IMPROVING SELF-ESCAPE FROM UNDERGROUND COAL MINES

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

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Committee on Mine Safety: Essential Components of Self-Escape

Board on Human-Systems Integration

Division of Behavioral and Social Sciences and Education

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THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, NW Washington, DC 20001

This study was supported by Contract/Grant No. 200-2011-38807 between the National Academy of Sciences and the Centers for Disease Control and Prevention. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number-13: 978-0-309-28276-5
International Standard Book Number-10: 0-309-28276-4

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, NW, Keck 360, Washington, DC 20001; (800) 624-6242 or (202) 334-3313; http://www.nap.edu.

Printed in the United States of America

Suggested citation: National Research Council. (2013). *Improving Self-Escape from Underground Coal Mines*. Committee on Mine Safety: Essential Components of Self-Escape. Board on Human-Systems Integration, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

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Acknowledgments

This report is the work of the Committee on Mine Safety: Essential Components of Self-Escape, a project of the National Research Council's (NRC's) Division of Behavioral and Social Sciences and Education, overseen by the Board on Human-Systems Integration. This study was sponsored by the National Institute for Occupational Safety and Health (NIOSH) Office of Mine Safety and Health Research. The committee is grateful for the support and contributions of NIOSH staff, Jeffery Kohler, associate director for mining, and director, Office of Mine Safety and Health Research, National Institute for Occupational Safety and Health, especially for assisting the committee to better understand the coal mine industry, and Marie Chovanec for her able assistance throughout the study process.

The committee thanks the numerous individuals for their presentations at the public workshop on April 24, 2012. The workshop included presentations and discussions from five panels. Panel 1, Mine Operator Perspectives, included the following individuals: Richard Abraham, RIO Group, Inc.; Dale Byram, Jim Walter Resources, Inc.; John Gallick, Alpha Natural Resources; and Joseph LaMonica, consultant, Bituminous Coal Operators Association. Panel 2, Training, Decision Making, and Teams, included the following individuals: Dana Brooks, Prince George's County Maryland Fire/EMS Department, Fire Training Academy instructor; Janis Cannon-Bowers, University of Central Florida; Hendrick Ruck, Human Performance Consulting Group; and Eric Weiss, U.S. Army, George Mason University. Panel 3, Design and Health, included the following individuals: Robert Cohen, Stroger Hospital of Cook County, Illinois, and Sundaresan

Jayaraman, Georgia Institute of Technology. Panel 4, Systems, Communication, and Lifeline Technology, included the following individuals: Warren Gross, Lockheed Martin; Michael Hastings, Carroll Technologies Group; Steven Shope, Sandia Research Corporation; and Larry Stolarczyk, Stolar Research Corporation. The final panel, Panel 5, Breathing Apparatus Technology, included the following individuals: Kent Armstrong, Draeger Safety, Inc.; Steven Berning, Ocenco, Inc.; and Scott Shearer, CSE Corporation.

The committee also benefited from briefings in support of their data-gathering to inform the contents of this report, provided during the committee's four initial meetings. From the NIOSH Office of Mine Safety and Health Research, we thank Tom Barczak, director, Division of Mining Science and Technology; Michael Brnich, mining engineer, Human Factors Branch; R.J. Matetic, director, Division of Mining Research Operations; and staff members Rohan Fernando, senior research engineer; Launa Mallett, acting team leader, Training Research Development Team; and Joseph Waynert, team leader, Electrical Safety and Comunication Team. From the technical support group of the Mine Safety and Health Administration, we thank Jeffery H. Kravitz, acting director, and John Urosek, chief, Mine Emergency Operations. We also thank Kathleen M. Kowalski-Trakofler, consultant; Kris Lilly, Redbone Mining; Joseph Sbaffoni, director, Pennsylvania Bureau of Mine Safety; and John Wreathall, John Wreathall & Company, Inc.

The committee participated in two site visits during the course of the study to the Consol Energy Bailey Mine, an underground coal mine in southwestern Pennsylvania, and the Academy for Mine Training and Energy Technologies at West Virginia University (WVU). At Consol Energy, we thank Eric Schubel, general superintendent, for his facilitation of the committee's visit. At WVU, we thank Joshua Caldwell, director, Academy for Mine Training and Energy Technologies; Jay Cole, chief of staff, President's Office; Thomas Hall, extension agent; Randy Long, laboratory instrumentation specialist; Steven Perkins, extension agent; Henry Pisegna, instructor; and George Rannenburg, extension agent. The committee would also like to acknowledge the self-contained self-rescuer manufacturers who donated product for the committee during the WVU activity: Kent Armstrong, Draeger Safety, Inc.; Scott Shearer, CSE Corporation; and Jerry Stickler, Ocenco, Inc.

Prior to the formation of the committee and throughout the duration of the project, the contributions of consultants and staff have been critical. Consultants to this study included Gary Klein, senior scientist, MacroCognition LLC, and Edward Levine, professor emeritus, Department of Psychology, University of South Florida, Tampa. Among the NRC staff, special thanks are due to Barbara Wanchisen and Melissa Welch-Ross, director and former deputy director, respectively, of the Board on Human-Systems Integration who provided oversight and support of the study. Julie Anne Schuck, senior program associate, contributed to all aspects of report preparation including research, editing, and writing. Renée L. Wilson Gaines, senior project assistant, provided administrative and logistical support throughout the study. Matthew McDonough, research associate, also provided critical substantive and organizational support to the committee's public workshop held in April 2012. Anthony Brown, senior program assistant, provided additional logistical support for the public workshop. Cherie Chauvin, senior program officer, also assisted in substantive and organizational tasks throughout the study. And finally we thank the executive office reports staff of the Division of Behavioral and Social Sciences and Education, especially Eugenia Grohman, who provided valuable help with the editing and production of the report; Kirsten Sampson Snyder, who managed the report review process and prepublication release; and Yvonne Wise, who managed the production process. Additional research and technical assistance was provided by Matthew Von Hendy, research librarian, and Ellen Reid, summer intern.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: Winston "Wink" Bennett, Human Performance Wing, Human Effectiveness Directorate, Wright Patterson Air Force Base; Jim Brinkley, Occupational Health and Safety, International Association of Fire Fighters, Washington, DC; Dale Byram, Safety Efforts, Walter Energy, Inc., Birmingham, Alabama; Elaine T. Cullen, Prima Consulting Services, Chattaroy, Washington; Sara J. Czaja, Department of Psychiatry and Behavioral Sciences Scientific and Center on Aging, University of Miami Miller School of Medicine; Dave Feickert, consultant, Whanganui, New Zealand; Sundaresan Jayaraman, School of Materials Science and Engineering, Georgia Institute of Technology; Syd S. Peng, Mining Engineering, West Virginia University; Eduardo Salas, Department of Psychology and Institute for Simulation and Training, University of Central Florida; and Stanley C. Suboleski, Evan Energy Investments, Richmond, Virginia.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the content of the report nor did they see the final draft of the report before its release. The review of this report was overseen by Matthew Rizzo, Departments of Neurology and Mechanical and Industrial Engineering, and the Public Policy Center, University of Iowa, as coordinator, and Georges S. Benjamin, American Public Health Association, Washington, DC, as review monitor. Appointed by the NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the author and the institution.

William S. Marras, *Chair*
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Committee on Mine Safety: Essential Components of Self-Escape

Contents

Summary

1 Introduction

2 Mine Safety Regulations and Practices

3 Understanding Self-Escape

4 Decision Making

5 Safety Culture

6 Training

References

Appendixes

A Regulations Relevant to Self-Escape

B Mine Accident, Injury and Illness Report

C Biographical Sketches of Committee Members and Staff

Summary

Coal mine disasters in the United States are relatively rare events; many of the roughly 50,000 miners underground will never have to evacuate a mine in an emergency during their careers. However, for those that do, the consequences have the potential to be devastating.

U.S. mine safety practices have received increased attention in recent years because of the highly publicized coal mine disasters in 2006 and 2010. Investigations have centered on understanding both how to prevent or mitigate emergencies and what capabilities are needed by miners to self-escape to a place of safety successfully. This report focuses on the latter—the preparations for self-escape.

In the wake of the 2006 disasters, the U.S. Congress passed the Mine Improvement and New Emergency Response Act of 2006 (MINER Act), which was designed to strengthen existing mine safety regulations and set forth new measures aimed at improving accident preparedness and emergency response in underground coal mines. Since that time, the efforts of the National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA) have contributed to safety improvements in the mining industry. However, the Upper Big Branch mine explosion in 2010 served as a reminder to remain ever vigilant on improving the prevention of mine disasters and preparations to help miners survive in the event of emergencies.

Concerned with further advancing the safety of miners, the Office of Mine Safety and Health Research at the National Institute for Occupational Safety and Health asked the Board on Human-Systems Integration at the National Research Council to appoint a committee to examine the essential components of self-escape. The Committee on Mine Safety: Essential Components of Self-Escape was asked to focus on underground coal mines and define self-escape in the context of mining emergencies. We were to consider environmental and human-systems factors as well as technologies to understand the system in which the miners work and then to propose ways to improve self-escape preparations and training for mining personnel and identify knowledge gaps where further research is needed.

Mine emergencies, as the term is used in this report, are unplanned events that have the potential to cause serious injuries or loss of life; they disrupt mining operations and require that underground miners get to a safe place outside the mine. Although this report does not address prevention strategies directly, we acknowledge that actions taken to prevent emergencies in the first place have an important role in the preparation for successful escape. These actions extend well beyond the individual miner and rest with the system of mine operators, the regulatory agencies, and other industry stakeholders.

This study was set in the context of human-systems integration, a systems approach that examines the interaction of people, tasks, and equipment and technology in the pursuit of a goal. It recognizes this interaction occurs within, and is influenced by, the broader environmental context. A key premise of human-systems integration is that much important information is lost when the various tasks within a system are considered individually or in isolation rather than in interaction with the whole system. In this study, the task of self-escape is part of the mine safety system.

Self-escape from adverse events in underground mines is inherently not a solo effort, even in the case of a single individual escaping alone. It is a broader effort of multiple teams and personnel acting in concert. Recognizing this complexity, it is still necessary to begin with a definition of self-escape that must embrace the concept of *individual* escape. This permits appropriate focus on identifying the needs of individuals in any effort to resolve the emergency, or if it cannot be resolved, on removing themselves from harm. In general, however, the circumstances that require self-escape occur in a setting where a group, or team, of coal miners is together. Being in groups and having leaders, therefore, can be advantageous but cannot replace attention to the needs of each individual.

We define self-escape in the event of a mine emergency as the ability of an individual or group of miners to remove themselves from the mine using available resources.

While the definition of self-escape references only actions taken after an event is under way, safety management before, during, and after an event is important. Self-escape begins well before any emergency occurs. Keys to preparing for self-escape include planning and training. Mine operators must ensure that everything to support escape is in place and available. There should be no impediments to escape that are within the control of planning. First and foremost, mine operators must be compliant with mine safety regulations. Next, they need to work with miners to master the ability to recognize and/or respond to warning signals and harness the knowledge of the specific hazards, exits, and resources of their particular mines.

> **CONCLUSION: Efforts on the part of mine operators and other industry stakeholders to empower self-escape in a mine emergency—to include, but not be limited to, training, technology, equipment, and emergency response plans—need to be fully integrated and coordinated, using a human-systems integration approach, to establish unified, efficient, and effective protocols. Among the key issues to be considered in pursuit of this goal are robust data collection, careful and constructive assessment of emergency response plans, feedback mechanisms from miners and mine operators to identify residual challenges and remedies, and active engagement with technology suppliers.**

With modest effort and investment, the mining industry can derive great benefit by learning from its own efforts to plan for emergencies as well as from what is currently known in areas such as technology development, decision-science, safety culture, and training. The committee offers seven recommendations below (and with more details in the chapters) on how existing knowledge can be used and how more can be learned to improve the capability of miners to self-escape.

ASSESSMENT OF EMERGENCY RESPONSE

Coal mines vary in size and coal production, but each mine operator has the responsibility to mitigate hazards in the coal mine environment and keep miners safe. This vast variability across the industry leads to difficulty in describing a single, best approach to manage mine safety. Regulations have been created to ensure mine safety that can be equitably applied to all mines, regardless of the mining method, production capacity, number of employees, geography of the mine, and other factors. Consequently, regulations, generically written, tend to enforce only least-common denominator factors. Regulatory compliance may serve the basic needs of some mines; however, mines can benefit further by employing a safety management approach that extends beyond focusing only on regulatory compliance. An important component of such an approach requires having an understanding of how well one's emergency plans can be executed and an awareness of what improvements can be made.

The mining industry has made many significant strides forward to mitigate hazards, train miners, and advance mine safety. Improvements in regulations, procedures, and technologies have positively altered the mine environment and consequently reduced the frequency and severity of emergencies. Yet the committee is concerned that improvements in mine safety, especially in regulation, have historically followed major mine disasters. This approach often draws the attention of legislators to apply what was learned from disaster investigations and enact rules meant to mitigate the specific causes of particular incidents. What has been missing is the consideration of safety improvements in advance of incidents, using the available knowledge from research, and consideration of larger systemic issues.

To promote a more systemic assessment, one needed element is a public database populated with pertinent information across a wide range of mine incidents or emergency scenarios to support development of self-escape training and research. Such a database could possibly be populated with data from information already collected, but data relevant to escape from mines are very limited and currently insufficient for analytic and information-sharing purposes. Another possibility is to include data from interviews with select miners to gather knowledge from their experience about emergency situations and how to deal with them.

Overall, systematic efforts are needed to collect and analyze regularly information from escape situations and make outcomes and lessons learned available to stakeholders for future improvements. The currently required quarterly escapeway drills provide an avenue for collecting such information with minimum additional impact on mines and miners. Under the regulations, escapeway drills are intended to use different emergency scenarios quarterly to test emergency preparations (e.g., miners' knowledge of the mine, conditions and locations of emergency equipment, use of breathing apparatus, and plans for diverting smoke and fighting fires).

> **RECOMMENDATION 1: At least annually, and in conjunction with one of the required quarterly escapeway drills, mine operators should conduct a comprehensive self-escape scenario exercise at every underground mine. These exercises should be an integrative practice incorporating the roles of miners, the responsible person as defined in 30 Code of Federal Regulations § 75.1501, the mine communications center, and any other stakeholders that the operator deems pertinent to a successful self-escape, including representatives of the miners where applicable. The scenario should test all aspects of the mine's emergency response plan and mine emergency evacuation and firefighting program to assure that these are effective and up to date. Information gathered from the proposed annual exercises will speak to the effectiveness of current practices and processes specifically with regard to effective decision making and action(s) at both the individual and systems levels.**
>
> **Appropriate staff from the National Institute for Occupational Safety and Health (NIOSH) should attend as many exercises as necessary to collect and interpret pertinent outcomes and lessons learned using a standard process. The NIOSH assessment of performance at individual mines of all key personnel, both internal and external, and the effectiveness of emergency response systems should be shared with the personnel involved in each exercise. In addition, a report that has been scrubbed of identifying markers, detailing the outcomes and lessons learned should be prepared and entered into a public database for use by any interested parties to develop better self-escape capabilities (overall practices, policies, technologies, and training). New resources for NIOSH to accomplish**

this responsibility should be identified so as not to draw resources from critical program elements.

TECHNOLOGY

The mining industry has spent nearly $1 billion on emergency preparations since 2006 and continues to look for better technologies. Several areas have been identified as needing upgrades, and cooperative efforts are under way that involve miner representatives, operators, technology providers, and the government. Given the challenges that face the miner under emergency situations, it is imperative that the human-technology interface be as efficient and effortless as possible and that attention be given to technology survivability during an emergency.

Operational requirements for emergency supplies of breathable air need to be revised to ensure a supply of breathable air for self-escape that will function in atmospheres of various compositions, that is they need to ensure performance against all harmful gases and an adequate supply of breathable air in oxygen deficient atmospheres. Additionally, filtered devices (used in a small number of mines) that only protect against carbon monoxide and do not supply breathable air should be removed entirely unless specifically justified.

RECOMMENDATION 2: The National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration should review their operational requirements for emergency supplies of breathable air. Furthermore, NIOSH should allocate funds for research and development to improve the functionality of emergency supplies of breathable air, with special focus devoted to resolving a wide range of issues including

- **verbal communication,**
- **positive pressure,**
- **facial hair,**
- **device weight and size minimization,**
- **device changeover or air replenishment in toxic environments,**
- **fit testing where applicable, and**
- **adequate vision through clearing or removal of condensation.**

RECOMMENDATION 3: The National Institute for Occupational Safety and Health, the Mine Safety and Health Administration, and technology companies should accelerate efforts to develop technologies that enhance self-escape. These technologies should use human-centered design principles with specific attention to facilitating improved situational awareness and decision making. The technologies should include, but are not limited to:

- **communications, both miner to miner and miner to surface;**
- **real-time gas monitors that are appropriate for all miners;**
- **fail-safe tracking that is hardened and survivable; and**
- **multifunction devices that combine technology to reduce physical burden and excessive demands on attention.**

The current technology regulatory and approval process in the United States appears to be a deterrent to rapid technological innovation and access to global markets, which hampers the commercial viability of innovation.

RECOMMENDATION 4: The National Institute for Occupational Safety and Health and the Mine Safety and Health Administration should reexamine their technology approval and certification processes to ensure they are not deterring innovation in relation to self-escape technologies that are used in other industrial sectors and global markets. They should collaborate in convening a joint industry, labor, and government working group to identify a range of mechanisms to reduce or eliminate any barriers to technology approval and certification, which should include exploring opportunities to cooperate with other international approval organizations to harmonize U.S. and international standards without compromising safety.

DECISION SCIENCE

A miner’s regular job is to produce coal or to perform support work to maintain the mine, making it a safe work environment. Miners appropriately absorbed in their daily work assignment routine may be susceptible to missing or misinterpreting emergency warning cues. It is important to make miners aware of the warning signals most likely to occur in their mine environment so appropriate early decisions can be made. Mine emergencies are stressful and complex events, often characterized by unanticipated conditions and the need for decision making and complicated by hazards that vary widely from mine to mine.

The findings from research in the field of decision science, broadly defined as the investigation of decision processes and communication strategies by individuals and in groups, have much to offer planning for mine self-escape. Decision science research has identified thinking and reasoning patterns that can commonly occur in stressful situations such as optimism (or false alarm) bias, backup avoidance, or compromised reasoning. Under stress, one's ability to think systematically is often compromised. Research has shown that just knowing about this possibility and related biases can aid decision making in stressful situations. In addition, if life-saving behaviors that have been defined in emergency plans are trained so they are automatic (without much thought) then cognitive capacity can be preserved so that adequate attention can be directed at the unexpected events and conditions.

To effectively remove themselves to a place of safety, miners need to have working knowledge of their surroundings and self-escape equipment and technologies; they also need to have the psychological tools to make effective decisions and communicate effectively.

