus; and the selection of a winner. Contest training provides notable benefits including the building of team cohesiveness, trust among working groups, rapid problem solving, and the learning of basic mine rescue principles. Teams with opportunities to spend a large amount of time in competition training are taught to think independently of a command center, move quickly, and behave like a team. They know procedures, rules, and protocol better than teams that do not compete. However, without enhancing the current contests with hands-on training and changing some contest rules to be more realistic, they may not necessarily be fully prepared to respond to a major mine emergency. The 2006 MST&TC report supports these findings.

Although contest rules were designed as a foundational training tool and as a means to systematically judge teams, many of the contest rules have been found to be unrealistic in practical application. For instance, the maximum gas levels, travel distances, and water levels appear to have been developed for ease of judging contests and often contradict the necessary real-life procedures during a mine emergency response. Hence, learning contest rules has been found to confuse team members, especially new ones, when it comes time to understand the difference between contest rules and a real life situation. As much as 50-80% of available training time is spent on contest training in order to achieve acceptable team performance at contests. This disproportionate consumption of available time hinders teams from being adequately prepared for real-life mine emergencies.

Current mine rescue contests are deficient in realistic and hands-on exercises to assess competencies in emergency response skills including specialized fire fighting techniques, navigation in smoke, and building ventilation controls under apparatus. The structure of mine rescue contests is designed more for the convenience of judging consistently and to choose a winning team than to assess individual skills and competencies. Contests are not designed to correct deficiencies in individual skills or provide mentoring to teams that need to improve. Furthermore, contests are not held in a mine-like environment; they are predominantly held outdoors on a grassy field, in a gymnasium, or in a convention hall. There has been some movement towards the integration of realism into mine rescue contests, but it is limited to a small percentage of teams.[18]

The international philosophy about mine rescue contests is different from that in the United States. South African mine rescue teams do not participate in contests and have chosen to focus exclusively on mine emergency preparedness. Many teams in China, Australia, and some countries in Eastern Europe regularly participate in contests. Rather than emphasizing the determination of a winner, they are designed to audit individual skill sets, assess problem solving abilities, provide hands-on training, and impart mentoring and coaching from the contest judges. Typically contests are held in a local underground coal mine or in a simulated mine and are designed to be as realistic as possible. Some examples of contest exercises in New South Wales are the following: deployment of hydraulic lift bags, stretcher carry (175-lb person), ventilation survey, virtual reality simulated exercises (coal outbursts/roof and rib hazards), fire fighting in the burn gallery, shift boss and mine examiners' skills test, first aid on unconscious patients and CPR, theory and problem solving, and individual practical (demonstration of breathing apparatus and gas detectors). The main goal of these contests is to ensure that every individual mine rescue team member is competent, fully equipped, and ready to respond to a mine emergency. All team members, officials, and incident managers who participate gain respect and trust under the common training experience.

6.2.4 Recruitment and Retention of Team Members

Stakeholder meeting participants reported that retention has become more difficult because the popularity and respect associated with being a mine rescue team member has declined over the years due to increased training time, number of contests, and the way recent coal mine disasters were reported in nationwide news coverage. The MINER Act has increased the number of teams and made recruitment harder because more team members are required to fulfill the mandate. Operators do not always treat mine rescue team training as a part of the work week, which impacts miners' income and fatigue. Thus, recruitment and retention of team members has become difficult. Some companies have increased incentives for team membership and good performance including financial bonuses, time off, a more accommodating training schedule, and special recognition by means of clothing, hats, and other gifts. Special treatment of mine rescue team members, including financial incentives, is practiced internationally. United States stakeholders report that turnover is a significant issue with small mines because the mine rescue training helps qualify miners to become foremen, who are typically in short supply and generally are not permitted by their companies to participate on teams.

[18] The WV Alliance, Mine Technology & Training Center and Edgar Mine have expanded contests to include skills training and varied the rules with the approval of the MSHA District Managers.

NIOSH has identified student mine rescue teams as a potentially powerful recruitment and retention tool for mine rescue and qualified management. Mine emergency response training is a growing part of some mining engineering programs. The Missouri University of Science and Technology (Rolla) has offered a mine rescue team curriculum for many years and has two student mine rescue teams that compete against professional teams. Expansion of this program in the last year at The Pennsylvania State University and the Colorado School of Mines is evidence that other universities recognize that hands-on participation will generate lasting knowledge, interest, and continuing support for their programs, while supporting mine rescue throughout the industry as these students progress in their careers. These programs are well-attended by the students, and statistics show that nearly 80 % of students continue to be active in mine rescue after graduation. In addition, these programs at the graduate level provide a strong opportunity for future mine emergency response research ideas. Barriers to starting more teams include funding to fully equip and maintain a team[19] and finding experienced faculty.

6.2.5 Rescue Operation Time Delays

Common sense and recent experience reveal that the longer rescue is delayed, the lower the probability of a positive outcome. Mine-wide wireless communications and tracking systems are technologies that will reduce time delays in the command center due to the quick transfer of location and emergency response information. Furthermore, mine rescue team wireless communication systems also reduce time delays. However, mine-wide and the mine rescue team communication systems are not compatible. During an emergency response, this incompatibility causes the relay of critical communication verbally, back and forth, from mine rescue teams to command center personnel, causing increased time to elapse and a greater chance for miscommunication.[20]

Time delays could be reduced by fully utilizing the new communication/tracking systems and enhancements in other technologies, including mine atmosphere monitoring systems, robots, miner location devices, portable gas chromatographs, electronic map boards, thermal imaging cameras, extraction equipment, and emergency response vehicles. South Africa annually practices drilling a large-diameter rescue borehole[21] and using risk assessment tools (e.g. a down- hole probe/camera for surveillance, lighting, communications, and gas sampling). Eastern European countries offer mine rescue ambulance services (equipped with operating rooms), rescue dog services, and specialized technology including portable, hand-carried jet engines for inertization and an explosive charge connection system for tapping into steel water lines at any location. Australian mines conduct mine-wide emergency drills annually to test their response procedures and equipment. Recent U.S. mine recovery operations successfully tested rapid exploration techniques using wireless communications, multiple teams, and a mobile fresh air base while in clear air.