> **RECOMMENDATION 5: The National Institute for Occupational Safety and Health should use current decision science research to inform development of self-escape training, protocols, and materials for training for effective decision making during a mine emergency. Miners and mine operators should be knowledgeable of typical warning signals and able to determine if a true emergency exists and decide how to respond appropriately. All miners should be trained using standard protocols developed for predictable components of self-escape. This will allow miners to devote adequate attention to unexpected events and enhance situational awareness.**

SAFETY CULTURE

Safety culture forms the organizational context in which all safety-related actions take place. It is defined by the safety-related behaviors that are expected, the resources available to support safety, and the steps taken to identify, eliminate, or control hazards. Safety cultures develop over time as a function of leadership and as organizations operate and adapt to local conditions or respond to events. It is understood that mine operators have an obligation to comply with the law. However, to enhance self-escape capabilities, mine operators should also pursue efforts that create a strong, positive culture of safety. Safety needs to be recognized as a core value throughout the industry. There exists a repository of information on safety culture from other industries that can be reviewed for guidance relevant to the mining industry. The National Institute for Occupational Safety and Health is to be recognized for recently initiating research on safety culture specific to underground coal mining.

RECOMMENDATION 6:

A. The National Institute for Occupational Safety and Health (NIOSH), in coordination with mining stakeholders, should compile the existing research and recommendations on safety culture from other high hazard and process industries and disseminate them to the mining industry. Such information would provide a useful resource that mine stakeholders could use to examine their own safety cultures and identify strengths and weaknesses specific to their organizations.

B. NIOSH should expand its safety culture research efforts to include a larger and more generalizable sample of mining organizations as well as to examine linkages between cultural attributes and safety performance, ideally using longitudinal data on safe work practices and accident and injury outcomes. NIOSH's current data base of qualitative and questionnaire data would appear to provide a strong basis for this expansion. Ultimately, the results from this research effort could be used to produce a set of safety culture tools that could be used by the entire mining community. This compilation of data collected using these tools could then be used for further analyses and benchmarking activities.

TRAINING

Training is a necessary step in preparing individuals and groups to use available resources appropriately. Regulations relevant to training for self-escape appear to emphasize training duration and frequency rather than training to mastery. To ensure that miners can function effectively in an emergency, a train-to-mastery system with competency standards is needed, not time in class. A detailed systematic task analysis would identify knowledge, skills, abilities, and other personal characteristics (KSAOs) critical to a successful self-escape. These KSAOs will provide a general blueprint for self-escape training programs and essential competencies. The definition of mastery varies by what level of performance and reliability is acceptable —and increasing levels come with higher price tags of training time and general cost. The committee envisions that after step A. in Recommendation 7 below is completed, and the KSAOs for self-escape are identified, a consensus group of stakeholders will meet to determine what level of performance is acceptable and define competency standards for those KSAOs. This meeting would include representatives from NIOSH, mine operators, and miner organizations.

RECOMMENDATION 7: To advance self-escape training:

A. The National Institute for Occupational Safety and Health (NIOSH) should conduct or sponsor a formal task analysis and an analysis of the knowledge, skills, abilities, and other personal attributes (KSAOs) required for miners to self-escape effectively in coordination with the efforts of the responsible person, the communication center and mine management.

B. On the basis of these analyses and working with interested stakeholders, NIOSH should undertake the research required to identify the training modalities, techniques, and protocols best suited for those KSAOs as well as the interactions between miners, responsible persons, the communication center, and mine management. Thereafter, NIOSH should review current training and identify existing gaps within the mining industry.

C. On the basis of the research and review in step B. above, and using best practices within the training field, the Mine Safety and Health Administration (MSHA) and NIOSH should revise or

develop training flows that bring miners, responsible persons, communication centers, and mine management to mastery in those KSAOs, including interactions between those three groups.

D. NIOSH should conduct research to verify the effectiveness of training developed in step C. above and miners' retention of information learned under simulated emergency conditions.

E. In its current review of facilities supporting mine rescue training, MSHA should also evaluate whether these facilities could support self-escape simulation and scenario training.

1

Introduction

Coal mining is a major industry in the United States with 26 states producing coal for energy uses. There are an estimated 50,000 underground mine workers, about one-fifth of these are contractors, in 549 coal mines of varying size. The size of a mine is determined by the number of employees. There are 172 small mines employing less than 20 underground miners each, 366 larger mines employing 20 to 500 underground miners each, and 11 mines employing 500 or more underground miners (Mine Safety and Health Administration, 2011).

There are inherent hazards in the coal mine environment, including noise, respirable dust, electrical accidents, diesel exhaust, rock falls, fires, and explosives. If not managed safely, these hazards can lead to situations that require evacuation from the mine such as gas and coal dust explosions and inundations of gas or water. Although recent advances in mining research and practice have improved the safety (and health) of mineworkers, there remains a need for additional analysis and research aimed at targeted concerns, particularly those in regard to miners' ability to self-escape in the event of emergencies.

Scrutiny of U.S. mine safety practices has increased in recent years due to highly publicized accidents, such as the Sago mine disaster of January 2, 2006, which resulted in 12 fatalities, and the Upper Big Branch mine disaster of April 5, 2010, which resulted in 29 fatalities.[1] Subsequent investigations into these accidents suggest that both could have been prevented or mitigated through better human-systems integration practices (Mine Safety and Health Administration, 2007; McAteer et al., 2011).

In the wake of the Sago disaster, Congress passed the Mine Improvement and New Emergency Response Act of 2006 (MINER Act), which strengthened existing mine safety regulations and introduced new measures aimed at improving accident preparedness and emergency response in underground coal mines. However, there exists relatively little research indicating how mine operators have complied with the new regulations or whether they have been effective, particularly as they relate to self-escape.

In an effort to inform and develop a proactive approach to mine safety, the National Institute for Occupational Safety and Health (NIOSH) conducted a study in 2007. The study included interviews with staff at both small and large mines across the country, not just miners but also rescue team members, safety officers, and corporate-level managers. NIOSH also commissioned research papers to obtain additional information. The initial results indicated that some concerns were universal, such as efficient and accurate surface-to-mine communications and the variation in the physical capabilities of individual miners. However, the study also revealed a diversity of practices across the United States that dictates the need for tailor-made assessments. One overall message that emerged from the NIOSH study is that escaping very early in the stages of a mine emergency makes the difference between life and death.

But how do mining personnel make decisions under stressful and dangerous conditions? How can they become better equipped to make those decisions? What technology improvements would add to effective self-escape? Specifically, what communications and respiratory escape apparatus advances are possible? And where can improvements in infrastructure and work organization increase effectiveness of self-escape?

To help answer these questions, NIOSH asked the National Research Council to appoint a committee to consider the behavioral, environmental, and human-systems factors and the tools and technologies that could contribute to effective decision making and the potential for self-escape from mine emergencies. The committee was asked to identify competencies that are essential for mine workers and to suggest the most effective training methods for the mining industry. The committee was also asked to identify any gaps in the scientific literature. See Box 1-1 for the committee’s full statement of task.

The Committee on Mine Safety: Essential Components of Self-Escape was set up to carry out the study. In essence, we were asked to understand the system in which miners work and then to characterize appropriate training for mining personnel and identify knowledge gaps where further research is needed. Although our study is on underground coal mining practices, it is likely that at least some of our findings, conclusions, and recommendations are applicable for underground metal and nonmetal mining, as well as related industries.

SELF-ESCAPE: DEFINITIONS AND CONTEXT

Self-escape from adverse events in underground mines is inherently not a solo effort, even in the case of a single individual escaping alone. It involves a broader effort of multiple teams and personnel acting in concert to affect a successful escape. However, it is still necessary to begin with a definition of self-escape that must embrace the concept of *individual* escape in order to focus on identifying the needs of individuals in any effort to resolve the emergency, or, if it cannot be resolved, remove themselves from harm. In general, however, the circumstances that require self-escape occur in a setting where a group, or team, of coal miners is together. Being part of a group having leaders can be helpful in an emergency, but it cannot replace attention to the needs of each individual.

Self-Escape

> **We define self-escape in the event of a mine emergency as the ability of an individual miner or a group of miners to remove themselves from the mine using available resources.**

The committee's definition of self-escape requires miners to move outside the mine (to the surface), but we recognize that there are some circumstances when certain individuals may be required to stay in the mine (e.g., to extinguish a fire). For our purposes, the committee considers self-escape to be uniquely separate from rescue, which is a specialized response of trained rescue teams to assist miners who have become trapped or injured underground and can no longer remove themselves from the mine on their own. "Aided escape" falls under self-escape: it refers to conditions in which miners cannot walk out easily on their own and must rely on aids or resources, such as information from the surface, technologies, and assistance from other miners.

Although the committee's definition of self-escape references only actions taken after an emergency is under way, safety management issues before, during, and after an event are also important. Miners must be maximally prepared to react when an emergency happens, either to resolve it if possible or to take effective actions to escape. An underlying principle of this preparation is recognition that self-escape begins well before an emergency occurs. Successful self-escape requires creating the conditions and competencies that promote the best chance for success. First and foremost, mine operators need to be compliant with mine safety laws and ensure that everything to support escape is in place and available. There should be no impediments to escape that are within the control of planning and preparation.

BOX 1-1
Statement of Task

An ad hoc committee will be appointed to identify and synthesize the literature relevant to understanding "self-escape" in the context of mine safety. The committee will review literature in areas such as judgment and decision making under conditions of uncertainty and stress, training of personnel in high-risk professions, technological advancements that may facilitate self-escape (e.g., signaling), physiological and biomechanical effects of stress, and systems approaches to improve the likelihood of success self-escape. This study will focus on underground coal mining but with the understanding that findings and recommendations for that industry will likely be informative to the underground metal/nonmetal mining industry. Basically, the stated purpose of this study is: What in the context of mine operations does it take to give mine workers self-escape capabilities during an emergency?

Based on a careful review and collation of a variety of data, the committee will

1. define “self-escape” in the context of mining emergencies;
2. consider environmental and human-systems factors as well as technologies that contribute to the potential for self-escape from mine emergencies. Among the factors the committee may consider are escapeway conditions, availability of refuge alternatives, communication systems, improved decision-making capabilities, the availability of information, and/or providing physical conditions that would make it easier to escape under adverse conditions;
3. suggest the most effective training methods for the mining industry to adopt in order to impart those skills to miners and to validate individual competency levels of same;
4. identify competencies that are essential for mine workers to have in order to allow them to execute self-escape methods, which will include cognitive competencies as in hazard recognition and decision making, as well as physical abilities; and
5. identify any “gaps” in scientific findings and the science of human error applied to mining that could inform this issue, thus help to set a possible research agenda for future funding strategies for NIOSH [National Institute for Occupational Safety and Health].

In addition to a careful review and discussion of written literature, the committee will engage a variety of stakeholders who are invested in the issue of mine safety such as mining unions (e.g., United Mine Workers Association), industry (e.g., through the National Mining Association), other government agencies (e.g., MSHA [Mine Safety and Health Administration], Navy, NASA [National Aeronautics and Space Administration]), and explore accounts of miners who have self-escaped. Also, the committee will be asked to consider any safeguards planned or in place for analogously dangerous situations in which workers could be faced with a life-threatening situation in which they have to self-escape from the hazardous environment to a place of safety. Examples might include civilian or military firefighting, working in certain industrial facilities, undersea construction or exploration, and the setting up of space stations—i.e., situations where individuals may become “trapped” in a life-threatening environment.

Mine Emergencies

We define a mine emergency as an unplanned event that has the potential to cause serious injuries or loss of life and requires the disruption of mining operations and removal of miners from the mine. Given the nature of past disasters and known hazards in the underground coal mine environment (see Chapter 3), we focus on emergencies that are likely caused by explosion, fire, inundation by water or toxic gases, or collapse of portions of a mine.

Self-Escape Timeline

Self-escape in the context of mine safety can be viewed as consisting of eight interconnected stages organized into four phases: (1) prevention/planning; (2) detection; (3) assessment; and (4) escape phase (see Figure 1-1). The prevention/preparation phase is a critically important stage that includes comprehensive and coordinated efforts to minimize hazard occurrences and maximize preparation for adverse events. Workers’ pre-event experiences (prior events, false alarms, training, etc.) can have marked effects on subsequent escape performance.

The “time window” for successful escape opens with the initiation of the hazardous event. During the detection and assessment phases, miners have to recognize and confirm available cues and then make decisions about the severity of the event and the need to escape and through which routes. The active escape phase (organized movement of personnel) does not actually begin until the hazardous situation has been detected, confirmed, and determined to be severe enough to warrant escape or evacuation. In many, if not most, situations timely completion of the detection and assessment phases will lead to better escape performance. Time delay at any stage can complicate a successful escape. Training, communication, and technology are important for each stage and phase.

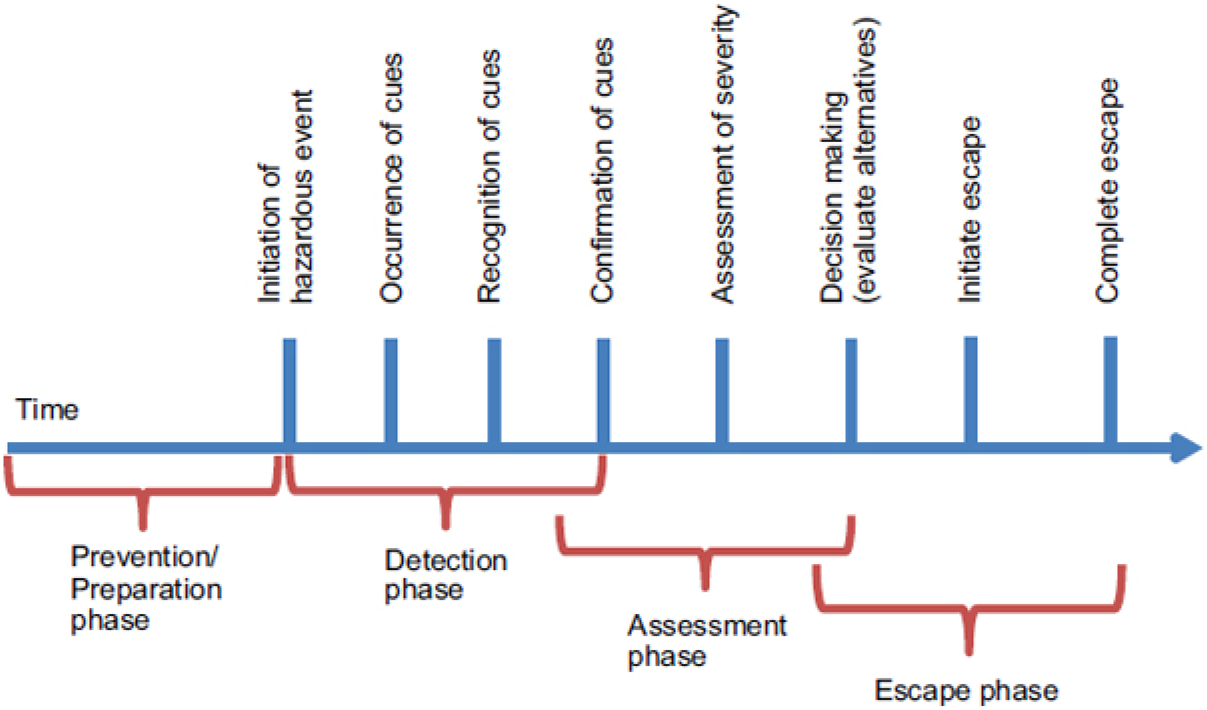

FIGURE 1-1 Timeline for underground coal mine escape phases.
SOURCE: Adapted from Australian Building Codes Board (2005).

HUMAN-SYSTEMS INTEGRATION APPROACH

Self-escape is a task that directly and indirectly involves multiple teams, acting before and during the escape itself, in a dynamic environment. Successful escape depends on available resources, actions of the organization and the miners, and the interactions between them. Human-systems integration examines the interaction of people, tasks, and equipment/technology in the pursuit of some goal (Booher, 2003; Czaja and Nair, 2006), in this case self-escape. This interaction occurs within, and is influenced by, the broader organizational and environmental context (Henriksen et al., 2008). A key premise of human-systems integration is that much important information is lost when the various components of the system are considered individually or in isolation.

A human-systems integration approach acknowledges that people differ in terms of their cognitive, perceptual, and physical capabilities and that these capabilities influence how they engage in different tasks and how they interact with equipment and technology. Tasks, equipment, and technology also have certain characteristics and therefore place varying demands on users or operators. Most broadly, these interactions take place in an organization and are influenced by contextual and environmental factors that can facilitate or impede the successful use of equipment and technology and the completion of tasks. Human capabilities and limitations are considered in the context of a dynamic system that may change based on both external and internal factors (see Figure 1-2).

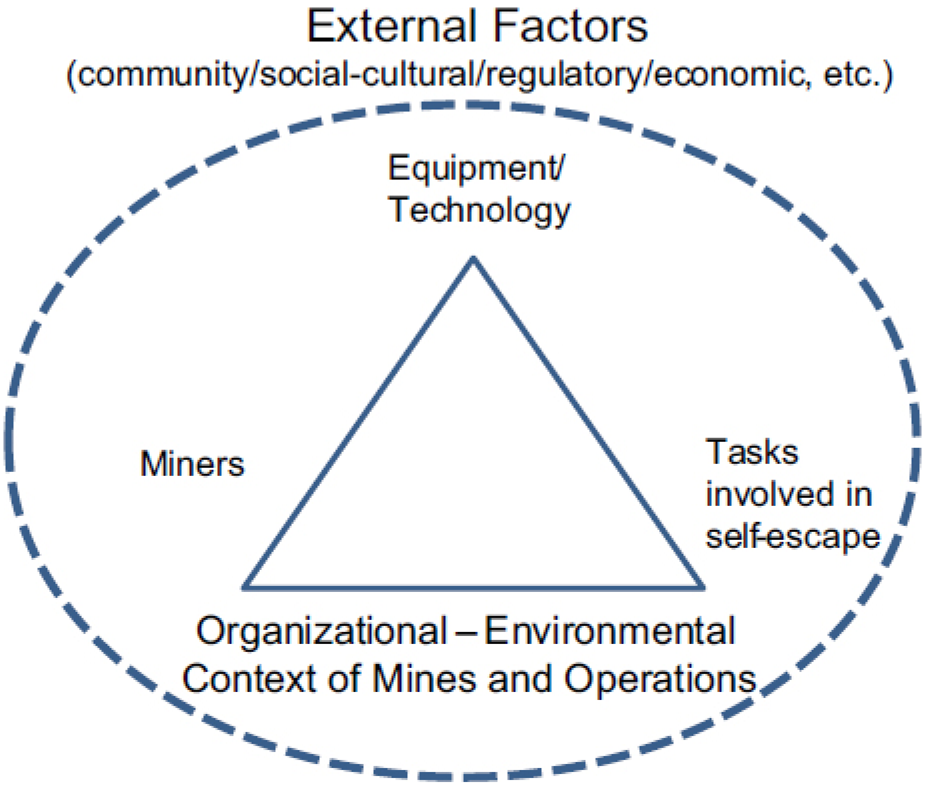

FIGURE 1-2 Human-systems integration model of self-escape.

STUDY APPROACH AND REPORT STRUCTURE

Study Methods

The committee met five times over the course of a year to gather information and deliberate over available research and current practices. The meetings included a workshop and other public sessions in order to hear from a variety of stakeholders, including mine operators, technology developers, representatives from NIOSH and the Mine Safety and Health Administration, and experts in self-escape from other industrial sectors.