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[19]The 2006 Mine Rescue Handbook produced by the NMA lists the direct cost of starting and training a mine rescue team as $120,000 the first year and $38,000 annually, which does not include salaries, facilities, or overhead [NMA 2007]

[20]Note that MSHA has a prototype linking electronic mine maps at the fresh air base and the command center via a 10,000-ft fiber optic cable. Unfortunately many mines are larger than this.

[21]South Africa owns the large diameter drilling equipment which is used to drill a hole every year so that the operators stay proficient and the equipment is operational. Each mine has a trailer loaded with a generator, borehole fan, small cable hoist, communication equipment, and emergency supplies to minimize response time in the event that miners need to use the strata refuge chamber [Marx et al. 2008].

A current barrier to utilizing some of the above time-saving technologies is that no single worldwide approval and certification criteria of equipment for use in underground coal mine hazardous atmospheres exists.[22] This would involve normalizing the approval and testing safety criteria used by the International Standards Organization (ISO) and U.S. agencies while maintaining the current level of safety. Until this occurs, the United States cannot share the benefits of the larger world market for new coal mining technologies. Also, the cost of developing products for approval is often not justified because of the small U.S. mining market or manufacturer restrictions on disclosure of intellectual property details to testing agencies.

Finally, building flexibility into the application of mine rescue protocols could also save time. Command center and teams should be encouraged to utilize new methods and technologies if safety of the team and the trapped miners can be maintained. Most current exploration procedures and rules have not been systematically re-examined in over a half century. Some examples are the number of mine rescue team members required underground during an emergency response, fresh air base protocols, and the current limitations of advancement during exploration. For example, the 1,000-ft exploration limit was determined by the distance that teams could travel under oxygen wearing a 2-hour re-breather before the Second World War. Since then, teams have adopted the 4-hour apparatus, but no changes were made to increase the exploration limit. The 2006 MST&TC report also noted opportunities for improvement, including splitting 6-man teams for "shotgunning" exploration, relaxing the 1000-ft exploration limit when conditions permit, working barefaced (for a limited time) at levels of carbon monoxide above 50 parts per million and at a lower percent oxygen than 19.5, and expedited procedures for managing the fresh air base. Other countries use less stringent exploration guidelines when lives are at risk than when recovering property.

6.3 Rescue Recommendations

Rescue teams in the United States will continue to enter mines following mine fires, explosions, or other emergency incidents when conditions allow. They deserve the best possible equipment and training opportunities. Based on analysis of stakeholder data, incident reports, pertinent literature, and contract reports, the following recommendations are made for safe-rescue:

a) Standard, realistic training - In order to upgrade coordination between unrelated teams and reduce the potential for misunderstandings, all mine rescue team members must receive standardized, real-life mine emergency response training in all basic mine rescue skills and cross-train on multiple team positions.
b) Regional mine rescue training facilities - The United States should more fully utilize the current 10 coal mine rescue training facilities and add up to 2 more to create 12 regional or centralized miner training facilities. The purpose of these facilities is to provide efficient, effective, realistic, and comprehensive training, especially for smaller mines or mines with fewer team resources. These facilities

[22] International standards for explosion protection have been recognized by other federal agencies such as OSHA and the U.S. Coast Guard. Like MSHA, the U.S. Coast Guard historically developed its own standards for electrical equipment used in potentially explosive environments for shipboard locations. NIOSH researchers are suggesting that the mining industry take a detailed look at a process similar to what the U.S. Coast Guard did, without decreasing the current level of safety measures in place.

could offer the required competencies and provide all-weather mine rescue practice fields, virtual reality theaters, and other services including medical testing facilities, a wellness center/gymnasium, and support facilities including dorms and a cafeteria. Regional facilities would serve to standardize training skills, combine mine rescue resources, centralize mine rescue experts, develop emergency response leaders, and house specialized rescue equipment. NIOSH recommends that a broad-based U.S. coal mine rescue task force advisory committee be created to facilitate the development of regional mine training centers and to ensure program consistency and realism, assess competencies, and allocate resources.

c) Contest skills development - In order to refocus training time on preparing teams for actual emergencies, mine rescue contests and national rules must be revised to emphasize realistic conditions, contests should be held in a simulated or underground coal mine, and contests should be used to assess mine emergency response skills and provide on-the-spot mentoring to team members.

d) Communication system interoperability - Exchange of information between mine rescuers and mine-wide communication, tracking, and data systems in a manner that is secure and effective is highly desirable. NIOSH recommends that the functional requirements for interoperability be established for mine rescue communication and the technology be developed, applied, or acquired to make this possible.

e) College student level emergency response training - Student mine emergency response and mine rescue programs (at collegiate levels) have been shown to effectively train future emergency response leaders. NIOSH recommends that college programs be incorporated into the overall U.S. mine rescue system. An expanded industry-sanctioned program for mine emergency response should also be integrated into mining engineering curricula, and a method of funding for mine emergency response university programs and research partnerships should be created.

f) Rapid advance improvements - The current mine rescue protocols and procedures (underground exploration limitations, number of teams and team members, fresh air base management, etc.) need to be openly re-examined, taking into account the current technology and research findings. Although maintaining team safety is first priority, certified teams and command centers should be permitted a greater measure of discretion to use their resources as strategically as possible during a mine emergency where lives are at stake.