To become better acquainted with the coal mine environments and current practices and equipment, the committee visited one mine and one mine training site: the Consol Energy Bailey Mine, an underground coal mine in southwestern Pennsylvania, and the Academy for Mine Training and Energy Technologies at West Virginia University. The Bailey Mine has nearly 500 employees and uses longwall and continuous mining machines to produce about 10 million tons of coal a year. The Academy for Mine Training and Energy Technologies provides emergency response training to hourly and management employees; the training includes hands-on donning and transfer of self-contained self-rescuers in a smoke-filled environment and wayfinding with lifelines with tactile indicators. This facility can conduct classroom activities integrated with environmental simulations of mine emergencies.

The committee reviewed multiple sources of information as background for the study, such as relevant government and stakeholder reports and research, federal legislation (i.e., the MINER Act), relevant code of federal regulations, and investigation reports from recent mine emergencies that included testimony from miners as well as academic literature, particularly that in regard to emergency response in mine emergencies, decision making, safety management, and training.

Report Organization

The next two chapters provide the context for understanding current mine safety and the conditions of mine emergencies: Chapter 2 reviews current efforts in mine safety relevant to the committee's charge, including the regulation of emergency preparedness and the adoption of needed technologies, and Chapter 3 describes the challenging conditions of mine emergencies and examines the task of self-escape and the people and technologies currently involved in it. Chapter 4 considers the relevant decision-science research that can inform self-escape preparations. Chapter 5 looks at the role of a positive safety culture. Chapter 6 looks at both current training for self-escape and lays the groundwork for designing and delivering more effective training. Appendix A reproduces parts of the Code of Federal Regulations that are relevant to self-escape; and Appendix B reproduces the federal form for reporting all mine accidents, injuries, and illnesses.

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[1] The term “mine disaster” historically has been applied to mine accidents claiming five or more lives. Available: http://www.msha.gov/MSHAINFO/FactSheets/MSHAFCT8.HTM [May 2013]. We use the term “emergency” more broadly to indicate accidents or events that have the potential to result in any serious injuries and/or deaths.

2

Mine Safety Regulations and Practices

In this chapter, we consider the regulations related to emergency preparedness, both their context and implementation, as well as processes for the adoption of needed technologies. We discuss mine practices and how they could be improved if information gathered under the normal working conditions unique to coal mining would be used to apply lessons learned to assess the efficacy of current procedures. We end the chapter with our conclusions and recommendations.

REGULATORY CONTEXT AND COMPLIANCE

As noted in Chapter 1, in the United States, the number of underground miners ranges from less than 20 to more than 500 (Mine Safety and Health Administration, 2011). The breadth of mine operations in size, multiplicity, and longevity in the United States leads to separate consideration of small mines and large mines (Yang, 2011). Although opportunities may exist for small mines to benefit from the experience and investment opportunities of large mines, uniform rules or regulations are more often interpreted as forcing small mines to try to keep up with larger mines (e.g., in purchasing power for cutting-edge training, safety systems, and technology). This range of operations across the industry leads to difficulty to proscribe a single, best systematic approach to manage mine safety. Regulations create a process to ensure mine safety that can be effectively applied to all mines, regardless of the mining method, production capacity, number of employees, or other mine characteristics. Consequently, regulations may be generically written to enforce only least-common denominator factors. Regulatory compliance may serve the basic needs of some mines; however, many mines employ their own safety inspectors and have a safety management program that extends beyond focusing only on regulatory compliance.

Housed in the U.S. Department of Labor, the Mine Safety and Health Administration (MSHA) is charged with carrying out regulatory provisions of the Federal Mine Safety and Health Act of 1977 (includes the original 1969 act and amendment in 2006[1]) to enforce compliance with mandatory safety and health rules in U.S. mines. While the Mine Act designates responsibility for mine safety to the mine operator, MSHA is still considered to be a major factor in assuring mine safety (Independent Assessment Panel, 2012). Mine operators have an obligation to comply with the law. That compliance may be an important element of mine safety, because regulations require specific processes designed to prevent emergencies.

In states where both MSHA and state-level agencies exercise authority over mine operations, regulatory compliance is enhanced but can be challenging. Although not all coal mining states have their own legislation, most do, for example, Pennsylvania and West Virginia. In many instances, opportunities exist for the actions of state agencies to positively influence the actions of federal agencies: for example, West Virginia legislation preceded federal legislation on refuge shelters. And in some cases state agencies have stronger safety rules for mines in their own jurisdiction than required by federal legislation: for example, regulations on diesel exposure are stricter in West Virginia and Pennsylvania than those implemented by federal regulations.[2] The committee recognizes the potential value of understanding the differences of state and federal levels of enforcement, including why some states appear more active in mine safety than others or the federal government; however, these issues are beyond the scope of this study.

The most significant federal regulation influencing mine safety procedures in the last decade is the Mine Improvement and New Emergency Response (MINER) Act of 2006. This legislation, largely a response to the Sago Mine and Darby Mine No. 1 incidents, laid out a series of new safety expectations for mine operators. First and foremost, the MINER Act requires operators to develop an emergency response plan specific to each mine, to be regularly updated and approved by MSHA. It also requires rapid deployment of local rescue teams and provides certain liability protection for those working in mine rescue or recovery operations.

Also critical in the MINER Act are penalties: regulatory compliance is a moot point without enforcement capabilities. The act increased both civil and criminal penalties for violations of federal mining safety standards and gave MSHA the ability to temporarily close a mine that fails to pay the penalties or fines. Unfortunately, violations of the law have too frequently been associated with mine disasters, which compliance with the law may have prevented (Independent Assessment Panel, 2012). However, all possible emergency contingencies cannot be anticipated and therefore cannot be prevented through regulation. Compliance is an important component of prevention and a minimum requirement for safety, but it is important to realize that it is only a starting point in a more comprehensive process of managing hazards, promoting safe behaviors and when necessary facilitating self-escape. Ultimately, every mine operator has the responsibility to promote mine safety using every available resource.

In its final sections, the MINER Act calls for the establishment of a Technical Study Panel on the Utilization of Belt Air and the Composition and Fire Retardant Properties of Belt Materials in Underground Coal Mining, additional research to be carried out by the Office of Mine Safety and Health at the National Institute for Occupational Safety and Health, and scholarships. These mandated programs have ushered attention to mine safety as well as to the improvement and development of more advanced communication systems, tracking devices, dust explosibility meters, and shelters and chambers. The committee heard from industry stakeholders who all reported significant safety advances since 2006. Research continues to explore new technologies that will further benefit the health and safety of miners, such as improved ventilation systems, emergency communication and tracking systems, and breathable devices. Research is also being conducted to improve escape training, firefighting preparedness, and rescue training. Independent groups of stakeholders have also played a role in influencing mine safety procedures. The West Virginia Mine Safety Technology Task Force and the Mine Safety Technology and Training Commission have both produced reports with several recommendations to improve mining technology, among other things (see West Virginia Mine Safety Technology Task Force, 2006, and Mine Safety Technology and Training Commission, 2006).

REGULATORY PROCESSES

Enforcement

In recent years, MSHA's highly prescriptive regulatory paradigm and its enforcement have come under criticism (Yang, 2011; Luxbacher, 2012). A recent report analyzing the agency's performance in relation to the Upper Big Branch disaster identified underlying and structural problems in the federal enforcement process for the Upper Big Branch incident as well as five previous disasters. The report also concluded that the current operations are problematic due to the breadth, complexity, and growth of MSHA inspector responsibilities (Independent Assessment Panel, 2012). The task of mine inspection has become one in which "few if any could be expected to succeed … the MSHA IR [Internal Review] Report describes in detail a workforce that is unprepared to undertake the full scope and complexity of inspecting the mines and overseeing the enforcement process" (Independent Assessment Panel, 2012). MSHA's assistant secretary reported that reductions in staffing in the early to mid-2000s, particularly experienced inspectors, affected the agency's ability to complete all mandatory inspections. They have since hired more inspectors; new hires go through extensive training, and the agency has just recently begun to recover the needed expertise and manpower (Main, 2012).

Technology Approval and Certification

Similar deficiencies have been identified with the federal approval and certification process for technology. The mining technologies and products that are used in U.S. coal mines, ranging from small devices to large mining systems, are subject to MSHA's approval and certification process. Equipment, instruments, and materials are evaluated and tested by technical experts for compliance with federal regulations. Organizational, managerial, and resource constraints within MSHA can pose a challenge to the introduction of new technology and mining methods that can improve miner safety and health.

The regulations require a full subchapter in Title 30 CFR, including Parts 6, 7, 14, 15, 18, 19, 20, 22, 23, 27, 28, 31, 32, 33, 35, and 36.[3] A wide range of items are presented in these parts including flame resistant conveyor belts, electrical equipment, intrinsically safe electrical systems, cap lights, diesel engines, to name a few, as well as other technologies specifically relevant to the task of self-escape (see discussion in Chapter 3).

A range of stakeholders informed the committee that the current technology regulatory and approval process in the United States appears to be a deterrent to rapid technological innovation and access to global markets. Furthermore, lack of congruence between MSHA and internationally acceptable requirements for approved equipment frustrates access to global markets for equipment designed for the U.S. market, which hampers the commercial viability of innovation (Luxbacher, 2012).

At various times, MSHA's Approval and Certification Center is understaffed and in need of equipment upgrades to properly test new submittals for compliance with the existing rules. For instance, when new regulatory requirements are established MSHA's workload is increased so that mines can comply with the law. An example of a challenge of this increased workload occurred following the passage of the 2006 MINER Act. The act required all U.S. underground coal mines to have communication and tracking systems. Since the solutions were not yet commercially available, this requirement has driven advancements in technology, known as "technology forcing." As the industry scrambled to find suppliers for these products, MSHA was swamped with new submittals. In many cases, the manufacturers had not fully developed their technologies, but were jockeying for position to hold a place in the line. It took some manufacturers more than 2 years to finalize their products and get them approved. This process also slowed the approval of all other products going through the pipeline at the same time. Clearly, this hampered mine operators' attempts to utilize the latest technologies.

Some foreign companies who have relevant working systems have opted not to incur the costs of approval in the U.S. market when demand is so uncertain. In fact, there is a question as to whether the U.S. underground coal mining market is large enough to generate broad interest from manufacturers of new technologies unless they have an opportunity to capture the lion's share of the market (see West Virginia Mine Safety Technology Task Force, 2006). This situation, known as the "small market" issue, effectively eliminates any opportunity for small companies to overcome the financial barriers to enter this marketplace while simultaneously creating a disincentive for large companies to do so.

In addition, MSHA is having a difficult time recruiting the expertise needed to better understand emerging technologies and how they can be safely applied in the mining environment. The Independent Assessment Panel (2012) report on the Upper Big Branch disaster cited gaps in technical knowledge and practice among the MSHA work force that need to be highlighted and systematically addressed.

Furthermore, MSHA decided to abstain from full participation in an international standard certification effort (Chirdon, 2012),[4] which impedes the acceptance of safety equipment certifications issued by other respected agencies, both domestic and abroad. This factor, along with the time, cost of approval, and MSHA's resource limitations, delays the development and introduction of new technology in U.S. mines.

For a number of years, independent groups, analysts and other stakeholders have recommended that the approval process be expedited and harmonized with international standards. A key recommendation from the Mine Safety Technology and Training Commission (2006, p. 9) report stated, "In particular, MSHA should work to expedite the approval and certification process for technologies that can improve life safety." A similar statement was made more than a decade earlier in 1993 through the National Performance Review (1993, recommendation DOL07):

> The harmonization of MSHA standards with those of industry and foreign governments will allow manufacturers already in the market (as well as those who previously found the industry to be unprofitable) to compete in world markets by permitting a single, globally acceptable product line with better control of replacement parts, reduced manufacturing costs, and improved quality control.

International Standards for Equipment

Some countries, such as Australia, have had success having their national certification process closely aligned with international certification schemes. An internationally recognized certification system, under the auspices of the International Electrotechnical Commission for Certification to Standards Relating to Equipment for Use in Explosive Atmospheres (IECEx), promotes international cooperation on standardization for the safety of equipment in explosive areas where the objective is “to facilitate international trade while maintaining the required level of safety.”[5] Key characteristics include

- Reduced testing and certification costs to manufacturer
- Reduced time to market
- International confidence in the product assessment process
- One international database listing
- Maintenance of international confidence in equipment and services covered by IECEx certification

The IECEx designation is accepted in more than 30 countries.

Australia provides a good example of how participation in the IECEx has expedited the certification process. Most of the relevant Australian (and New Zealand) standards have now been derived from the IECEx standards so they are equivalent if not exactly the same. Testing may be done by an Australian laboratory, but the regulators will also accept certification from other nationally accredited testing stations. The country then has the choice of whether or not to accept certification from overseas stations. If concerns arise, testing agencies undertake a desktop exercise on behalf of the regulators that can take a few days to assess the quality of a certification from outside the country. This approach is much easier and quicker than a full assessment, which can take 12 weeks to 18 months to process, depending on the backlog. In contrast, the MSHA process requires that it does all testing for all equipment. Australian manufacturers, by having IEC certificates done in Australia, can very easily market to the European countries with Australian manufactured products.

U.S. certified equipment may not meet IECEx certification standards and so cannot be marketed internationally without further testing. If IECEx standards were used in the United States, U.S. products could be marketed in Europe and other countries and the “small market” challenge could be reduced.

Part 50 Reportable Accidents

Section 50.20 of Part 50, Title 30 requires a Mine Accident, Injury, Illness Report (Form 7000-1) to be prepared and filed with MSHA for each accident, occupational injury, or occupational illness (see Appendix B). The requirement includes all accidents, injuries, and illnesses as defined in Part 50, whether company employees or a contractor's employees are involved: accidents that are immediately reportable are shown in Box 2-1.

Although separate reporting of incidents requiring self-escape is not required, a review of Part 50 provides the opportunity to consider these incidents as reported on the 7000-1 forms. From an online database of more than 7,000 reports filed for 2006-2011, the committee examined data from all nonfatal reports to identify any incidents requiring evacuation from mines. Using the limited incident narratives, we used the terms "evacuate," "escapeway," "got out," "withdrawn," and "SCSR" (self-contained self-rescuers).

The search identified 22 evacuations without fatalities: 8 due to inundation of water, 5 from inundation of gas, 5 from mine fires, 1 from ignition of methane, and 3 were precautionary because equipment used in a primary escapeway was down or an escapeway was blocked. In all but two cases of mine fires, the fire was extinguished.

From the brief narratives included with the reports, the committee noted conditions that triggered the response to evacuation. These included water flowing into active working areas; detection of elevated levels of carbon monoxide (CO) or methane through readings or atmospheric monitoring system (AMS) alerts; and detection of odor of burning coal. It was not always clear who initiated the evacuation, but the language indicates some sort of order is given, such as: "The mine was evacuated." "Miners were withdrawn." "The CO system sounded an alarm and the section crew was notified." "Based on [the] findings [from two longwall coordinators] a decision was made to evacuate the mine." "The AMS operator was alerted…. Shift Coordinator was notified and investigated. The odor of burning coal was detected and the order was given to evacuate the mine." It was not clear whether SCSRs were donned in any of the incidents.

BOX 2-1
Immediately Reportable Accidents

1. DEATH: A death of an individual at a mine;
2. SERIOUS INJURY: An injury to an individual at a mine which has a reasonable potential to cause death;
3. ENTRAPMENT: An entrapment of an individual for more than 30 minutes or which has a reasonable potential to cause death;
4. INUNDATION: An unplanned inundation of a mine by a liquid or gas;
5. GAS OR DUST IGNITION: An unplanned ignition or explosion of gas or dust;
6. MINE FIRE: In underground mines, an unplanned fire not extinguished within 10 minutes of discovery; in surface mines and surface areas of underground mines, an unplanned fire not extinguished within 30 minutes of discovery;
7. EXPLOSIVES: An unplanned ignition or explosion of a blasting agent or an explosive;
8. ROOF FALL: An unplanned roof fall at or above the anchorage zone in active workings where roof bolts are in use; or, an unplanned roof or rib fall in active workings that impairs ventilation or impedes passage;
9. OUTBURST: A coal or rock outburst that causes withdrawal of miners or which disrupts regular mining activity for more than one hour;
10. IMPOUNDING DAM: An unstable condition at an impoundment, refuse pile, or culm bank which requires emergency action in order to prevent failure, or which causes individuals to evacuate an area; or, failure of an impoundment, refuse pile, or culm bank;
11. HOISTING: Damage to hoisting equipment in a shaft or slope which endangers an individual or which interferes with use of the equipment for more than thirty minutes; and
12. OFFSITE INJURY: An event at a mine which causes death or bodily injury to an individual not at the mine at the time the

event occurs.

SOURCE: MSHA Mine Accident, Injury and Illness Report, Form 7000-1, see Appendix B.

The current Form 7000-1 for reporting injuries and illnesses includes a number of elements that might complement information necessary to monitor and assess experiences with self-escape. The form collects identifying information on mine/contractor and on the injured/ill individual; a crude code for type of accident that is immediately reportable; location and timing of accident/injury/illness; equipment involved (if any); work activity at time of accident/injury/illness; experience of injured, and information about disability and/or return to work. There are two sections for narrative descriptions. The first (#9) provides several lines to respond to the query “Describe Fully the Conditions Contributing to the Accident/Injury/Illness, and Quantify the Damage or Impairment.” The second (#20) provides only one-half line to describe “What Directly Inflicted Injury or Illness?”

Information required with an accident, injury, or illness reportable on Form 7000-1 could be enhanced to regularly characterize any instances in which self-escape efforts were initiated. In the review conducted by the committee, basic information about events that involved evacuations was identifiable. However, there was insufficient detail on such a range of factors, such as whether an SCSR was donned, when the decision to evacuate was made, and the number of miners evacuated. The lack of information may be due to the limited space on the form. If so, the additional data necessary to improve self-escape training could be provided by MSHA personnel with brief written reports of self-escape incidents that are linked to the relevant Form 7000-1.

The committee’s assessment required a word search of narrative sections of the reports and hence was limited to those reports in which the narrative included key words. A more structured inquiry about self-escape experiences (even in the absence of any accident, injury, or illness) could provide important data to enhance understanding of successful self-escapes. If the inquiry included information about escape training and drills, it might prove possible to associate successful self-escape with the quality, timing and frequency of self-escape related exercises.

PLANNING FOR EMERGENCY RESPONSE

The U.S. mining industry has a number of ongoing programs and procedures that promote planning for emergencies. Understanding these was a critical part of the committee's deliberations and development of their recommendations presented later in this chapter and the summary. This section includes a brief overview of four such programs and procedures of particular relevance to the committee's charge: mine emergency and fire evacuation plans, mine emergency response development (MERD) exercises, quarterly escapeway drills, and emergency response plans (ERPs).

Mine Emergency Evacuation and Firefighting Program

Title 30 CFR (§ 75.1502) defines the mine emergency evacuation and firefighting program of instruction. As its title implies, it requires each mine operator to plan and train for evacuations and firefighting. The mine operator's program of instruction is approved at the MSHA district level and must define procedures for:

> (i) Evacuating the mine for mine emergencies that present an imminent danger to miners due to fire, explosion, or gas or water inundation;
> (ii) Evacuating all miners not required for a mine emergency response; and
> (iii) The rapid assembly and transportation of necessary miners, fire suppression equipment, and rescue apparatus to the scene of the mine emergency.

The regulation also requires that miners be instructed on the use and maintenance of SCSRs and refuge alternatives. While it requires training programs on SCSR usage, it does not specify training hours or frequency; instead, it requires that instructors of such training be able to "evaluate whether miners can successfully don the SCSR and transfer to additional SCSR devices." It also emphasizes training programs that use scenarios to encourage discussion of options and optimal decisions given a wide range of potential conditions that could be experienced in a mine emergency. The regulation also includes provisions for training miners on the mine map and locations of emergency equipment and materials, as well as escape routes, all of which are important elements to wayfinding, communications, and self-escape in an emergency.

Mine Emergency Response Development Exercises

All mines are required to have emergency, firefighting, and evacuation plans, but having a plan does not guarantee knowing that it works and how it works. Unless practiced and tested through the use of MERD exercises, system failures in response plans may be hard to identify and could compromise the response process in the case of an actual emergency. MERD exercises are command-center-based training role-playing exercises designed to test emergency response. They are not required by regulation, but MSHA does provide guidelines and allows the option for a MERD exercise to satisfy as a “local mine rescue contest,”[6] of which two of these are required, provided certain conditions are met.

Furthermore, MERD exercises should not only test the plans in place, but they should also test the success of training. That is, have key emergency personnel been trained to competency or simply completed the training time required?

To be maximally beneficial, MERD exercises should not be conducted in isolation. They should include a review of past incidents at other mines and all facets of past response incidents. While it may be tempting to limit participation in a MERD exercise to emergency personnel, including mine management, rescue teams, federal and state government officials, and local emergency responders (U.S. Department of Labor, 2008), the role of additional actors should not be overlooked. For example, role playing to represent the interests and actions of family members, hourly workers, the media, and other individuals and groups could prove beneficial to understanding the impact of the response plan to all the people who may be affected in the case of a mine emergency.

Quarterly Escapeway Drills

Under CFR Title 30 (§ 75.1504 Mine emergency evacuation training and drills), regulations now require that all miners participate in emergency evacuation training and drills and that these should occur at minimum on a quarterly basis. Among other expectations, these activities include

> (a) knowledge of all SCSRs in use at the mine, how the devices function and what might be indications of malfunction, and direct experience in donning the SCSRs and transferring between devices;
> (b) escapeway drills that use different scenarios each quarter, [with] participation by all individuals traveling primary and alternate escapeways in entirety including addressing the different complications present in the different routes, locating and using lifelines as well as locating all relevant refuges and SCSR caches; and
> (c) a sound understanding of the mine map and location of equipment for firefighting and plans for diverting smoke from escapeways.

In addition there will be annual "expectations training" that includes the donning and transferring of SCSRs in smoke or equivalent degraded environment and the use of training units that provide the sensation of SCSR airflow resistance and heat. Individual miners should also experience how to deploy the available refuge alternatives. No assessment of the effectiveness of these drills is required.

Emergency Response Plans

A new safety preparedness requirement included in the MINER Act of 2006 was the ERP to be developed by operators of underground coal mines and uniquely created for each mine. The mine's ERP is updated and recertified by MSHA at least every 6 months. According to the MINER Act (Section 2803), approved ERPs shall

> (i) afford miners a level of safety protection at least consistent with the existing standards, including standards mandated by law and regulation;
> (ii) reflect the most recent credible scientific research;
> (iii) be technologically feasible, make use of current commercially available technology, and account for the specific physical characteristics of the mine; and
> (iv) reflect the improvements in mine safety gained from experience under this Act and other worker safety and health laws.

It is worth noting that many mine operators have, in addition to their required ERPs, emergency response protocols designed to address specific events such as serious injury, search for missing miners, and severe weather. Like the ERP, miners are trained on these protocols.

The MINER Act defines several content areas that must be included in an approved ERP: post-accident communications, tracking, breathable air, and lifelines; training; and local communications. The ERP should attend to the likely survivability of equipment and technology in the case of a fire or explosion and include redundant systems, as appropriate. Further guidance for the contents of ERPs is contained in MSHA-issued program information bulletins,[7] program enforcement letters,[8] and procedure instruction letters.[9] Although the required ERP contents are critical, notably absent are human-systems and human behavioral considerations, particularly those relevant to self-escape. Those considerations could include, for example, the role of individuals (or position duties) involved in an emergency: the responsible person, communication center officer, mine management, underground team leader, and rescue teams.

TESTING EMERGENCY RESPONSE: LESSONS FROM AUSTRALIA

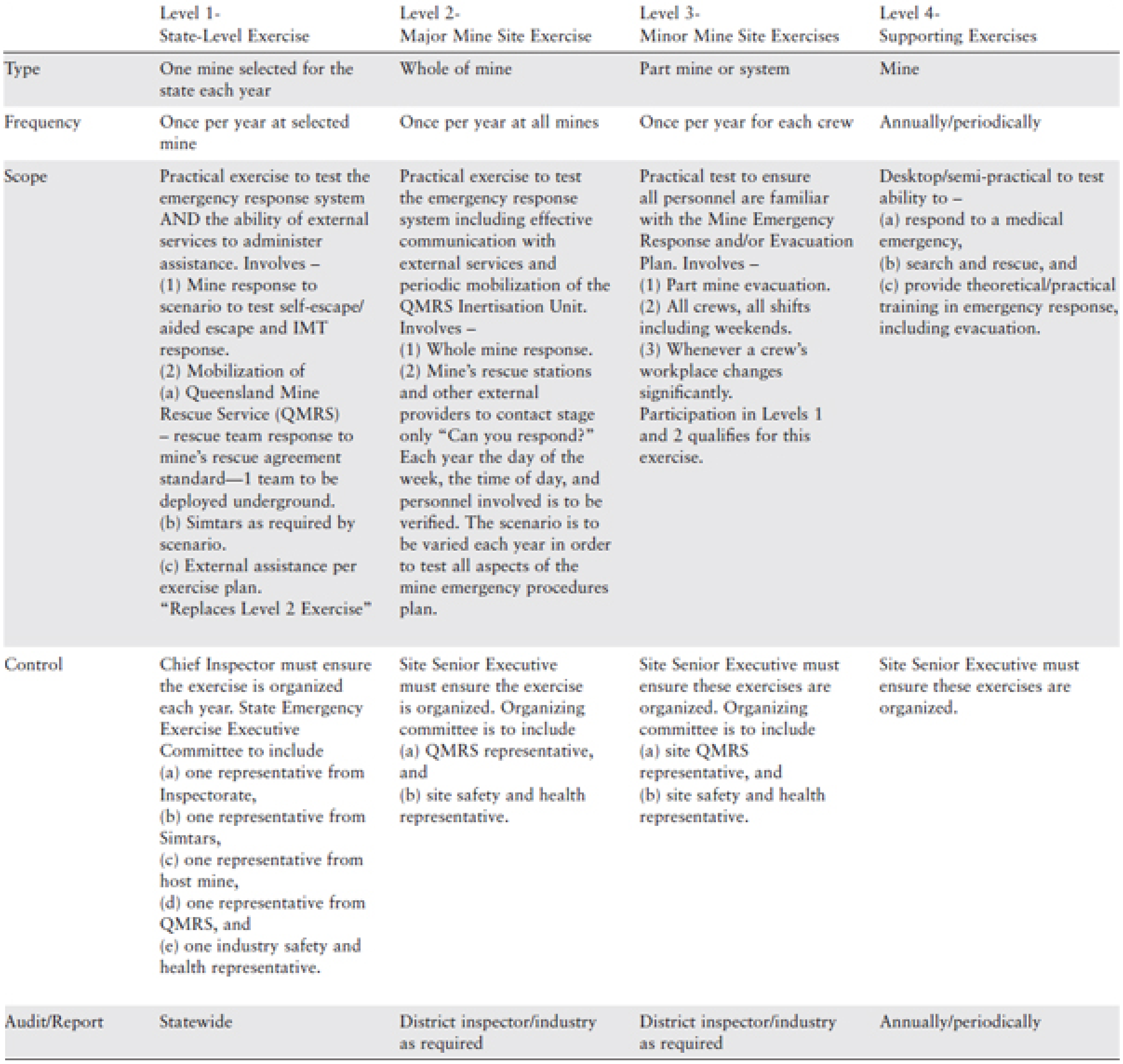
As noted above, testing of an emergency response system must be done rigorously and under the stresses and conditions that would occur during a real incident. In Queensland, Australia, training requirements in mine emergency management are outlined in *Recognised Standard 08: Conduct of Mine Emergency Exercises* (Queensland Government, 2009). Table 2-1 summarizes a hierarchy of exercise types across four levels ranging from statewide exercises to supporting exercises in individual mines. These standards provide a way to meet safety and health obligations, but they are not mandatory. Other ways of managing risk may be adopted. However the method adopted must show that it was at least equivalent to the recognized standard method.

Each year in Queensland[10] the emergency preparedness of one underground coal mine is tested through an audit by a team of external personnel, with up to 50 assessors. The audit team includes **representa**tives from regulators, the mining union, and mining companies, as well as specialist technical experts. The aim of the exercise is to test the whole emergency response system, including interaction with other agencies, the media, and government. It is often these complex interactions that can impede an expeditious and appropriate emergency response.

An incident scenario is developed that is based on incidents at the mine or nearby mines that will require management of the incident and may require evacuation of all or part of the mine. Often there are “injured” personnel to cope with and “lost” or “disoriented” persons.

The process, which has been under way since 1998, has been judged to have resulted in significant benefits for the whole industry (Watkinson and Brady, 2008). Real progress has been made in underground escape, including the introduction of compressed air breathing apparatus (CABA), changeover stations, lifelines, and in seam first response. It has been possible to critically evaluate the status of other initiatives, such as personnel and equipment tracking systems, refuge bays, nonverbal communications, and remote sealing capacity. The exercise has highlighted such issues as the need to be in regular contact with underground personnel during an evacuation and the need to know what has happened and what is happening underground. The reports from each exercise are publically available from the Queensland government.[11] In addition, the findings from each exercise are made available to the mining industry through presentations at conferences and forums to promote discussion and improvement in emergency preparedness (Queensland Government, 2009).

TABLE 2-1 Summary of Queensland Emergency Exercises Standard



	Level 1- State-Level Exercise	Level 2- Major Mine Site Exercise	Level 3- Minor Mine Site Exercises	Level 4- Supporting Exercises
Type	One mine selected for the state each year	Whole of mine	Part mine or system	Mine
Frequency	Once per year at selected mine	Once per year at all mines	Once per year for each crew	Annually/periodically
Scope	Practical exercise to test the emergency response system AND the ability of external services to administer assistance. Involves – (1) Mine response to scenario to test self-escape/aided escape and IMT response. (2) Mobilization of (a) Queensland Mine Rescue Service (QMRS) – rescue team response to mine's rescue agreement standard—1 team to be deployed underground. (b) Simtars as required by scenario. (c) External assistance per exercise plan. "Replaces Level 2 Exercise"	Practical exercise to test the emergency response system including effective communication with external services and periodic mobilization of the QMRS Inertisation Unit. Involves – (1) Whole mine response. (2) Mine's rescue stations and other external providers to contact stage only "Can you respond?" Each year the day of the week, the time of day, and personnel involved is to be verified. The scenario is to be varied each year in order to test all aspects of the mine emergency procedures plan.	Practical test to ensure all personnel are familiar with the Mine Emergency Response and/or Evacuation Plan. Involves – (1) Part mine evacuation. (2) All crews, all shifts including weekends. (3) Whenever a crew's workplace changes significantly. Participation in Levels 1 and 2 qualifies for this exercise.	Desktop/semi-practical to test ability to – (a) respond to a medical emergency, (b) search and rescue, and (c) provide theoretical/practical training in emergency response, including evacuation.
Control	Chief Inspector must ensure the exercise is organized each year. State Emergency Exercise Executive Committee to include (a) one representative from Inspectorate, (b) one representative from Simtars, (c) one representative from host mine, (d) one representative from QMRS, and (e) one industry safety and health representative.	Site Senior Executive must ensure the exercise is organized. Organizing committee is to include (a) QMRS representative, and (b) site safety and health representative.	Site Senior Executive must ensure these exercises are organized. Organizing committee is to include (a) site QMRS representative, and (b) site safety and health representative.	Site Senior Executive must ensure these exercises are organized.
Audit/Report	Statewide	District inspector/industry as required	District inspector/industry as required	Annually/periodically

SOURCE: Queensland Government (2009, Table 1).

This process also places a lot more pressure on mine sites than do internal training exercises and has highlighted the limitations in the incident management process. It also allows the evaluation of linkages with external agencies and the capacity of other mines to render assistance in a timely manner. This in turn has led to the Queensland Mines Rescue Service, which developed the Mine Emergency Management System from the Incident Control System (ICS),[12] which is widely used by emergency services in Australia. The exercises have also provided the catalyst for a number of major research projects that have led to improved capabilities for mine environmental monitoring, improved mine reentry capabilities, and incident management.

During a training exercise, some of the evacuating miners don SCSRs, giving the miners experience in how they feel and operate. This practical experience has greatly increased the acceptance and understanding of SCSRs. Over the years using real SCSRs has also identified a number of design and operational limitations of various units. During the exercises, miners are also often placed in simulated smoke environments. Practical experience in these environments under controlled conditions reduces the level of uncertainty and the fear of the unknown among the workers.

Requiring the testing of an emergency response plan through a rigorous and realistic exercise not only aids training, but also provides a valuable opportunity to improve system and safety performance through the careful and constructive assessment of the plan. The outcome of such an effort contributes to a human-systems integration approach. Information gathered speaks to the effectiveness of current practices and processes specifically with regard to effective decision making and action(s) at both the individual and systems level.

CONCLUSIONS AND RECOMMENDATIONS

The mining industry has made many significant strides forward to mitigate hazards, train miners, and advance mine safety. Improvements in regulations, procedures, and technologies have positively altered the mine environment and consequently reduced the frequency and severity of emergencies. Yet the committee is concerned that improvements in mine safety, especially in regulation, have historically followed major mine disasters. These often draw the attention of legislators to apply what was learned from disaster investigations and enact rules meant to mitigate the specific causes of particular incidents. What has been missing is the consideration of safety improvements in advance of incidents, using available knowledge from research, and consideration of larger systemic issues.

This chapter has specifically addressed MSHA's role relevant to self-escape. However, there are other stakeholders in successful miner self-escape, including other federal agencies, like the National Institute for Occupational Safety and Health, state and local mining agencies, miner organizations, as well as the mine operators and miners themselves. They differ in mission, and these specialized divisions and units add value of depth in expertise. However, bureaucratic divisions also facilitate isolation and discourage unity. Mismatches between needs, standards, practices, and evaluations were a source of frustration to many who made presentations to the committee. The perception (whether factual or not) that advances in self-escape are hampered by the actions of people outside one's own organization is detrimental to both the specific tasks and the strategic mission to improve mine safety. Although the committee does not advocate abolishing these bureaucratic divisions, the need for improved collaboration and integration is paramount.

Regulations and compliance provide a key support to mine safety, but regulations alone cannot guarantee safety. Improving the ability of miners to self-escape cannot be extracted and examined in isolation from the entire system. The operational realities of relationships and interactions between organizations and individuals simultaneously present opportunities and challenges. Although the challenges may seem daunting at times, there are many opportunities that remain unrealized and which could significantly improve mine safety.

CONCLUSION: Efforts on the part of mine operators and other industry stakeholders to empower self-escape in a mine emergency—to include, but not be limited to training, technology, equipment, and emergency response plans—need to be fully integrated and coordinated, using a human-systems integration approach, to establish unified, efficient, and effective protocols. Among the key issues to be considered in pursuit of this goal are robust data collection, careful and constructive assessment of emergency

response plans, feedback mechanisms from miners and mine operators to identify residual challenges and remedies, and active engagement with technology suppliers.

One need to promote a more systemic assessment is a public database populated with pertinent information across a wide range of mine incidents or emergency scenarios to support development of self-escape training and research. Such a database could possibly be populated with data from information already collected, but data relevant to escape from mines are very limited and currently insufficient for analytic and information-sharing purposes. Another possibility is to include data from interviews with select miners to gather knowledge from their experience about emergency situations and how to deal with them. Systematic efforts are needed to collect and analyze regularly information from escape situations and make outcomes and lessons learned available to stakeholders for future improvements. The currently required quarterly escapeway drills provide an avenue for collecting such information with minimum additional impact on mines and miners. Under the regulations, escapeway drills are intended to use different emergency scenarios quarterly to test emergency preparations (e.g., miners' knowledge of their mines, conditions and locations of emergency equipment, use of breathing apparatus, and plans for diverting smoke and fighting fires).

RECOMMENDATION 1: At least annually, and in conjunction with one of the required quarterly escapeway drills, mine operators should conduct a comprehensive self-escape scenario exercise at every underground mine. These exercises should be an integrative practice incorporating the roles of miners, the responsible person as defined in 30 Code of Federal Regulations § 75.1501, the mine communications center, and any other stakeholders that the operator deems pertinent to a successful self-escape, including representatives of the miners where applicable. The scenario should test all aspects of the mine's emergency response plan and mine emergency evacuation and firefighting program to assure that these are effective and up to date. Information gathered from the proposed annual exercises will speak to the effectiveness of current practices and

processes specifically with regard to effective decision making and action(s) at both the individual and systems levels.

Appropriate staff from the National Institute for Occupational Safety and Health (NIOSH) should attend as many exercises as necessary to collect and interpret pertinent outcomes and lessons learned using a standard process. The NIOSH assessment of performance at individual mines of all key personnel, both internal and external, and the effectiveness of emergency response systems should be shared with the personnel involved in each exercise. In addition, a report that has been scrubbed of identifying markers, detailing the outcomes and lessons learned should be prepared and entered into a public database for use by any interested parties to develop better self-escape capabilities (overall practices, policies, technologies, and training). New resources for NIOSH to accomplish this responsibility should be identified so as not to draw resources from critical program elements.

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[1] Available: http://www.msha.gov/REGS/ACT/MinerAct2006home.asp [November 2012].

[2] For West Virginia, see Chapter 22A, Article 2A and Title 196, Series 1, Federal Section 72.502, available: http://www.wvminesafety.org/PDFs/Law%20Rev%202011%20-CORRECTED.VERSION.09.2.11.pdf [November 2012].

[3] Available: http://www.msha.gov/30CFR/CFRINTRO.HTM [November 2012].

[4] 30 CFR Part 6

> permits manufacturers to have their products approved based on non-MSHA product safety standards. [However], this will occur only after MSHA has determined that such standards are equivalent to its applicable product approval requirements or can be modified to provide at least the same degree of protection as those MSHA requirements. To date, MSHA has reviewed the International Electrotechnical Commission (IEC) Standards for Flameproof (Explosion-proof) Enclosures and has found that these standards can be modified to provide at least the same degree of protection as those MSHA requirements. (Chirdon, 2012, p. 7)

[5] Available: http://www.iecex.com/about.htm [November 2012].

[6] A local mine rescue contest is training that provides an objective evaluation of demonstrated mine rescue team skills and can be a MERD exercise or a practical simulation exercise, such as a fire or explosion drill, where the rescue team participates in simulated mine rescue team exercises and wears breathing apparatus.