7.0 Incident Command

7.1 Introduction

The organization and dynamics of incident command are critical in a mine emergency. A small village in Lassing, Austria, became famous after a tragic mining accident in July 1998 and provides an important example of crisis mismanagement. At a depth of 200 ft underground, water and mud broke into a shaft of the mine. Ten years later people remember the huge hole in the earth that swallowed up several houses, a mine worker who survived for 10 days, and the 10 miners who could not be reached and remain buried in the mine. A rescue leader declared the death of all mine workers prior to the rescue of the one survivor, and chaos prevailed for one week. Initial leadership was lacking and the most crucial after-the-fact finding was that most mistakes were caused by disagreements over which group would be the lead agency. A positive amongst the chaos was the precision of the drilling teams. Interestingly, it was concluded that better leadership would not have made a difference in rescuing the 10 miners who perished; however, as this example demonstrates, the lack of a clear leadership structure in a crisis can take an enormous human toll and could lead to further loss of life or injuries [Hersche and Wenker 2000].

The Department of Labor Reports [MSHA 2007, Teaster and Pavlovich 2008] for both the Sago and Crandall Canyon mine disasters describe similar behavioral and technical command center issues. These issues include leadership struggles, intimidation, confusion, technology difficulties, protracted data gathering and analysis, security weaknesses, communication difficulties, the transmission of wrong information, excessively long working shifts, and undue media influence. In addition, strained personnel dynamics and inadequate training led to uncertainty as to what protocol to follow and to confusing lines of authority.

NIOSH has identified four major areas of incident command that warrant improvement in order to ensure that mine rescue efforts are well-supported: a) mine emergency management systems; b) decision-making criteria; c) technology; and d) human factors.

7.2 Mine Emergency Management Systems

The National Incident Management System (NIMS) was developed by FEMA so that responders from different jurisdictions and disciplines can work together better to respond to natural disasters and emergencies, including acts of terrorism. NIMS utilizes the Incident Command System (ICS), a standard, on-scene, all-hazards incident management system already in use by fire fighters, hazardous materials teams, rescuers, and emergency medical teams outside the mining industry. ICS has been established over 40 years as the standardized incident organizational structure for the management of all incidents. MSHA developed a version of ICS in 1994 that is called Mine Emergency Command System (MECS). There are eight functions in the MECS system: command, safety, operations, information, liaison, logistics, planning, and finance. NIOSH has identified functional limitations with command and planning in the current MECS system and a major problem with a lack of trained personnel to professionally carry out incident management.

7.2.1 MECS Command Function

The MECS command function differs from ICS protocols in the way that authority and responsibility are aligned. ICS focuses on a chain of command with the ideal being a single commander who has authority for the response, subject to advice and inputs from the command group. ICS recognizes the need for unified command when several independent agencies have authority to respond. There must be a strict, shared protocol for unified response to be successful. The MECS command group comprises representatives of the mine, the state regulatory agency, MSHA, and labor, all of whom provide input into the decision making process. However, conflicting interests from the multiple leaders representing different constituencies can make the decision-making process arduous and cause major conflicts with no timely or efficient way to resolve them. Although a mine operator representative is responsibly "in charge," his/her decisions are dependent on a formal approval process including a written rescue/recovery plan that is submitted to MSHA for approval before it may be implemented. This process is managed by a 103(k)[23] order that MSHA issues under its statutory authority to ensure the safety of any person in the mine during an emergency [Lazzara 2008].

The MECS command function is a breach of standardization from ICS-suggested protocols. Although input from all four groups is essential, the authors suggest that the present system needs examination and it may be better to have one ultimate authority making time-critical decisions and receiving input from the others, not subject to the delays that an external and formal approval process implies. This is not a recommendation to remove deliberation, careful hazard analysis, or responsibility from command decision-making. It is recognized that responsibility and authority to act are inseparable. Emergency response experts [Kowalski et al 2009 in publication], stakeholder comments, and recent disaster results have made it clear that the current decision-making model in the command center is inefficient and not performing adequately. The NIMS ICS concept of having one ultimate authority has worked well across a broad spectrum of industries to manage natural and man-made disasters when senior participants are well-trained and experienced. Although many issues would have to be overcome, the assignment of one ultimate authority could be a viable model to improve upon and upgrade the MECS command function.

Other coal producing countries have also organized and established mine emergency management systems. Their pre-determined hierarchy of leadership is often based on military models with guidelines for a systematic and organized command center. The senior mine rescue official serves as the ultimate authority and the responsibility to act in the command center (when mine rescue teams are involved) in China, South Africa, and New South Wales. His/her functions include the coordination of all consulting services (planning, technology, information, etc.) and control of the rescue operation. If rescue teams are not involved, the mine rescue official serves as a consultant to the highest-ranking mine manager. In Queensland, the highest-ranking mine manager controls the mine emergency and the mine rescue official functions as a consultant. Eastern Europe follows a military model, exercising a rigid hierarchy of professional mine rescue leadership. In short, all these countries have one well-trained and experienced person in ultimate authority with a responsibility to act to save lives, and whose decisions are not subject to the delays a formal approval process requires.

7.2.2 Command Center Training

Since major U.S. mining accidents are rare, only a handful of persons have participated directly in actual mine emergency operations and very few in multiple events. To make matters worse, stakeholder reports reveal that in the United States over much of the last 20 years, incident command training was rarely conducted, was incomplete, and was unstructured. Emergency response training is not required for senior leaders in the command center; only intermediate level mine management who serve as Responsible Persons are required to have any training. The 2006 MINER Act and subsequent regulations now require a trained Responsible Person on each shift. MSHA, the UMWA, and some companies conduct training in isolation. This does not advance the development of trust or synergism claimed to exist in the best functioning command centers and that could arise from sharing other points of view and common experience in training so that there are fewer sources of contention during an

[23]Section 103(k) under the Federal Mine Safety and Health Act of 1977, as amended

emergency response. The 2006 MST&TC Report recognized this deficiency and recommended that broader requirements for incident command training be established.[24] Australia requires any person functioning in an incident command position during a mine emergency response to demonstrate competency through prior training.

In response to the above issues, command center training has started to re-emerge across the United States. However, newer and better training exercises are needed. One training tool is a NIOSH-developed computer-based emergency simulation exercise for mining personnel called The Mine Emergency Response Interactive Training Simulation (MERITS). Another much older tool developed in 1981is a Management Emergency Response Development (MERD) [Kravitz and Peluso 1986] framework on which an exercise can be created involving a simulated mine emergency with missing miners and a staffed command center. In these table-top or simulated drills, the command center analyzes the problem, decides on an action plan, and directs the response activities.[25] The command center may communicate with actual mine rescue teams or a knowledgeable person in another room representing the fresh air base briefing officer during this exercise. There are software companies that are working on web-based interactive command center training tools which do not require all participants to meet in the same room.

7.2.3 Pre-planning

Adequate pre-planning for a mine emergency is critical to achieving rapid response actions. However, planning beyond the minimum required to meet the Emergency Response Plan requirement is often overlooked, resulting in valuable time lost in establishing the incident command center and making decisions. Each of the MECS functions has special needs that should be addressed in pre-planning including staffing, availability of maps, data management, technology, secured phone lines, etc. South Africa legislation provides comprehensive guidelines for incident command center and control room pre-planning, including information on refuge chambers, emergency control centre structure and procedures, and duties and responsibilities of staff. Guidance is given for staffing and training requirements, the availability of maps and emergency response plans, physical features of command center and control rooms (furniture and seating, lighting, barometers, communications), media relations, technology, etc.

At times the volume of data sent to the command center is paralyzing. It is necessary to provide better systems for managing data in command centers, i.e. documenting, tracking, transmitting, summarizing, analyzing, and providing decision-quality information to management. Managing an emergency is difficult, stressful, and urgent, and all the information needed is not available. The command center participants have a very difficult job to do. If they are not trained to work together using the same process their performance will be less than

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[24]One example of mine emergency response training is provided in Queensland Mines Rescue Services. Queensland adopted US ICS protocols to develop its Mine Emergency Management System (MEMS). The 4-day MEMS training program demonstrates the hierarchy of leadership and decision-making in a command center. Mine managers from multiple mine sites manage a simulated emergency response and answer to the overall incident command authority, the highest-ranking mine manager. Results of using this training model show how command center activities can become systematic and well-defined. In comparison to untrained managers, those trained in this model make better quality decisions and make them faster.

[25]The addition of a requirement to document the proposed action plan and obtaining MSHA approval would make these drills more realistic but would also take more time to conduct.

optimal. Best practice is to prepare ahead of time using the same protocol and not leave command center coordination and cooperation to on-job-training.

Smaller mines and mines in remote locations have greater difficulty due to fewer resources and topographic access limitations; they must rely on pre-developed mutual aid agreements with other organizations. The state of West Virginia has recognized this need and has created a service that offers a fleet of emergency response and support vehicles. This service is available 24/7 and is specially designed to provide communications, rescue, and fire service to mines in remote locations. The Mine Emergency Operations group at MSHA is expanding the number of response equipment centers to three. Similar command post vehicles are becoming available through Homeland Security funding in other metropolitan areas, but may not be available for mine incidents without a mutual aid agreement.

7.3 Decision-Making Criteria

When there is a mine emergency, stakeholders report that there is uncertainty about what criteria will be used to approve emergency rescue plans, what information is required by MSHA to adequately forecast the potential hazards teams may encounter, and how to mitigate these hazards. The emergency rescue plan that operators must file, and which must receive MSHA approval before mine rescue teams are dispatched into the mine, is an example of risk minimization planning. Each case is unique, time is critical, and teams must not be put into unsafe situations. Each identified risk must be addressed.

MSHA personnel have the most experience with emergency response since they are on-site at every incident and can act as advisors, but they have no responsibility for developing the plan. Therefore, two actions are needed. The first is that MSHA clarifies the basic criteria used and data needed for emergency rescue plan approvals and fully participates in creating the plan. Second, operators, MSHA, State and labor representatives need practice in performing realistic simulations of emergency responses together (perhaps in a MERD setting) including preparing complete emergency rescue plans. These drills would be enhanced if typical plans were available as templates for multiple types of incidents. These templates could also serve as checklists to help ensure that all issues are covered. This situation deserves a transparent process to address all concerns related to making the decision to safely deploy mine rescue teams.

7.4 Technology Utilization

Maintaining in-mine systems (communications, tracking, and air monitoring) during a mine emergency is essential for timely incident command decision-making and protecting the safety of in-mine victims and rescuers. In the past, these systems were not permissible and were de-energized to reduce the possible number of ignition sources during a mine emergency response. As a consequence, extremely valuable underground information was unavailable. Most electrical power ignition sources are eliminated by disconnecting power. However, some sources such as unprotected batteries located in fresh air under normal mine operations, remain energized and cannot be remotely disconnected or de-energized, which typically causes time delays for mine rescue team deployment.