[7] MSHA program information bulletins are available: http://www.msha.gov/REGS/COMPLIAN/PIB/PIB.HTM [August 2012].

[8] MSHA program enforcement letters are available: http://www.msha.gov/REGS/COMPLIAN/PPLMEN.HTM [August 2012].

[9] MSHA procedure instruction letters are available: http://www.msha.gov/REGS/COMPLIAN/PILS/PIL.HTM [August 2012].

[10] There are currently only 12 underground coal mines in Queensland, employing a total of about 6,500 workers, producing about 30 million tons of coal.

[11] They can be found on the government’s website: http://mines.industry.qld.gov.au/safety-and-health/emergency-excercise-reports.htm [November 2012].

[12] The ICS was first developed in the United States for the management of wildfires in California.

3

Understanding Self-Escape

Chapter 2 provided the context for understanding self-escape in terms of the regulations and safety practices of underground coal mining in the United States. In this chapter, the committee turns to the specific task of self-escape in a mine emergency. One thing that has become clear over the course of this study is that neither the formal statement of task for the committee's work nor the time allowed was sufficient to permit the committee to detail the full extent of the complexities of self-escape. Thus, although this chapter discusses self-escape in some detail, it is intended as an overview of the task.

Our framework for understanding self-escape is provided by concepts central to human-systems integration (see Chapter 1). Human-systems integration studies the relationships among people, tasks, and the tools and equipment needed for them and the environment and broader system within which they must operate. These relationships are examined to optimize safety and performance and to determine better ways to train people: they are particularly important to examine for complex environments that are high stress and potentially life-threatening.

We begin the chapter with discussion of the context of past mine emergencies in which self-escape took place. Next we discuss analyzing the task of self-escape to determine the demands placed on miners and offer a first order look at breaking down the steps of the self-escape task. We then turn to the people and technologies currently involved with self-escape. We conclude with our recommendations.

CONTEXT OF MINE EMERGENCIES

This section reflects a wide range of input to the committee, including information presented to the committee by a range of stakeholders in mine operations, a review of investigation reports from recent mine emergencies (which included transcripts from interviews with miners who escaped), the available research, as well as the knowledge gained during committee site visits to an underground coal mine and a mine training facility.

Since the 2006 MINER Act, a number of safety improvements have been made to emergency preparedness in underground coal mines. Mines have increased their supply of self-contained self-rescuers (SCSRs) with units available to individual miners and caches placed at fixed distances within escapeways. Mine operators have been instructed to train underground coal miners quarterly on the use of SCSRs. Mines have installed lifelines in their primary and secondary escapeways and provided tethers to link miners together in emergencies (National Mining Association, 2009). Improved communications and tracking systems, many with hand-held wireless radios, have been deployed. (The resources available to assist miners during emergencies are discussed in greater detail later in the chapter.) However, because many of the available reports and investigations, as well as the research, reflect experiences in mine emergencies prior to 2006, this summary does not necessarily reflect all the improvements and current conditions.

It has become clear to the committee that the conditions surrounding past major mine emergencies and subsequent escapes were complex. Moreover, we found few commonalities except that there was a problem that necessitated escape and that efforts were made to follow protocol and training to make decisions during the escape. Even in the same type of incident, such as a fire or an explosion, the underlying causes and subsequent failings have varied such that miners’ considerations and reactions are different. The number and type of personnel underground at the time of mine emergencies is also variable. This section illustrates this complexity. We examine the events precipitating emergency incidents, initial responses, the mine environment and what can change in it during an emergency, the physical and psychological demands on miners, and the role of other miners and personnel for support.

Precipitating Events

Across history, most disasters (defined as an incident with five or more fatalities) have been classified as caused by explosions (82 percent of disasters, 92 percent of fatalities) (see Table 3-1). Those caused by fire are a distant second by number of events (7 percent) as well as fatalities (6 percent), followed by ground fall and then inundation. In the past decade, the events causing and signaling dangerous conditions have varied across all the emergencies, including those with no fatalities. Explosions, explosions in sealed areas, fires triggered by belt slippages, rock falls, lightning strikes, water inundation, and roof/rock falls have all necessitated the evacuation of miners from underground coal mines (U.S. Department of Labor, 2002, 2003a, 2003b, 2007a, 2007b, 2007c, 2011; West Virginia Office of Miners' Health, Safety, and Training, 2006; United Mine Workers of America, 2011, n.d.). In some cases, conditions in the mine have exacerbated the situation and increased the danger to miners, such as accumulated coal dust or other combustible materials, poor ventilation, ventilation controls damaged by explosion, missing or damaged firefighting equipment, or the release of toxic gases.

TABLE 3-1 Underground Coal Mine Disasters, 1900 to 2011

Type	Number of Events	Number of Fatalities
Explosion	421	10,419
Fire	35	727
Haulage	21	145
Ground Fall/Bump	14	92
Inundation	7	62
Other	17	199

NOTE: The Mine Safety and Health Administration defines a disaster as an incident with five or more fatalities and classifies disasters by cause and number of fatalities. Disasters due to haulage result from failures in the transportation of personnel, material, or equipment. Disasters due to ground fall or bump indicate the fall of roof rock or outward bursting of walls in an underground work area.
SOURCE: Brnich and Kowalski-Trakofler (2010, Table 1).

Warning signals have been highly variable and have included carbon monoxide (CO) alarms, the smell of smoke or visible smoke, belt stoppages and subsequent investigations of why belts stopped running, visible fires, heat, blasts of air, dust or debris, breathing difficulty, inundations of water, rock falls, and unusual noise.

Initial Response

In some emergencies, warning signals were normalized or dismissed by the miners until they received a notice to evacuate or conditions worsened. As discussed in Chapter 4, this kind of minimizing reaction is common human behavior. However, time is lost, making the efficiency of escape more critical once the necessity of evacuation is determined.

In a study of the first moments of response to an underground emergency, researchers for the National Institute for Occupational Safety and Health (NIOSH) interviewed miners who had survived mine emergencies to gather information on what happens at the beginning of an emergency (Kowalski-Trakofler et al., 2010). Those survivors often credit the outcome to having a good response plan in place and having been adequately trained on the plan. In the first few minutes of the emergencies, miners have sought to gather information and first aim to understand the nature of the emergency, which people are affected, and whether a second event can happen. They often look toward a leader and note that successful leaders appear confident and calm and are able and willing to make decisions.

When faced with a fire or other alarm or notified to evacuate, miners have responded as they were trained—to report to a designated area and assemble as a group. Then they coordinated the evacuation. For nearby fires, miners who have been designated (and trained) for firefighting often stayed behind to try to extinguish the fires. The miners determined whether the mantrip[1] could be used for exit. When it was not, traveling by foot was necessary and a smoke-free path if available was the first choice. When communication was available, the status, location, and plans for evacuation were reported to the surface or nearby sections, usually by the foreman. Groups of miners stayed together and in poor visibility grabbed onto one another. In conditions of dense smoke, heavy dust, or elevated gas levels, miners stopped to don their SCSRs. Investigations of emergencies have revealed that the donning of SCSRs was not always an initial response and was at times put off longer than the conditions warranted (U.S. Department of Labor, 2007a, 2007b; Kravitz and Gibson, n.d.).

Mine Environment During an Emergency

A great deal of variability exists across underground coal mines on many dimensions: geologic features of the seam (dip, undulations, seam thickness variations, etc.), mining method (primarily longwall or room and pillar), equipment selection (continuous haulage, belt, rail, etc.), egress points, and property boundaries. In addition, roof heights vary from very low (low seams are 42 inches or lower) to very high (14 feet). The number of possible exits is also highly variable, with mine configuration and size as well as constraints to provide required communications and ventilation.

Every mine is required to have designated at least two separate and distinct escapeways that meet the requirements laid out in the code of federal regulations (see Appendix A). However, lengths of these escapeways will vary from mine to mine. In some mines, there may be long distances to the mine exit. In recent escapes, miners have traveled the primary escapeway, track entry, intake air course, or belt entry to exit the mine. In one emergency, miners had to travel approximately 3 miles to reach an exit (U.S. Department of Labor, 2007b).

In some mine emergencies, resources that are usually available were not. In several incidents, the mantrip could not be used or later became unavailable because of heavy smoke or debris on the track, and the miners had to travel out of the mines on foot. Similarly, in fires in which the fire or heat destroyed equipment, communication was lost or incomplete (e.g., in the Fairfax Mine fire underground miners could hear the surface but the surface could not hear them). Other equipment, such as fire suppression systems and ventilation controls, was also damaged in some incidents.

Heavy smoke or dust (or both) made the atmosphere less breathable and decreased visibility in several events and was present in some paths or sections though not others. In poor visibility, miners reported using the coal rib[2] or other miners to guide themselves out. The atmosphere also can be toxic: in some incidents, miners died of CO poisoning or others were found with significant amounts of CO in their blood.

Physical and Psychological Demands

Known and unexpected conditions (e.g., heat, limited visibility, low ceilings, obstacles, effects of CO) and escape requirements (e.g., wearing SCSRs, walking long distances and inclines) have taxed miners' physical and psychological abilities. Miners of varied ages from their 20s to their 60s, and likely varying abilities, have been involved in past emergencies. Emergencies put everyone in nonroutine roles where they have to make decisions in relatively unfamiliar and stressful circumstances. In recent events, added stresses have included loss of communication either through equipment damage or use of the SCSRs, smoke and loss of visibility, unmarked doors and paths, and missing crew members. Miners have reported feeling scared; some have reported paralyzing fear when faced with concerns about physical capabilities, families, and imminent dangers (Kowalski-Trakofler et al., 2010).

Recent investigations have uncovered the difficulties miners encounter when donning SCSRs. Difficulties have included problems taking the SCSRs out of the carrying pouches and finding the lanyards to activate the units, perceptions that the units are not working, feelings of nausea, and loss of the units' safety goggles (U.S. Department of Labor, 2007b). In addition, despite warnings and obvious hazards, miners have not put the units on if they felt they could breathe well enough on their own or believed the ability to communicate or yell was more important (West Virginia Office of Miners' Health, Safety, and Training, 2006; U.S. Department of Labor, 2007a, n.d.-b). In some cases, after donning the SCSRs, individual miners took the units off to communicate to or yell for other miners (U.S. Department of Labor, 2007b).

Some members of the committee had the opportunity to experience simulated conditions of a mine emergency in a training mine. A quarter-mile walk in heavy theatrical smoke and wearing SCSRs took us 25 minutes. Although some experiences were anticipated—inability to see in the smoke, inability to talk when wearing SCSRs, discomfort with SCSRs, and heat and other limiting conditions—we concluded that these difficulties are not fully appreciated or understood until experienced. We found that being among the group, holding the lifeline, and having visual experiences (reflections from headlamps on the smoke or reflectors on the miners' vest or in the mine) created some comforts during the drill. But losing sight of one's fellow miners for short periods, as well as the slow movement, heat, sweating, and dry mouth created mild anxiety.

Other Miners and Personnel

The committee was told often that miners stick together as a group to the extent possible. They are a highly cohesive population with a special bond. We know from the research that leaders emerge in emergency situations and that these people are not necessarily the day-to-day leaders. These leaders who emerge have been recognized as aware and knowledgeable, open to input from others, decisive yet flexible, having a calming influence and the ability to gain followers' confidence, and logical decision makers (Kowalski-Trakofler et al., 1994).

For the most part, the people involved in emergency events have been able to account for miners who are underground and have demonstrated working knowledge of their locations at the start of the events, as well as potential paths for egress. This has broken down when communications were lost and conditions in the mine became unknown. For example, in the 2002 Fairfax Mine fire, with communications down, a group of miners who went back into the mine to look for a section crew did not cross paths with the exiting group. The section crew exited well before the searching miners gave up and exited the mine (U.S. Department of Labor, 2003b).

Although most underground mining personnel are directed to evacuate in an emergency, some miners have roles to try to mitigate the situation or have done so in the process of evacuating. They have fought fires, and some of these fires were extinguished in a short period and others were not. They have opened air-lock doors to clear smoke and made other adjustments to ventilation.

It is clear from investigation reports that communication is important. When possible, there were frequent calls to the surface to get and provide information. As miners with supervisory roles entered and moved about the mine to assess the situations, they provided information to those underground. When conditions warranted wearing SCSRs or otherwise restricted verbal communication, miners who were grouped together found ways to communicate, either by using standard head lamp or hand signals or writing in notepads or in the dust.

The preceding discussion summarized what the committee learned about the nature of self-escape from past emergencies and disasters (U.S. Department of Labor, 2002, 2003a, 2003b, 2007a, 2007b, 2007c, 2011; West Virginia Office of Miners' Health, Safety, and Training, 2006; United Mine Workers of America, 2011, n.d.) and from what was reported to the committee. We now discuss how to formally analyze the task of self-escape and why it is important to do.

ANALYSIS OF SELF-ESCAPE TASK

A critical aspect of preparation for successful self-escape is a thorough analysis of the processes associated with escape. NIOSH reported to the committee that a formal task analysis of the self-escape task from the miner's perspective has never been done. Given the limited time and resources available to the committee, a full analysis of self-escape could not be conducted. However, it is an important next step toward the development of future training for self-escape. See further discussion in Chapter 6 on the development of training.

Comprehensive task analyses describe in detail the behaviors, technology, and procedures that must be performed and the information that is required in an uncomplicated version of the task, and they provide a reference for identifying training competencies, decision points, key communications, and needed resources. To fully understand the demands placed on miners in a self-escape task, a comprehensive and systematic analysis of the set of decisions and actions during the detection phase preceding escape, during the escape process itself and those following escape would be required. Components of the team and system within which these actions would occur would be included in the analysis. Consideration of system features is a necessary supplement to task analysis and critical incidents analysis and will also inform any needed training.

A systematic analysis of the activities that comprise self-escape would yield a number of benefits. First, the concept of self-escape itself would be defined crisply, so that subsequent discussion can focus on a clearly understood set of activities and behaviors that occur within a certain period of time. Discussion regarding aspects that are unrelated or only marginally related to this task, such as mine rescue, can be treated as such.

Second, human behaviors, decision points, information that is required to make good decisions, use of available technology, and critical interactions between people can be made clear. When these facets are clear, it is possible to understand the full spectrum of demands that self-escape makes on individuals, as well as the human competencies and technological capabilities necessary to effect a successful self-escape.

Third, following from the above, once what is necessary is clear, it becomes apparent what is missing to support the miners and key personnel, especially in the areas of information, training, and technology. These benefits immediately pertain to the self-escape task and are consistent with those noted in recent research by Brannick et al. (2007), Wilson (2007), and Pearlman and Sanchez (2010).

There are a number of ways to perform an analysis of a work process (Brannick et al., 2007). The self-escape task, given that it is a relatively rare event in the United States, may be most amenable to analysis by the critical incident technique (Flanagan, 1954). This kind of analysis calls for the specification of incidents of excellent and poor performance in the work process of interest—in this case, self-escape. Job holders and other knowledgeable individuals are asked to specify the context that led up to the incident, what steps the individuals involved took, and what the consequences were. The method offers useful information for the development of safety programs and training.

A thorough analysis of the self-escape task by this method would require time and systematic methodology. Structured interviews with veterans of past emergencies, disaster survivors, experienced trainers, and other knowledgeable people would have to be conducted; transcripts of post-accident hearings and depositions would have to be combed; the available research would have to be reviewed; and any other pertinent information or data would have to be gleaned for additional insight.

Another approach that would be needed to supplement critical incidents analysis is what can be termed task analysis. In such an analysis for self-escape, the goal would be to describe the sequence of events, decision points, and actions taken by miners who are confronted with an emergency from which escape is mandatory, without regard to successful or unsuccessful outcomes (Brannick et al., 2007). Following the listing of these elements, one can identify and evaluate what are termed the KSAOs: knowledge (e.g., knowledge of location of SCSR caches), skills (e.g., skill in donning an SCSR), abilities (e.g., ability to lead a team in an escape), and other personal attributes (e.g., safety values) needed to accomplish the escape process.

It is important to note that every mine disaster has been and will be different because of the complexity of a mine emergency situation. For instance, when a mine explosion occurs, the path of destruction cannot be fully anticipated. When a mine fire occurs, the miner’s location is not the only determining factor to a successful escape. For instance, the fire may cause damage that blocks pathways, or ventilation disruption may cause air flow direction to change or methane to build up.

For demonstration purposes, we present a rudimentary example that illustrates the concept and benefits of analyzing the task of self-escape and provides a direction on which others can build. The committee chose to analyze self-escape from a fire in a coal mine. In our example, the task is definitively bound at the beginning by the onset of the emergency and at the end by the arrival of the miners on the surface. The human activities that occur between these two times are further limited to those activities performed by the miners to escape the mine and those activities performed by the personnel on the surface to support the miners’ escape. The actions and decisions needed in our example are shown in Figure 3-1. As part of the process, we envisioned challenging conditions and obstacles in order to identify those difficult decision points at which the availability of more information, either before or during the event, the miner(s) could make better decisions.

Underlying the entire process of self-escape is the ever-present need for information to inform decision making. Once escape starts, decision making is influenced by protocol and changing events and therefore must be dynamic, allowing for unexpected circumstances besides the initial hazard. Depending on events, miners need to know many things in order to make good decisions for a successful escape, such as: Where is the fire located? Is the fire spreading and, if so, where? Where are my fellow miners? Is anyone injured or trapped, and, if so, where? Which escapeways are clear of smoke and carbon monoxide? Should we enter a refuge? How far is the next SCSR cache? Which way is outby? Key personnel on the surface also want the answers to many of the same questions.

If decision points and information are to be probed, researchers may benefit from using a cognitive task analysis approach (Crandall et al., 2006, provides a very clear explanation). This procedure brings to light the information needed at a critical decision point, what information was used, and how it was applied. Although this approach is likely to be excessive for all escape decisions, it may be helpful in understanding the decision making at one or two critical junctures, both in the mine and for surface personnel.

A key outcome of a detailed systematic task analysis, as indicated above, is the precise identification of KSAOs critical to a successful self-escape. These KSAOs will provide the general blueprint for self-escape training programs. Within this blueprint, the specific training content and instructional design would be derived from a detailed breakdown of tasks that show the stimuli faced by the miner in an emergency, the context and variations that may be encountered (which would be derived from critical incidents analysis), the information processing needed for decisions (derived from a cognitive task analysis), and the responses that should follow. Without this detailed information, training is not likely to be designed successfully. (See Chapter 6 for further discussion on developing training programs.)

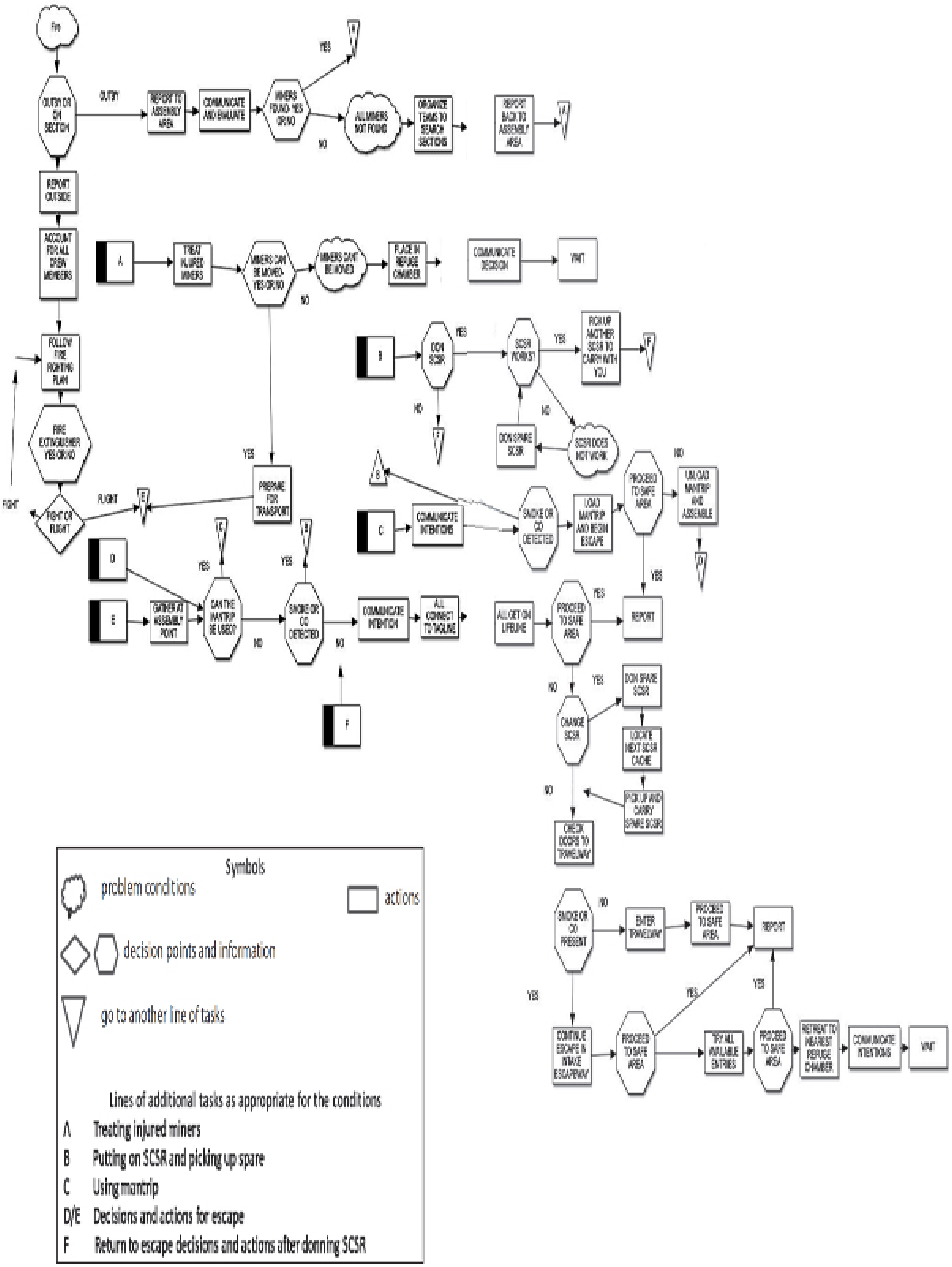

FIGURE 3-1 Self-escape reference task exercise.
NOTE: CO = carbon monoxide; SCSR = self-contained self-rescuers.

SYSTEM ASPECTS OF SELF-ESCAPE

Over many years the mining industry and its labor force have responded to the evolving technology and the lessons of emergencies to develop roles for the people that would be involved in emergency response and the technologies to aid them. We now turn our attention to describing the current state of persons and technologies that would be involved in self-escape.

People

When a mine emergency requires the escape of even one miner, many people play important roles. We organize our review of the system of people who contribute to a successful escape in three categories: (1) the individual, (2) the group or team, and (3) the communication centers and responsible persons. While these groups have a significant role during self-escape, we note there are many other people who have roles prior to the need for self-escape. Their roles include establishing and maintaining safe working conditions and preparedness for emergency responses. This requires an ongoing, high level of effort prior to any emergency to create a shared understanding of all parts of any response to nonroutine circumstances. They provide the miners and key surface personnel (e.g., communication centers) with an infrastructure and resources with which they can make decisions and take action during the emergency and with effective training to use those resources. (See Chapter 2 for an overview of current safety practices and Chapter 5 for a discussion of safety culture.)

Individual Miners

Individual miners enter the mining industry along a well-traveled route of training in the job tasks required by the different technologies and in the safe practices required to protect them and their coworkers. New miners wear a different colored hard hat so they can be recognized by all miners as in training, such as the “red hats” in West Virginia (West Virginia Office of Miners’ Health, Safety, and Training, n.d.). This identification lasts a minimum of 6 months (108 shifts) and provides a new miner with time to learn his or her role while being recognized as an apprentice miner.

Although mine operators vary in the training offered to new miners on technology and health and safety, MSHA rules require that all miners receive a minimum of 40 hours of training on health and safety in their initial year and then 8 hours annual retraining thereafter.

A recent study by NIOSH found that the majority of coal mine employees are male (96.2 percent). A vast majority is white (96.4 percent). The remaining population in this survey is American Indian and Alaska Native (2.5 percent) and African American (1.2 percent). Based on ethnicity, 1.9 percent of the employee population was identified as Hispanic. The study also found that 93.8 percent have at least a high school education; 16.8 percent reaching an education level beyond high school (National Institute for Occupational Safety and Health, 2012).

Although we could not find data on other population characteristics, based on what we heard from industry representatives, we would expect, in terms of mental and physical capabilities, that the work force in underground coal mining generally reflects the overall U.S. working population. As such, some miners can be expected to suffer from various chronic conditions and diseases, be overweight or obese, be middle-aged or older, and have relatively poor levels of physical fitness, roughly in proportions similar to the overall population of workers.

It is reasonable to expect that some miners will be significantly challenged to escape unassisted from a coal mine. From a general safety perspective, the usual approach in such situations is to make escape as easy as possible and to anticipate that some people will need assistance in escaping. Measures taken to provide this assistance typically include assistive equipment and devices, trained personnel within the work unit, rapid intervention teams, rescue equipment, refuge or shelter-in-place facilities, and locator and communication systems or protocols.

In developing self-escape strategies, mine operators need to take into consideration the variability in the physical abilities of the miners, the contingencies that arise if a miner becomes injured, and the potential conditions created by an emergency.

Groups or Teams

The group cohesion and social solidarity of coal miners in their typical environment affects escape behavior when a group of miners confronts an emergency (Vaught, 1991; Vaught et al., 2000). For example, Vaught et al.

(2000) note “that when a major fire occurs in an underground coal mine, a new type of group will be formed: an escape group. This group may be made up exclusively of members of a work crew, or it may be a group of individuals who have little or no previous experience working together. [Either way], the escape group must handle tasks very different from those that are part of their routine work activities. The physical environment and new emergency tasks will help define group dynamics and decision making during an escape” (p. 3).

When miners are placed into an emergency situation, they are not likely to function as well as an established, tightly functioning team whose members have been trained to fill key roles and work together in emergency situations. In team effectiveness terms, one can generally expect weak teams and diffused responsibilities. This expectation is in no way a criticism of miners, but rather reflects what is known about creating effective teams to function in hostile and high-hazard settings and occupations. At the same time, miners have also historically worked very well in these situations, and many escapes have been made safely and successfully (see detailed discussion on relevant team training for self-escape in Chapter 6).

It is important to remember that the training and organization of miners is optimized for the production of coal and may not necessarily create an effective team to escape. Moreover, applying principles used to train crisis or emergency personnel (e.g., firefighters or military special operations personnel) may not be an appropriate, practical, or effective strategy. The primary task of coal miners is to produce coal, while the primary task of crisis or emergency personnel is to deal with that crisis or emergency. Furthermore, conditions related to personnel selection, practice and rehearsal, team building, situational exposure, and command and control structures cannot be readily duplicated. Creating such teams has proven to be a challenge even in the modern military due to rotating deployments, service rivalries, complex technical systems, and other various incompatibilities.

Communication Centers and Responsible Persons

Communication centers are instrumental supports to the decision-making processes for miners who are attempting to evacuate the mine. Communication centers may be located immediately at the mine’s surface, or they may be situated as a regional center, operating some distance from the actual mine emergency. Regardless of their location, however, communication centers are an information relay and processing hub. As illustrated in the simplified task analysis delineated above, the information exchanged between miners and communication center personnel (if clearly, correctly, and successfully communicated) informs the choices made by the escaping miners at critical junctions in the process. A communication center must be able to communicate information and update miners when new information becomes available. Critical in this communication network is the "responsible person" (see description in Appendix A), who should ideally be located above ground, have access to information, have the ability to communicate effectively, and be familiar with the emergency response plan (ERP). Attention to adequate special training for these individuals needs to be recognized, especially in decision making and other nontechnical skills (see further discussion on training for responsible persons and responsible person teams in Chapter 6).

The effectiveness of an escape process will be influenced by the extent to which the communication center roles are clear to all, the personnel have been trained to sort and transmit reliable information, and the available resources have been properly aligned with the information needs of the miners, the emergency personnel, and miners' families. Consequently, the communication center personnel and their activities during an emergency have to be regarded as an integral part of the miners' self-escape toolkit.

Technologies

A range of technologies equip miners to be successful in self-escape. Some of these are part of the technology for routine mining, but most are uniquely designed for health and safety maintenance, as well as self-escape. Current essential technologies that are available to miners and relevant to self-escape include sources of oxygen, gas monitors, wayfinding, communications and tracking (including miner-to-miner and miner-to-surface), and refuge chambers. This section discusses each of them and their current limitations.

Sources of Oxygen

In any mine emergency, access to breathable air is critical to survival. As described above, lack of oxygen and the presence of poisonous gases may occur during a mine emergency. Therefore, the development of technologies that provide sources of oxygen to miners have been a key focus of safety efforts. An overview of currently available oxygen sources is provided in Figure 3-2. Systems that supply either oxygen or air can be split into two types: those that operate on a closed circuit and those that operate on an open circuit or a once-through system.

Closed circuit or rebreathing systems provide oxygen and remove moisture and carbon dioxide from the breath. These are normally termed self-contained self-rescuers (SCSRs). The oxygen can be supplied through a chemical reaction initiated by the moisture in a person's breath. Other SCSRs provide breathable air through a cylinder of compressed oxygen and remove carbon dioxide using either lithium hydroxide or soda lime. Typically, an SCSR weighs 3 to 6 pounds and is worn on a miner's belt. To use an SCSR, a miner has to insert a mouthpiece into his or her mouth, which significantly hampers or prohibits verbal communication with spoken words. When using an SCSR device, breathing resistance increases over the operating time, and heat associated with the production of oxygen in the unit can increase to the point where it is severe enough to cause superficial burns.

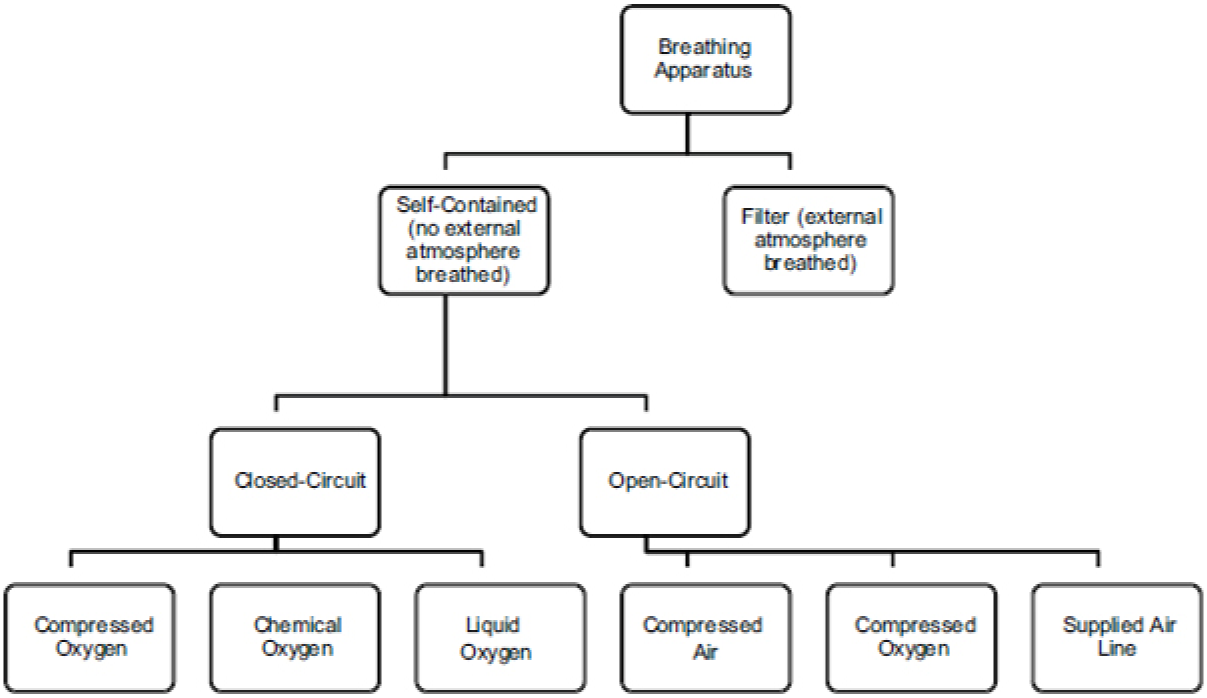

FIGURE 3-2 Classification of respiratory escape apparatus.
SOURCE: Adapted from Bollinger and Schutz (1987).

Open-circuit systems provide air or oxygen under positive pressure from a compressed gas cylinder. Compressed air breathing apparatuses (CABAs), which have a full face mask rather than a mouthpiece, are gaining wide acceptance in the Australian mining industry. They offer the capacity to overcome a number of the issues when using a closed-circuit SCSR, including the heat-generated, limited flow rate available, and the user's inability to communicate with spoken words. CABAs can be quickly refilled by underground miners from banks of cylinders or from a compressed air line without the need for the miner to take it off. CABAs are much heavier than most SCSRs, weighing approximately 20 pounds for a single cylinder and up to 40 pounds for a twin cylinder system. The twin cylinder system can supply air for more than 90 minutes. Currently, CABA (open-circuit) systems are used in the United States in only one mine in New Mexico. It should be noted that a belt-wearable SCSR (closed-circuit device) is necessary to reach a CABA storage area, and a transfer from the SCSR to CABA is required.

Both open and closed systems have a limited life (10-90 minutes) and require change-out to replacement devices during a prolonged escape or rescue. Their use requires that miners are trained to replace devices during escapes without inhaling ambient air, which could be toxic. This need to change-out also means that additional units need to be strategically positioned around a mine and units in use swapped with them before being exhausted or refilled if applicable. Though the number of changeover stations vary by mine depth and size, it is quite possible that up to five changeovers could be required for a mine worker to exit a larger mine (Brady and Xu, n.d.).

Gas Monitoring

Real-time gas monitoring is critical in the mining industry, both to alert miners to adverse conditions that have the potential to be controlled and to provide them with essential information during escape (Brady, 2008). Ideally, in an emergency, every miner should know two things: the quality of air at current location and the quality of air in nearby areas (especially along possible escape paths).

Information about a miner's current location is normally achieved through the use of personal gas monitors that can measure the major gases of interest: methane, CO, carbon dioxide, oxygen, and oxygen deficiency. Other gases, such as oxides of nitrogen and sulphur compounds, can be included. These devices are generally issued to supervisors or foremen and maintenance employees and to equipment operators, such as miner operators, roof bolters, and mine examiners.

Information about air quality in nearby areas is much harder to acquire. In the United States, fixed gas monitoring is usually located only in the conveyor roadways to detect carbon monoxide from conveyor belt heating. All coal-extracting mining equipment in the United States have methane monitors: on longwalls, they are also located on the shearer, midface, and on the tailgate drives. Stationary CO monitoring equipment is usually located at battery charging stations and diesel equipment and fueling storage locations. Other sources of information can come from fan charts, which are located at air shafts, and in many cases mine seals have monitoring systems in place as well.

In Australia, fixed gas monitoring systems are mandatory in return roadways from all operating sections of the mine and unsealed goaf areas,[3] as well as at the upcast fan shaft(s) (see, e.g., Queensland Consolidated Regulations, 2001). These systems comprise banks of sensors or tubing that extract the mine air and transport it back to the surface for analysis (a tube bundle system). They continuously monitor the air for methane, CO, carbon dioxide, and oxygen. In addition, in Australia, monitoring of conveyor belts is required, and it is common practice to monitor sealed areas for products of oxidation on a regular basis. Monitoring is also becoming more common in intake roadways.

Equipment-mounted methane detectors are fitted to a wide range of equipment, usually to ensure that miners do not operate in flammable atmospheres, with automatic cutoffs to remove power before this can happen.

Wayfinding

Effective wayfinding out of the mine depends on miners knowing where they are and which paths lead to the outside (outby). Wayfinding technologies currently consist of signage, lifelines (metal or, less preferably, polyethylene lines containing tactile directional and resource information), and headlamps for light. Communication technology is also critical for wayfinding. These technologies are vulnerable to explosions, fire, smoke, and other conditions present during escape. For example, headlamps will fail when batteries run down, signage can be blown away, and lifelines destroyed or melted (if made of polyethylene). These technologies can be supplemented by more reliable ones that are hardy under emergency conditions. Examples of these include glow sticks and chemical light sources that last 8-12 hours, and passive tactile location and direction indicators embedded in the physical mine environment itself. An example of the latter would be a metal configuration of rivets on the door frames indicating outby direction. In addition, miners could be provided with tools, such as a cane, that would enable them to feel the environment and recognize key features, such as conveyors and overcasts, without endangering themselves.

Signage. In an emergency, knowing one's current location and that of the nearest escapeway is vital. Good signage can assist in this process. Given the possibility of low visibility because of smoke or other conditions, any emergency signage needs to be highly reflective and visible under low-light conditions (e.g., a cap lamp). Current regulations have requirements for certain types of signage such as that for SCSR storage (e.g., CFR 75-1714-2) dictate:

> A sign with the word "SELF-RESCUER" or "SELF-RESCUERS" shall be conspicuously posted at each storage location and shall be made of reflective material. Direction signs made of a reflective material shall be posted leading to each storage place.

See Appendix A for further information on the requirements of federal regulations relevant to self-escape.