Fully functioning wireless communication and tracking systems, mandated by the 2006 MINER Act, will remain active and will be able to provide continuous and vital information to the command center (refer to Sections 5.2.2, 5.2.3 and 6.2.5). However, the post-incident integrity and safety in hazardous atmospheres of mine air monitoring systems was not fully addressed by the Act. The data supplied by these systems if they remain active can be used to verify if the mine ventilation system is damaged, blocked by water because pumps are de-energized, or the atmosphere is trending into the explosive range. Without this information, reliance on manual sampling at fans or boreholes is necessary, and the information gathered from outside the mine is less revealing. Evidence from international reports supports that several countries are utilizing communications and air monitoring data acquisition systems that are approved for use in hazardous conditions under the ISO standards. Alternatively, the atmospheric monitoring tube bundle systems that are powered from outside of the mine are available today. These systems are being utilized in numerous Australian coal mines and one U.S. mine for spontaneous combustions monitoring and emergency mine air testing.

7.5 Behavioral Health Factors

Several human behavior issues stand out in incident command during a mine emergency including cumbersome communication and decision-making dynamics amongst leaders, fatigue, and on-scene psychological support covered in Section 5.

7.5.1 Leadership

There are currently no specified training requirements or competencies for incident command leadership in the U.S. mining industry, and leadership in the incident command center is critical for success. The Sago and Crandall Canyon Department of Labor reports, the 2006 MST&TC report, and U.S. stakeholder interviews have identified that leadership issues have been problematic and fraught with confusion. The outcome is often poor communications, a lack of clearly defined protocol, deferred decision-making, and absence of cooperation.

The fundamental question that needs to be addressed is who leads the U.S. incident command.[26] The mine has the ultimate responsibility over operations, but MSHA has the ultimate authority in emergency situations. There is also the influence of high-ranking state officials and labor union representatives. Multiple leaders can have conflicting interests. Uncertainty may lead one group to accept some risk to expedite a quick rescue, whereas another group might move with greater caution with a more zero-risk approach for mine rescue teams.

International practices primarily allow the highest-ranking leader from the mine rescue services or the senior mine manager to lead a mine emergency response. The end result is that one person has final decision authority and responsibility. This person generally is highly skilled and experienced with rescue operations and technology. Command center leadership makes decisions that are risk-based, systematic, and organized, and groups work together to support the person in authority. The role of each group in the command center is clearly defined and the ultimate authority is agreed upon in advance of the event.

[26] "Effective crisis management…is a systematic, orderly response to crisis situations in such manner that by pre-arrangement, a specific segment of an organization is designated to deal with the crisis utilizing any available organizational resources…Effective crisis management, therefore, mandates development of a set of special skills for managing an organization under conditions of intense stress…the more complex the task, the more likely that stress will disrupt performance" [Kravitz and Peluso 1986].

7.5.2 Fatigue

A newly studied problem in mine emergency command center response is fatigue. It is not something that is usually considered in mine emergency preparedness planning. In the stress associated with a disaster, rescue and recovery personnel many times report that they "run on adrenalin" and believe they can function well over periods of days. Nevertheless, fatigue is an important issue, especially in the incident command center, and can be a serious deterrent to effective rescue and recovery operations. NIOSH findings suggest that extended work shifts during disaster operations may contribute to a decline in cognitive abilities [Kowalski et al. 2003]. The implications for such a phenomenon would be an increased potential for impaired decision-making, poor communications, compromised interactions with public, families, etc. as the shifts are protracted during rescue and recovery operations. Currently, there are no limitations on the maximum allowable time spent in the command center. If shifts are limited to 10 hours (allowing overlap on a three shift per day rotation) then there must be additional well-trained persons available to relieve each shift. This forces the issue of training and trust to be addressed proactively (see Section 8).

7.6 Incident Command Recommendations

Incident command in the United States is in need of improvement. Proper training, supportive technology, stable management structures, and readiness are essential for incident command to function well during mine emergency responses. The following recommendations are made in the interest of improving command performance and reducing delays of coordinated responses:

a) Incident Command System - NIOSH recommends that the current 4-party MECS Command arrangement be replaced with a command function similar to the NIMS ICS system where one pre-selected, experienced person has ultimate authority and responsibility for management of the response, and that all incident command personnel should be specifically covered under Good Samaritan statutes.[27]

b) Incident Command competency development - Before any personnel are permitted to participate in command center functions during a mine emergency they must receive incident command training prior to the mine emergency event. These persons must demonstrate competency in the MECS system through a progression in responsibilities and successful performance in other MECS functions via training simulations and actual emergencies. Guidance must be provided to the mining industry on how to adequately prepare in advance for a mine emergency event, how to limit fatigue, and how to manage traumatic incident stress.

c) Decision-making criteria and protocol - Criteria and methods for making decisions and establishing tolerable risk should be included in the training that command center participants and responsible persons receive. Emergency response plans required for each mine must include evaluations for major possible incidents, forms for documenting mine emergency rescue plans, and training on how to develop them.

[27] The MINER Act of 2006 Section 116, Limitation on Certain Liability for Rescue Operations, refers to a COVERED INDIVIDUAL as a person "who is carrying out activities relating to mine accident rescue or recovery operations. Rescue team members and volunteers are specifically listed but not command center individuals.

d) Mine air monitoring system safety and survivability - Barriers must be resolved that prevent the mine air monitoring data acquisition and storage systems from being kept active and uninterrupted throughout a mine emergency. Such data must be easily available to trend analysis programs. Data about the condition of the mine ventilation system during an emergency that can be provided by monitoring systems is very valuable. It makes it possible to more confidently and safely guide the responders and escapees. However, current practice is to de-energize these systems because of a concern that they could become an ignition source if the immediate atmosphere is explosive.

e) Psychological services - Pre-, during, and post-psychological services for incident command and rescue personnel should be made available to sustain the highest levels of collective cognitive performance possible.

f) Incident command data management - Better systems for managing data in command centers, i.e. documenting, tracking, transmitting, summarizing, analyzing, etc. are needed to provide actionable information and to avoid data overload.

8.0 Training

8.1 Introduction

Mine safety experts agree that effective emergency preparedness training is critical for the underground coal mining industry. The Mine Safety Technology and Training Commission [2006] report states, "Although engineering or administrative controls may be effective in eliminating most of the risk, most often some risk will remain, and then training or the establishment of protocols or plans [to address human behavior] should be developed."

Since 2006, various reports have been written about the types of improvements needed in training for coal mine emergencies [MST&TC 2006; GAO 2007; West Virginia Mine Safety Technology Task Force 2006]. These reports present the opinions of various groups of knowledgeable persons associated with the U.S. coal industry. They contain information recently gathered through surveys, interviews, focus groups, and public hearings. The following recommendations for improving Mine Emergency Response (MER) training are based on a careful review of these sources as well as past training research studies by NIOSH and others. Although many types of improvements to MER training are needed, the following three areas are of critical importance for ensuring that miners acquire the skills necessary for self-escape and safe-rescue: a) evaluation of competencies, b) improved training methods, and c) new training content.

8.2 Evaluation of Competencies

Based on their survey findings, the MST&TC [2006] recommends that the industry, MSHA, and NIOSH focus on developing and/or improving methods of evaluating miners' self-escape and aided-rescue competencies. For the most part, U.S. mine health and safety (H&S) training regulations simply require miners to attend training classes for the prescribed number of hours. Miners are not required to pass any written or oral exams. The regulations do not require miners to actually demonstrate their competency with respect to emergency response, other than showing that they remember how to don an SCSR properly.

The regulations do require mine trainers to specify, in general terms, how the trainees' comprehension of the information will be evaluated. According to 30 CFR Part 48.5 (c) "Methods, including oral, written, or practical demonstration, to determine successful completion of the [safety and health] training shall be included in the training plan. The methods for determining such completion shall be administered to the miner before he is assigned work duties."

Detailed and valid instruments, checklists, or procedures for measuring individual miners' competencies are not usually provided to MSHA. There are no definitions or standards concerning what might constitute "successful" completion of mandated H&S training. There is no requirement that the trainer or mine operator document how the evaluation was performed, who performed it, the evaluator's qualifications, the results of the evaluation, etc. In short, there is no valid or verifiable system in place for ensuring that each individual coal miner is competent to respond to mine emergencies.

Therefore, it is recommended that methods for assessing the comprehension and retention of critical MER information be developed, and minimum levels of mastery be established. New policies and procedures for verifying competencies at regular time intervals should be established. This will require setting up a national system for competency assessments. The system should include:

- A comprehensive listing of MER competencies for miners, operators, foremen, managers, incident commanders, safety officials, and responsible persons.
- Curricula for teaching MER competencies.
- Methods/tests for determining the extent to which an individual has mastered each competency (including hands-on, non-classroom methods).
- Establishing minimum proficiency levels.
- Methods for conducting remediation with trainees who are below the minimum level.
- Establishing qualifications for individuals responsible for assessing trainee competencies.

It is recommended that a task force be formed to create a system of MER competency evaluations, and that U.S. regulations on mine safety training be expanded to include provisions for assessing emergency response competencies. Australia has already established such a system [Galvin 2008, pp. 23-24].

8.3 Improved Training Methods

Research on the effectiveness of occupational safety training methods suggests that such training is more effective when the training methods are highly engaging and realistic [Burke et al. 2006; Robson et al. 2009; Cohen 2004].

8.3.1 Realism

The GAO [2007] study suggests that considerable variability exists in the safety training methods and facilities used to train coal miners for emergencies. The GAO report states, "Without adequate training, including practice using safety devices in simulated emergency conditions, miners may be unable to safely and confidently escape a mine. To facilitate the transfer of training to the job, it is important that practice drills and simulations reflect actual conditions on the job as closely as possible. Such training builds miners' confidence and enables them to respond appropriately during an actual emergency. Unfortunately, although mine operators recognize the importance of simulated emergency training, many mines face challenges conducting such training due to their limited access to special facilities and the high cost of such training."

As mentioned previously in Section 6.2.2, NIOSH recommends that the United States create regional or centralized coal mine training facilities to efficiently provide more realistic and comprehensive training for miners and mine rescue teams. Each facility should contain equipment for conducting realistic hands-on evacuation and rescue training drills as well as a virtual reality theatre. The coal industry in New South Wales Australia recently built state-of-the-art virtual reality theatres at four mine rescue training stations. Initial indications are that this new form of training adds significant realism and is working quite well for mines of various sizes [Galvin 2008].[28] Virtual reality appears to be a very promising technology for improving the realism of MER training.

8.3.2 Engagement

Research suggests that higher levels of engagement in occupational H&S training are positively associated with knowledge acquisition and reduction in accidents, injuries, and illnesses [Burke et al. 2006]. Low engagement H&S training typically employs oral, written, or multimedia presentations of information by an expert source, but requires little or no active participation by the learner, other than attentiveness. Much of the H&S training miners currently receive is via low engagement delivery methods. Miners often do not have an active cognitive or behavioral role that can be clearly documented. With high engagement training methods, the trainee has a much more active role in the learning process. The trainee engages in significant cognitive and behavioral interaction with the material, and has many opportunities to ask questions of experts/instructors and engage in focused discussion with other trainees. High engagement training methods frequently provide trainees with opportunities to discover new cognitive strategies related to problem solving and decision-making. Participants are often involved in hands-on practice of the behaviors to be learned. Examples can range from table-top exercises conducted in a classroom setting, to mine emergency escape and rescue training within a real or simulated mine.