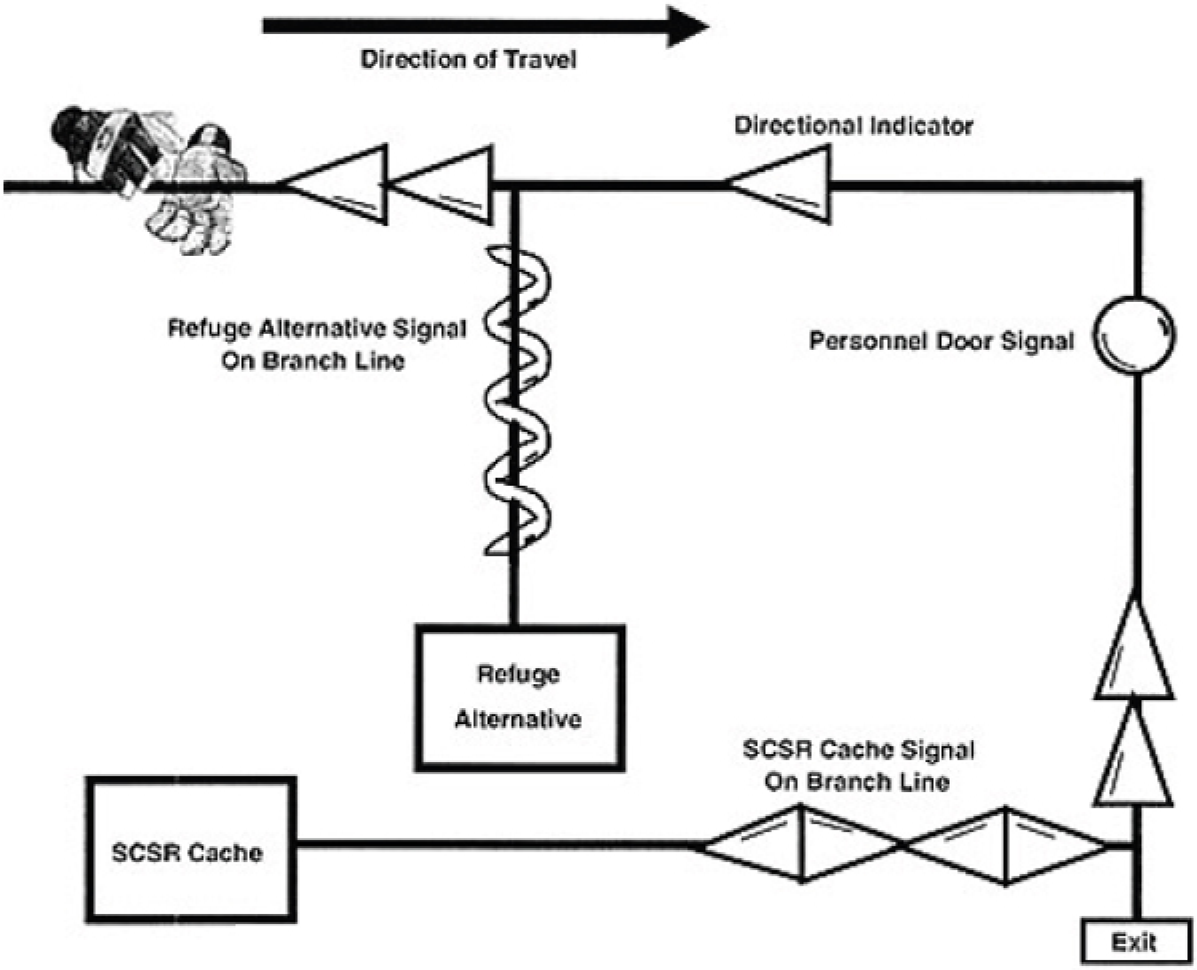

FIGURE 3-3 Lifeline indicators.
NOTE: For explanation of cone directions, see Appendix A.
SOURCE: Title 30 CFR § 75.380 (Illustration 1).

Lifelines. Current standard practice for guiding miners through designated escapeways is to install lifelines. Lifelines are fitted with directional cones to indicate the correct traveling route. In low-visibility environments, these cones are intended to be felt through a gloved hand. Current regulations (Title 30 CFR § 75.380) specify such things as minimum distances between cones. They also outline the other types of indicators (tactile shapes) that must be used on a lifeline to indicate such things as a personnel door, refuge alternative on branch line, and SCSR cache on branch line (see Figure 3-3).

Vision. Since low light and heavy smoke are quite possible in mine emergencies, miners would need equipment and technologies to protect and supplement vision. Currently, miners rely on their cap lamps for both lighting to aid vision and as a signaling device (e.g., miners can communicate with each other through head motions). The cap lamp is a technology that is heavily engrained in the culture and behavior of miners. Older lamp technology remained largely unchanged for more than 20 years (Lewis, 1986), but cap lamps are now produced with lighter weight batteries, cordless headpieces, and LED (light-emitting diode) lights.

Goggles or eyeglasses are another vision technology available to miners. Their primary function is to protect eyes from irritation, especially from dust, smoke, or other particles in the air or damage from toxic gases. They protect miners' eyes until they can move to an area with a cleaner environment and higher visibility. Currently, miners do not typically have access to goggles or eyeglasses that improve vision (through thermal technologies), but one could imagine ways in which such visual improvements could aid in self-escape.

Communication and Tracking

Maintaining communications between the mine and the surface and within the mine during normal mine operations is not an easy task. Since mining operations are in constant motion, with work at the face moving more than 50 feet a day, communications systems also have to move with the crew. Systems need to be robust to withstand the mine environment—more than 90 percent humidity, potential exposure to corrosive water and dust, electrical properties of coal that can attenuate certain communication frequencies, and a variety of interference sources present (Schiffbauer and Brune, 2006). In addition, any technologies used must be intrinsically safe so they do not create additional hazards underground. In light of these constraints, many mines use a combination of wired and wireless technologies to maintain communication. These systems often rely on mine cables and components that can be destroyed in a mine emergency (Welsh, n.d.).

As noted throughout the report, communication between miners and a surface communication center in an emergency is critical so that miners have real-time information essential to address the situation and to achieve safe self-escape. Communication is equally important among the miners, both those in close proximity and those out of the range of visual contact. The 2006 MINER Act required mines to have redundant in-mine communications systems, as well as a system that allows personnel on the surface to determine the current (or the immediate pre-accident) location of underground miners. This act also directed mines to provide, within 3 years, both two-way wireless media[4] for communication between the surface and miners underground and electronic tracking systems. MSHA maintains a publicly accessible list of communications and tracking systems that comply with MINER Act requirements.

We stress that although technology advances show promise, the failure of such systems remains possible. Consequently, mines should consider low-tech alternatives as backup to record locations and search for miners.

In recent years, there has been continuing progress on improving the nature and robustness of these systems to remain intact and functioning in adverse conditions. However, communication technology needs and gaps persist (see Box 3-1). The committee is concerned that many task force recommendations for improving mine safety technology, such as those from the West Virginia Mine Safety Technology Task Force (2006) and the Mine Safety Technology and Training Commission (2006), have remained "in progress" since they were made, now more than 5 years ago.

BOX 3-1
Communication Technology Needs and Gaps

Integrated Primary and Secondary Communication Systems to Improve System Survivability

- ✓ Mine-specific modeling and simulation tools
- ✓ Improved modeling of the communication links
- ✓ Better understanding of secondary systems
- ✓ Shared definition and quantitative measure of survivability
- ✓ Develop mine-specific modeling tools to be able to assess survivability for:
  - – Any mine configuration
  - – Any installed communication and tracking technology or combinations of technologies
  - – Various types of disasters in various locations within the mine

- Various location of miners

Primary Systems

- Similar to conventional radio handsets
- Use small antennas
- Wearable devices
- Long battery life
- Sufficient throughput for general operations

Secondary Systems

- Unconventional radios
- Unconventional signal propagation
- Require large antennas (not wearable)
- Typically one channel (very low throughput)
- Likely more survivable

SOURCE: Adapted from a presentation to the committee (Waynert, 2012).

Refuge Chambers

Refuge chambers originated in South Africa in the 1970s, and they have been common in the metalliferous mining industry worldwide for more than 20 years (Underground Coal Mining Safety Research Collaboration, 2003). In 2006, the MINER Act required every operator to provide refuge alternatives and specified the components to be included. Refuge chambers must be approved by MSHA. The specifications indicate that refuges must supply breathable air to sustain each person for 96 hours, refuges must have sufficient capacity for all persons underground, refuges must be located within 1,000 feet of working areas, and refuges must be spaced within 1 hour in travel time to an outby area. (See Appendix A for further details on refuge chamber requirements.)

The obvious risks of refuge chambers include the air supply being exhausted before escape; air supply that does not survive the incident or subsequent heat; and, if communications are down, the surface personnel may not know miners are sheltering in the refuge chamber. There would need to be a rigorous maintenance and inspection regime to ensure the refuge chambers were operable in the event of an emergency.

Functional Design of Technologies

It is important to view technology as part of any self-escape system. A human-systems integration approach typically assigns primary importance to the person or persons in the system. As such, it uses well-established and validated human- (or user-) centered design processes (Norman, 1993; Wickens et al., 2004). Although modern technological advances may be awe inspiring, their incorporation into the mining environment may not be in the best interest of the miner. A miner's body has a finite amount of space and strength to carry gadgets. In emergency situations, a miner should not be expected to monitor, understand, and synthesize data from multiple devices presented in multiple formats. In considering options for design improvements of any technology or tool, an analysis should incorporate human-centered design that takes into consideration human factors, such as natural behavior tendencies and ease of technology use in addition to the tasks required to self-escape.

In order for any new technologies to be effective, there are some general requirements which must be met before they will be accepted in the mining environment. Size and weight are critical factors if the technologies are to be used by individual miners during self-escape. A person can only wear or carry a limited amount of equipment in anticipation of an emergency, and if it is heavy or bulky, miners will not readily agree to wear or carry them. These technologies must also be easy to deploy and easy to understand. If miners do not know how to use the technology or do not trust that it will provide them with useful information or protections, they are less likely to use it.

We have identified some functional characteristics of technology that are needed and likely to enhance the transfer of information needed to facilitate and optimize self-escape:

- Tracking: It is critical for the hazard management purposes to understand who is in a mine and where they are located within the mine at any given time. This information should be available to the surface communication center and this information should also be transmissible to fellow miners so that the miners can congregate and form teams in order to optimize their self-escape capabilities.

- Communication: Communication during an emergency that is succinct and effective is essential. Thus, natural verbal communication should be enabled between the surface communication center and the miners, as well as between all miners within an area. Miners must be able to communicate with each other when they are in close proximity to each other as well as when they are within reasonable distance to each other (e.g., nearby sections). Any devices should be wireless, lightweight, easily accessible, and worn on the miner.
- Supplied Air: Sources of oxygen are critically important in potentially toxic environments. Supplied air devices (e.g., SCSRs) should be easy to use and easily accessible. Supplied air devices need to be updated so that they not only permit verbal communication but also accommodate a variety of physical features present within the miner population. Along with training, the devices should be designed with human-factors principles in mind so that they are easily donned and activated. These devices should also consider the human interface in that they should be less cumbersome, provide straps for convenient carrying (e.g., shoulder straps), and provide information about remaining safe air supply time to the user.
- Atmosphere Monitoring: All miners should have access to information regarding quality of the atmosphere especially during an emergency. They should have timely and easy to understand information that easily alerts them to any dangerous atmospheric conditions that are present or developing.
- Signage and Other Landmarks: Standard signage and other landmarks within a mine can help orient a miner during an emergency. Those that can be identified even under poor visibility conditions are necessary to facilitate effective self-escape. An alarm or strobe could serve as an orienting landmark that could be remotely activated to indicate the location of the primary and/or best exit from the mine.
- Wayfinding: Technology needs to be developed that tracks the miners' locations within the mine, information about air quality, fire sources, as well as other hazards, and incorporates this information into an easy to interpret display to enhance wayfinding.

- Directional Technology: Directional information that is usable even under poor visual and communication-deficient conditions is needed to direct miners to escapeways, rescue chambers, additional supplied air devices, man doors, etc. Underground cues to such locations can be provided with simple technology such as lifelines and passive tactile indicators embedded in the physical mine environment itself to provide real-time information to an escaping miner. However, it is important that such directional technologies be designed with human-factors principles in mind so that the miner can most effectively and accurately interpret the directional signals provided by these technologies.
- Vision Enhancement: Vision-enabling technology is needed to permit miners to see though smoke as much as possible.

RECOMMENDATIONS

The mining industry has spent nearly a billion dollars on emergency preparations since 2006 and continues to look for even better technologies. Several areas have been identified as needing upgrades and cooperative efforts are under way that include miners' representatives, operators, technology providers, and the government. Given the challenges facing a miner under emergency situations, it is imperative that the human-technology interface be as efficient and effortless as possible. It is also important that technology survivability during an emergency is given attention in development.

As discussed in Chapter 2, the committee heard from many stakeholders that the current technology regulatory and approval process in the United States appears to be a deterrent to rapid technological innovation and access to global markets, which hampers the commercial viability of innovation.

The operational requirements for emergency supplies of breathable air are in need of revision. An essential component of this interface is to ensure a supply of breathable air for self-escape that will function in a variety of atmospheric conditions. For example, an SCSR should ensure performance against all harmful gases, as well as an adequate supply of breathable air in oxygen-deficient atmospheres. Additionally, filtered devices that only protect against carbon monoxide and do not supply breathable air (used in a small number of mines) should be removed entirely unless specifically justified.

RECOMMENDATION 2: The National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration should review their operational requirements for emergency supplies of breathable air. Furthermore, NIOSH should allocate funds for research and development to improve the functionality of emergency supplies of breathable air, with special focus devoted to resolving a wide range of issues including

- **verbal communication,**
- **positive pressure,**
- **facial hair,**
- **device weight and size minimization,**
- **device changeover or air replenishment in toxic environments,**
- **fit testing where applicable, and**
- **adequate vision through clearing or removal of condensation.**

RECOMMENDATION 3: The National Institute for Occupational Safety and Health, the Mine Safety and Health Administration, and technology companies should accelerate efforts to develop technologies that enhance self-escape. These technologies should use human-centered design principles with specific attention to facilitating improved situational awareness and decision making. The technologies should include, but are not limited to:

- **communications, both miner to miner and miner to surface;**
- **real-time gas monitors that are appropriate for all miners;**
- **fail-safe tracking that is hardened and survivable; and**
- **multifunction devices that combine technology to reduce physical burden and excessive demands on attention.**

RECOMMENDATION 4: The National Institute for Occupational Safety and Health and the Mine Safety and Health Administration should reexamine their technology approval and certification processes to ensure they are not deterring innovation in relation to self-escape technologies that are used in other industrial sectors and global markets. They should collaborate in convening a joint industry, labor, and government working group to identify a range of mechanisms to reduce or eliminate any barriers to technology

approval and certification, which should include exploring opportunities to cooperate with other international approval organizations to harmonize U.S. and international standards without compromising safety.

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[1] A mantrip is a train-like vehicle that transports miners to and from locations within the mine.

[2] The coal rib, or wall, is the solid coal on the side of any underground passage.

[3] The cavity behind the longwall is also known as gob or goaf areas.

[4] Program Policy Letter No. P11-V-13 from the U.S. Department of Labor provides guidance for acceptable alternatives to fully wireless communication systems since this technology is not sufficiently developed at this time. “Examples of currently available technologies that may be capable of best approximating a fully wireless communications system include, but are not limited to, leaky feeder, wireless or wired node-based systems, and medium frequency systems” (available: http://www.msha.gov/regs/complian/ppls/2011/PPL11-V-13.asp [November 2012]).

4

Decision Making

Picture a situation where a coal miner is working and encounters smoke and flying dust. What does the miner do? Don the self-contained self-rescuer (SCSR)? Radio a supervisor? Find out where the smoke is coming from? Immediately set out for a place of safety? Which step comes first?

In this chapter, we explore the role that decision making plays in response to a potential mine emergency. To effectively respond to a mine emergency, miners must have the psychological tools to detect signs that an emergency exists and then use these tools to make effective decisions about how to act. In short, effective *decision making* is critical for ensuring that miners can extract themselves to a place of safety in an emergency.

We take a human-systems integration approach to understand decision making in a mine emergency. Our intent is to highlight knowledge about human strengths and limitations in the context of an interactive system of people, equipment, and their environment that will be useful for preparing miners for self-escape in the event of a mine emergency (see Henricksen et al., 2008). We focus on the miner, giving an overview of psychology and neuroscience work documenting what happens in the brain and body in stressful situations. We then use this knowledge to elucidate the factors that cause people to make decisions (good or bad) that could influence self-escape.

There are several different approaches to the investigation of decision making. For example, the normative approach describes how decisions ought to be made—the optimal, rational decision given a fully informed decision maker. In contrast, the descriptive approach characterizes how people actually make decisions, the biases they bring to the table, and the different factors that influence the decisions they make (Shafir and Tversky, 2002). Finally, naturalistic decision making can be loosely thought of as an extension of the descriptive approach. It addresses how people make decisions in demanding environments (e.g., uncertain and changing environments, stressful situations, or time pressure; Klein et al., 1993). Naturalistic decision making also accounts for how decision-making practices may change as a function of a person's experience, their work culture, etc. In this chapter, we take a more descriptive than normative approach. Our goal is to highlight the importance of considering decision making and decision science research more broadly for enhancing self-escape in a mine emergency.

Certain themes recur throughout this chapter. One such theme is the importance of the use of decision science research (arising from the fields of psychology and neuroscience) to inform and shape how miners deal with emergency situations. Miners need to be knowledgeable of typical warning signals and how to efficiently and accurately determine if a true emergency exists. Decision science research can shed light on the types of information miners might miss and the common mistakes that may be made in emergency situations. To the extent typical emergency scenarios can be predicted, decision science research can also inform the development of emergency protocols and training procedures so that mine workers are able to make effective decisions and take an appropriate course of action to escape to a place of safety in the case of an emergency.

A second theme in this chapter is communication. In mining emergencies, miners not only need to be able to communicate with one another underground, but they also need to send and receive information with communication centers on the surface. Effective communication involves an understanding of the cognitive capacities of individual miners and how information is conveyed from the surface personnel to miners underground and back and among those miners who are underground. Because technology is a key asset in these situations, successful communication also involves an adequate understanding of how miners use technology to communicate and the limitations of that technology. Communication is also driven by the emphasis placed on receiving timely and adequate information at the organization level. Often there are brief opportunities to intervene and stop a potential emergency event from building to the next level. These brief opportunities are referred to as “golden minutes” (see, e.g., Horne et al., 1995). The adequate exchange of information and fluent communication is necessary to take advantage of these “golden minutes” opportunities.

DETECTING A MINING EMERGENCY

Risk is an inherent component of underground coal mines. Therefore, miners must draw a distinction between routine hazards and those that require self-escape. How is such a distinction drawn?

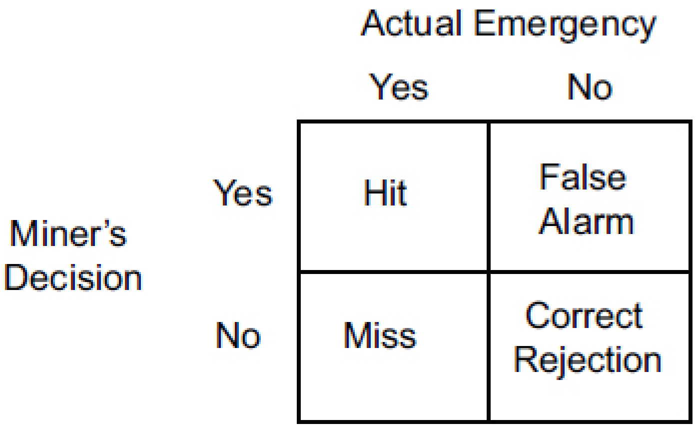
Sensitivity and Bias

One model to conceptualize the detection of a mining emergency, drawn from a rich literature in psychology of attention, is called signal detection theory (Green and Swets, 1966). Signal detection theory is driven by the general premise that almost all decisions people make take place in the presence of some uncertainty. Signal detection theory provides a language for representing decision making in the presence of uncertainty. As such, it may be useful for thinking about the decisions miners make (and the factors that influence those decisions) when faced with information that there may be an emergency.