The MST&TC [2006] encourages use of high engagement training methods to develop a higher level of conceptual thinking, as follows: "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

[28] This investment was justified by the workers compensation board to help reduce injuries to miners.

alternative escape strategies, effectively use available technology, and execute their decision all depends on their ability to think."

To help miners acquire these skills and capabilities, new training methods and scenarios need to be developed. Interactive group problem solving exercises, role playing exercises, and behavioral modeling training are potentially useful methods. NIOSH researchers have already developed a small group problem solving exercises dealing with coal mine emergency situations such as fires, inundations, first aid, etc.[29]

MSHA recently promoted the development of additional MER problem solving exercises through its 2006 Emergency Mine Evacuation final rule. This rule requires mine operators to "provide miners evacuation training on a quarterly basis using scenarios for three types of mine emergencies – fires, explosions, or gas or water inundations. Training must include best options for evacuation under each type of emergency. Scenarios must include a discussion of options and a decision as to the best option in each situation" [71 Fed. Reg. 71429(2006)].[30]

The development and testing of good training scenarios requires considerable time and effort. Safety trainers may need guidance on how to continually develop engaging new scenarios that are relevant to their mines. Mine operators' efforts to comply with this new regulation should also be evaluated. A means of sharing positive scenarios with other mines should be established. A library of MER training scenarios should be established at a central website and at the Academy.

The U.S. mining industry should regularly conduct full-scale emergency response drills. Full-scale drills would involve everyone expected to help respond to mine emergencies including: mine employees, participants from the local community, mine rescue teams, union representatives, and regulatory agencies. These drills would help participating mines to improve their training, equipment, and procedures. They would also help the various stakeholders to develop a much better understanding and expectation of what role they and others will play in managing disasters. These exercises should be conducted at least every 2 years in each major coal producing region of the United States.

8.4 Training Content

The MST&TC [2006] survey findings suggest that better training materials are needed to address significant MER knowledge and skill gaps. Specifically, additional materials are needed for training miners in the following areas: navigating through smoke, first responder fire fighting, refuge chambers, SCSRs, normal psychological and physiological human response to emergencies such as traumatic incident stress, and emergency communication. Additional training materials on a variety of topics are also needed for mine managers, responsible persons, mine dispatchers or mine-monitoring personnel, crew supervisors, mine rescue teams, and command center personnel.

New computer-based training simulations are needed to provide command center personnel with extensive opportunities to practice handling a wide variety of mine emergency

[29] See http://www.cdc.gov/niosh/mining/products/
[30] Federal Register. See Fed. Reg. in References.

situations. This would lead to improvements in the speed and quality of decisions made by command center personnel. Dynamic decision-making researchers are learning how to train people to make better decisions by observing the choices they make in computer training simulations. Much like the unfolding challenges of managing a mine emergency, these simulations require trainees to continually monitor the goals of the task, learn how to navigate the simulated task space, use their knowledge to diagnose current states and predict future events, form and update strategies, and finally, keep all of these activities connected in a coherent problem solving process. Saner and Gonzalez [2008] have identified several factors that have an important influence on the quality of decisions made in dynamic situations.[31] Several more computer simulations like the Mine Emergency Response Interactive Training Simulation (MERITS) need to be created to provide mine managers the opportunity to practice handling a wide variety of mine emergency situations.[32] The more experience people gain through participating in such simulations, the better prepared they will be to handle real-world events.

Many of the interactive mine emergency training simulations available from NIOSH or MSHA need to be updated and converted to electronic delivery format. MSHA began the process of these conversions a few years ago (see “I Can’t Get Enough Air” or “Travel Through Smoke” at http://www.msha.gov/interactivetraining.htm), but many more simulations need to be converted. Training materials and methods developed for other industries and internationally need to be adapted for U.S. mining conditions.

8.5 Training Recommendations

The mining industry needs additional guidance on how to adequately train miners to respond to mine emergencies. Significant improvements are needed in the methods and content of mine emergency response training, as well as the methods for evaluating whether miners have mastered critical emergency response skills and knowledge. Based on analysis of stakeholder data, incident reports, pertinent literature, and contract reports, the following specific recommendations are made:

a) Competencies evaluation - Methods for assessing the comprehension and retention of critical mine emergency response information should be developed, and minimum levels of mastery should be established. New policies and procedures for verifying competencies at regular time intervals should be established. This will require setting up a national system for competency assessments. The system should include:
    - A comprehensive listing of competencies for miners, foremen, managers, and responsible persons.
    - Curricula for teaching these competencies.
    - Methods/tests for determining the extent to which an individual has mastered each competency.
    - Establishing minimum proficiency levels.
    - Methods for conducting remediation with trainees who are below the minimum level.

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[31] See http://www.hss.cmu.edu/departments/sds/ddmlab/
[32] See http://www.cdc.gov/niosh/mining/products/product62.htm

- Establishing qualifications for individuals responsible for assessing trainee competencies.

A task force should be formed to create a system of MER competency evaluations. U.S. regulations on mine safety training should be expanded to include provisions for assessing emergency response competencies.

b) New and improved training facilities - As recommended previously (Section 6.2.2), the United States should create regional or centralized coal mine training facilities to efficiently provide more realistic and comprehensive training for miners and mine rescue teams. Each facility should contain a virtual reality theatre as well as equipment for conducting realistic hands-on evacuation and rescue training drills.

c) New and improved training materials - Engaging new training exercises should be developed to teach miners how to make decisions and solve problems they are apt to encounter during various types of mine emergencies. Mine operators' efforts to comply with new regulations requiring interactive evacuation training on a quarterly basis using various types of disaster scenarios should be assessed. Safety trainers should be provided guidance on how to continually develop effective new training scenarios that are relevant to their mines. A means of sharing positive scenarios with other mines should be established. Additional training materials on a variety of topics are also needed for mine managers, responsible persons, mine dispatchers or mine-monitoring personnel, crew supervisors, and mine rescue teams. Several of the interactive mine emergency training simulations available from NIOSH and MSHA need to be updated and converted to electronic delivery format. Also, training materials and methods developed for other industries and internationally need to be adapted for U.S. mining conditions.

d) New training simulations for command center personnel - Several new dynamic decision-making computer simulations should be developed to provide emergency command center personnel extensive practice in making decisions about how to handle a wide variety of mine emergency situations.

e) Full-scale emergency response drills - The U.S. mining industry should regularly conduct full-scale emergency response drills. Full-scale drills involve everyone expected to help respond to mine emergencies including: mine employees, participants from the local community, mine rescue teams, union representatives, and regulatory agencies. These drills would help participating mines to improve their training, equipment, and procedures. They would also help the various stakeholders to develop a much better understanding and expectation of what role they and others will play in managing disasters. These exercises should be conducted at least every 2 years in each major coal producing region of the United States.

9.0 Summary

An integrated self-escape and safe-rescue system has the potential to maximize the survival of all miners evacuating or trapped by fires and explosions. Current practices can be greatly improved based on findings contained in empirical data from the analysis of pertinent literature, incident reports, NIOSH contract reports, interviews, and stakeholder data. This will require a systematic review of all applicable laws, rules, regulations, and protocols in a transparent process similar to the continuous improvement method used by modern manufacturing enterprises under the ISO 9000 standard.

Our findings indicate evidence that safe-rescue, which includes well-trained mine rescue and incident command components, will improve underground coal mine rescue operations' success. However, this practice may not have the greatest impact on miner survivability. Rapid self-escape is believed to lead to the best probability of survival. Nevertheless, having well-trained mine rescue team members in every mine leads to an improvement of self-escape performance for all coal miners through their association with highly skilled responders and the distribution of potential emergency leaders throughout the mine.

The authors' key recommendations are intended to meet the objective to have a better training and preparation system (conceptually shown in Figure 3) that results in the following outcomes:

Figure 3--Coal mine emergency response is conceptually shown as a well-balanced solid 3-legged stool depicting the long-term goal for U.S. mine emergency management.

1. Self-Escape: Resilient miners who are equipped and capable of timely self-escape under adverse conditions and hazardous atmospheres, who can act as first responders that can safely and knowledgably assist others to escape, and who can mitigate limited hazardous conditions until help arrives;

2. Safe-Rescue: Mine rescue teams who are equipped and capable of rapid, state-of-the-art safe-rescue in irrespirable mine environments and are ready to respond quickly;

3. Incident Command: Incident command centers and emergency response systems, under the direction of a single professional with qualified advisors, who are prepared and competent to manage a rapid, dynamic decision-making process and to direct a multi-faceted response team.

The overarching goal is a robust underground coal mine emergency response system that best meets the survival needs of injured, trapped, or endangered miners. The United States has the most productive and diverse underground coal mining industry in the world. Therefore, one solution is unlikely to satisfy all mines. Flexible approaches are needed to find the best mix of emergency procedures. Progress will not be fast nor without controversy, and more importantly it cannot be achieved in isolation by government alone. These recommendations are interdependent and cannot be implemented piecemeal with the expectation that major improvements will result.

Key actions that warrant significant emphasis and commitment of resources necessary to achieve competent mine emergency response capability are requiring training competency, developing command center professionalism, providing universal access to facilities, training with post-incident working communications, preparing integrated escape and rescue systems, and incorporating human behavior services.

Stakeholders recognize that a minimum level of mastery or competency is a necessary foundation for all critical activities. New procedures for teaching skills and verifying proficiency to establish competency at regular time intervals should be established. Clear guidance must be provided to the mining industry on how to adequately prepare in advance for a mine emergency event, including all parties (miners, rescuers, command center personnel, and officials).

The current 4-party Mine Emergency Command System (MECS) command function must be aligned with the National Incident Management System Incident Command System (NIMS ICS) where one pre-selected, experienced person has ultimate authority and responsibility for management of the response, and this person should be covered under Good Samaritan statutes.

There is an inherently unequal mine rescue, incident command, and miner escape training environment in the U.S. coal mining industry because of funding, support, instruction, oversight, and access to quality curriculum materials and facilities, especially for small mines and companies. One solution is to enhance existing facilities or build new regional training centers so that 12 professionally staffed, new or upgraded regional underground coal training facilities at readily accessible locations are created. This regional system would provide leadership in standardizing training skills, combine mine rescue resources, centralize mine rescue experts, develop emergency response leaders, support university-based mine rescue programs, and house specialized rescue equipment.

The full benefits of the MINER Act with regard to survivable two-way communications and tracking systems during evacuations and rescues will only be realized when emergency breathing apparatus allows two-way voice communication, when mine rescue communications systems are made interoperable with mine-wide systems, and when air monitoring system barriers are removed so that they may remain active. Miners and responders also need practice demonstrating verbal communication skills during emergency drills.

Empirically based *behavioral health* concepts must be integrated into mine emergency training to provide resilience skills for miners for self-escape, command center personnel, mine rescuers, and the mining community at-large. Psychologically, preparation is the most important activity in which to engage to mitigate the effects of a disaster. Information lowers anxiety; planning quiets fears.

And lastly, to counteract the piecemeal nature of emergency response planning, an integrated systems approach to mine escape, rescue, and incident command is needed that incorporates a risk minimization process and that allows local customization and incorporates a process of continuous improvement. This process would allow each mine to demonstrate how its Emergency Response Plan achieves the best possible outcomes for the local circumstances, to practice the components of its plan, and to maximize the likelihood of successful escape.

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