Consider a situation in which a miner must decide whether there is an emergency situation. There are four possible outcomes (see Figure 4-1).

The miner’s goal is to accumulate information that will increase the likelihood of getting either a hit or a correct rejection, while reducing the likelihood of an outcome in the two error boxes. Signal detection theory can be used to conceptualize people’s ability to detect an actual emergency. There are two important factors: A miner’s *sensitivity* (i.e., the ability to detect an actual emergency) and *bias* (i.e., the predisposition to say whether there is an emergency or not). Sensitivity and bias are independent and thus can be influenced by separate factors.

In biomedical fields, sensitivity (as in the sensitivity of a test for a particular illness) relates to a probability of the test revealing a positive result given that a patient is ill. Making an analogy to mine emergencies, sensitivity refers to the likelihood of detecting that there is a mine emergency when there is in fact one occurring.



		Actual Emergency	
		Yes	No
Miner's Decision	Yes	Hit	False Alarm
	No	Miss	Correct Rejection

FIGURE 4-1 Possible outcomes faced by a miner.

To increase sensitivity, miners must become better at perceiving indicators of emergency situations. With proper training, a miner is more likely to learn what cues indicate a real emergency situation and which do not. This means that with more training, miners will be able to acquire more (and more reliable) information (Willingham, 2001). Sensitivity is also impacted by situational awareness. *Situational awareness* is, in simplest terms, knowing what is around you. Situational awareness can be defined as involving (a) the perception of a situation's elements in time and space, (b) comprehension of their meaning, and (c) projection of a near future status for the condition in question (Endsley, 1988; Endsley and Garland, 2000).

Related to the idea of situational awareness is the concept of *information uncertainty* (i.e., when a person does not have all the information pertaining to the situation at hand). Recognizing when information uncertainty exists—and the steps that need to be taken to obtain necessary information—is imperative for the effective diagnosing of a potential emergency situation.

Bias is influenced by characteristics of the miner, the self-escape task, and the equipment/technology in place to aid self-escape. As an example, people have a tendency to hold an optimism bias in which they initially ignore signs that there is a problem (Sharot et al., 2007). This bias could impact the immediacy with which miners recognize a problem exists and diagnose it as an emergency. In addition, if miners do not trust the safety equipment (e.g., SCSRs, carbon monoxide [CO] monitors) or have adverse expectations for what it will be like to use the equipment, they may be biased not to acknowledge that there is an emergency situation at hand. Bias is also impacted by organizational and external factors. For example, if there are external penalties for false alarms (e.g., lost productivity that could adversely impact the mining company or even peer influence with other miners not putting on their SCSRs), this may make miners less likely to respond, a conservative bias. Bias is also influenced by whether there is the presence or absence of an organizational safety culture, with the latter implicitly creating pressure not to false alarm (see Chapter 5).

In sum, many factors can influence bias and sensitivity. The factors outlined above are meant to provide an illustration of system and miner characteristics that can influence how miners respond to indicators of a potential mine emergency.

Next, we consider two specific examples of an emergency situation where the signal detection theory framework can be used to better understand a miner's decision-making process. In the first example, a miner encounters smoke and dust (and unbeknownst to the miner, toxic levels of CO in the atmosphere). The miner must decide whether or not the environmental factors encountered mean one should don the SCSR. Correctly diagnosing the atmosphere as unbreathable would be a "hit" (see Figure 4-1). In contrast, determining that the air is still breathable would be a "miss." Importantly, the miner's decision is not only influenced by sensitivity to cues about air quality but also by a bias not to acknowledge that there may be an emergency situation. If the miner does not have faith that the SCSR will work, is not properly trained on the equipment, or is fearful of negative consequences for using an SCSR when it might not be absolutely necessary, he or she might be biased not to acknowledge the gravity of the atmospheric conditions and thus conclude that the SCSR does not yet need to be used—which in this situation would be a "miss." In other words, even though a miner might be highly sensitive to environmental cues that the atmosphere is dangerous, the bias not to acknowledge the gravity of the situation may push one to conclude that there is no need to don the SCSR when in fact it would be the correct response.

In the second example, a CO monitor goes off and the miner must decide if one should self-escape. The CO monitor was actually triggered from several pieces of diesel equipment operating nearby and thus self-escape is not necessary. If the miner decides that there is no actual emergency situation because information is received from fellow crew members about the diesel equipment, then this would be a “correct rejection.” Note, however, that even without knowledge of the diesel equipment the miner might be biased to assume that everything is fine. This could be because the CO monitor has false alarmed several times in the past. In this second example, a miner’s bias would lead to the correct decision—pushing the miner to correctly reject the CO monitor alarm as a sign of an emergency.

This second example also illustrates the concept of “alarm fatigue,” a situation in which people learn to ignore alarms or possible environmental signs that there might be a problem because they routinely occur and usually do not indicate an imminent threat to safety. Although, in the above example, alarm fatigue did not lead to a failure to respond to an emergency, there are other situations where it could cause a miner to ignore important signs that a problem has occurred. It is imperative to make miners aware of the possibility of alarm fatigue and create training conditions that provide miners with knowledge about the mine and their equipment and technology so that they can successfully determine which alarms and abnormal environmental conditions (e.g., smoke) are most likely to represent an imminent threat to safety. Such training can provide information about circumstances under which miners should err on the side of caution (i.e., have a bias to say an emergency exists) because the benefits of a “hit”—correctly diagnosing a problem—far outweigh the negative consequences of a false alarm. One such example is donning an SCSR when there is smoke. Because breathing in this environment can be potentially very harmful, miners should be trained with a bias to don an SCSR when environmental conditions dictate it is likely needed (and not risk waiting to put it on until it is too late).

In summary, the above examples illustrate that it is not just a miners’ ability to interpret cues in the environment regarding whether self-escape is necessary, but also one’s bias for being willing to say that an actual emergency exists or not. Being aware that both sensitivity and bias can influence decision making for self-escape is important for devising the best training methods to prepare miners for possible emergency situations.

Expertise

One way to train emergency detection is to help miners see their environment through the eyes of a seasoned miner or “expert miner.”

Identifying the specific characteristics that constitute an expert miner is a difficult task. However, for the purposes of the present discussion, expert miners might be viewed as those nearing the end of a lifelong mining career (as opposed to those individuals who have only recently entered the work force). The expertise view (see Klein et al., 2013) is designed to allow less experienced miners to discover what an expert miner would identify as an emergency situation and why. Research on expertise demonstrates that highly knowledgeable individuals tend to classify situations based on their underlying causes while novices tend to be side-tracked by more trivial features. The bottom line is that a novice or inexperienced miner (or even a seasoned miner who has not been properly trained) may be missing important information needed to classify an event as an emergency or not.

There are techniques that can be helpful in eliciting expert knowledge (e.g., how a seasoned miner might act or make decisions in a potential emergency situation), such as verbal protocol analysis (Ericsson and Simon, 1999). Verbal protocol analysis is intended to capture the information an expert attends to when generating a decision or course of action rather than a description or explanation of what they are doing—the latter which may change by instructions to think aloud. Verbal protocol analysis is designed to simply help externalize the thoughts experts might otherwise keep internal. As such, it can be a useful method for ascertaining the implicit wisdom of expert miners.

It should be noted that experts do not always perform better than their novice counterparts. When an expert's goal is to predict the mistakes a novice may make, they often do this less well than novices themselves (Hinds, 1999). This is because experts often have trouble introspecting on their own performance knowledge (Beilock, 2010). It is also the case that when situations are ill-structured where a situation is not familiar, and it is hard to predict what will happen given initial problem cues, experts often do no better than their novice counterparts in interpreting these cues (Devine and Kozlowski, 1995). However, in situations where the information a miner encounters means there is a high probability of a certain event (e.g., smoke indicating a fire) and, given this information, there is an easily recognizable course of action (e.g., fighting the fire, deciding to self-escape), experts tend to outperform less experienced individuals in terms of diagnosing a particular situation and taking the appropriate course of action. In these situations, verbal protocol analysis may be advantageous in capturing this expert knowledge.

Two classic studies on the psychology of expertise demonstrate that experts tend to classify situations (especially well-structured situations) based on underlying causes while novices are often side-tracked by trivial information that can lead them down the wrong solution path. In the first study, physics professors (experts) and undergraduate physics students (novices) were asked to sort a number of physics problems based on the characteristics they deemed most important (Chi et al., 1981). Novices tended to categorize the problems by surface features of problems whereas experts classify according to the major underlying physics principle governing problem solution.

In a coal mining situation, this could manifest itself as an inexperienced miner concluding that, when a CO alarm goes off, this means that there is a fire (and, in turn, if the novice miner finds there is no fire, and then ignores the correct alarm). In contrast, a more experienced miner would understand that a CO alarm could be triggered from a variety of underlying sources (e.g., a faulty alarm, a fire, nearby diesel equipment, or an accurate reading of gases from some other source). The ability to recognize that there are multiple underlying causes of the same alarm is important for determining what other information one needs to obtain to make the best decision about how to react.

In the second study, Lesgold et al. (1988) assessed expertise in diagnosing X-rays. First- and second-year medical residents (novices) and radiologists (experts) viewed a series of X-ray pictures and verbalized their diagnoses. The expert radiologists quickly evoked a schema (a mental model) for the probable diagnosis. They then brought in additional information to test their diagnoses (to try and both confirm and disconfirm —see discussion of confirmation bias errors below). Critically, they changed or altered their diagnosis as more details were discovered. In contrast, the medical residents (novices) did not apply the appropriate or complete confirmation tests to the problem schema they invoked. Furthermore, the residents’ schema was usually based on surface features of the X-ray and did not change easily with new or contradictory information.

Two important qualities of expert performance can be taken from the above-mentioned work and can be incorporated into training for self-escape in mine emergencies. The goal is to help miners to classify a situation appropriately and act in the most successful way to facilitate self-escape.

- Expert performance is based on an extensive knowledge base and the organization of this knowledge in such a way that experts are able to recognize important underlying themes in a problem. This entails that experts see meaningful patterns of information where novices do not (Chi et al., 1981).
- Experts have strong self-monitoring skills and metacognitive abilities, especially in well-structured situations. Experts are more accurate at judging the difficulty of the problems they encounter and noticing where their thinking might have gone awry. This allows them to flexibly update their mental model of the situation when new or contradictory information is encountered (Lesgold et al., 1988; Kruger and Dunning, 1999).

AFTER A MINING EMERGENCY IS DETECTED

Noticing a potential oddity in the environment is largely subserved by an area of the brain called the prefrontal cortex. The very front part of the human brain that sits above our eyes—the prefrontal cortex—is the seed of thinking and reasoning abilities (Beilock, 2010). Once there is a realization that something is amiss, a variety of brain and body reactions occur in response to a potentially stressful situation. For instance, adrenalin increases in the bloodstream which results in several physiological responses such as a racing heart, sweaty palms, and muscles preparing for action. Cortisol is also secreted, which helps keep the heart racing and blood sugar up.

Registering that there is an emergency can also lead to worries about the situation and its consequences. These worries can overwhelm a person's *working memory*, which governs one's ability to think clearly in the moment, take in new and important information, and to make reasoned decisions (Wang et al., 2005; Beilock, 2008). Working memory is defined as a transient memory store involved in the control of a limited amount of information immediately relevant to the task at hand (Miyake and Shah, 1999). In simpler terms, working memory can be thought of as a flexible mental scratchpad that allows people to work with whatever information is inside consciousness. Working memory also helps people attend to some information while ignoring other information (Baddeley, 1986; Engle, 2002). When working memory is compromised in stressful situations, decision making can be impacted.

The concept of working memory in the context of the larger framework on human information processing is shown in Figure 4-2, a very general construal of human information processing with information bombarding a person from the outside world. At any given moment, people attend to some of what is around us and ignore other information. The information that is attended to enters working memory. Here, working memory is charged with the task of making sense of this new information in the context of what is already known (i.e., stored in long-term memory). As such, working memory plays an important role in the decision-making process. It represents a person's ability to work with whatever information is held in consciousness, match it to past experiences, and generate an appropriate course of action. It follows then that if working memory is compromised, a person may perform at a less-than-optimal level (e.g., make poor decisions or select an inappropriate course of action).

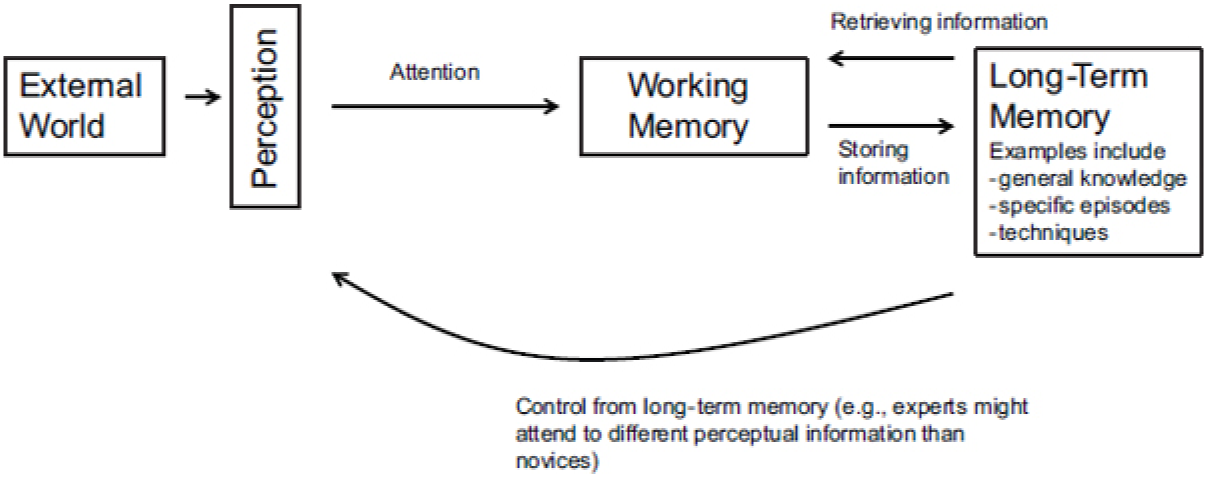


FIGURE 4-2 General view of human information processing.

Research demonstrates that simply making people aware of common internal reactions in stressful situations (e.g., sweaty palms, beating heart) can make these reactions less distracting (Jameison et al., 2010). It's also the case that training people to view their stress response as a sign of challenge rather than doom can lessen the negative impact of physiological arousal on effective thinking and reasoning (Mattaralla-Micke et al., 2011). One reason for this effect is that normalizing these responses makes people less likely to dwell on them. Dwelling on them further limits the working memory needed to be effective decision makers in stressful situations.

In addition to the stress signals generated from the body, it is important to note that CO poisoning—which is a danger in some underground coal mines—can impact brain functioning. Specifically, CO poisoning is thought to cause difficulty in making decisions and processing information, key functions of the working memory system (Cohen, 2012).

In nonstressful situations, working memory works in concert with emotional processing. However, when working memory is compromised, people's decisions can be unduly influenced by emotional processes, which can lead to poor outcomes. This occurs because there are, generally, two ways that people make decisions. One way relies heavily on mental resources, such as working memory. It is more systematic and analytic. The other way is based more on affective and emotional processes (Sloman, 1996; Stanovich and West, 2000; Kahneman, 2003). When people are in stressful situations, worries tend to co-opt working memory, leaving only the more affective processes to govern decision making. This condition may result in decisions that put other miners or oneself in danger, such as going back for friend, even though there are very clear indicators that this could put the rescuer and possibly other miners in extreme danger. Training miners to be aware that these emotion-driven decisions occur, and when they are most likely to occur, can provide them with better tools to understand their behavior and make optimal decisions in stressful mining emergencies.

This science may inform training. For example, a training exercise could be developed in which miners encounter fictitious situations in which they might have an impulse to go back into a mine to rescue others. If the consequences (both positive and negative) of such a decision are made clear, the miner may be better able to make the most appropriate decision in the moment. Such education could also address cultural norms that dictate that miners must stick together, regardless of the consequences. Miners need to be taught that cultural norms may push them to make decisions that are inherently risky and driven by emotions. Miners need to be trained to consider all of the possible options in these situations.

Note, a compromised working memory is not the only source of poor decision making. As an example, having an inappropriate procedure for donning an SCSR represents an error in long-term memory that could lead to problems with self-escape. The miner, here, is not compromised because of reduced working memory resources, but because he or she learned the wrong steps to begin with. Or, a miner may make the wrong decision about how to act based on analogy to a past circumstance that was similar in terms of surface features (e.g., a CO alarm) but not in underlying cause (e.g., a fire versus a source-unspecified gas leak). A lack of knowledge may lead to a particular course of errors (e.g., the miner finds there is no fire, so ignores the alarm, even though it is correctly diagnosing air problems), that could be avoided with training that provides a more detailed knowledge base of common environmental signs of problems, their underlying causes, and sensible courses of action.

We turn to the issue of knowledge acquisition in more detail below and to the development of optimal training practices in Chapter 6.

DECISION MAKING FOR SELF-ESCAPE

As noted throughout this chapter, effective decision making is a critical component of successful self-escape in a mine emergency. Importantly, effective decision making is not simply based on in-the-moment choices, but is also based on the long-term accumulation of knowledge and skills.

Knowledge of Equipment and Technology

Miners need to have extensive experience with the use of breathing apparatus, such as the SCSR, and they need to be able to use this equipment in conditions that are not optimal (including, but not limited to, poor visibility). Miners also need to be able to effectively operate these devices in stressful environments that compromise the working memory one would otherwise have at his or her disposal. One way this can be accomplished is by training miners so that the use of these devices is automatic or habitual.

It is believed that skill acquisition progresses through distinct phases characterized by differences in the memory operations supporting performance (Beilock and Carr, 2001). In the early stages of learning, skill execution is supported by working memory and monitored in a step-by-step fashion (Fitts and Posner, 1967; Anderson, 1993; Proctor and Dutta, 1995). However, procedural knowledge specific to the task develops with practice. Procedural knowledge operates largely outside of working memory and does not require constant control (Anderson, 1993; Beilock et al., 2002). Thus, in contrast to earlier stages of performance, once a skill becomes relatively well learned, attention may not be needed for the step-by-step control of execution.

One can think of procedural memory as a skill toolbox that contains a recipe that, if followed, will produce a successful bike ride, baseball swing, or the donning of an SCSR. Interestingly, these recipes operate largely outside of conscious awareness. This makes it hard for a person to articulate procedural memory. If a person does not think about the specific steps of performing a task, reporting these steps to someone else can be difficult. Thus, procedural memory needs to be assessed by demonstration rather than by verbal report. Having adequate procedural memory for example on how to don an SCSR helps ensure that miners can put these devices on flawlessly even when their working memory is impaired.

Another way to characterize the different types of thinking that occur at various skill levels is the “skill, rule, knowledge” approach (Rasmussen, 1983; see also Reason, 1990). The phrases skill, rule, and knowledge broadly characterize the degree of conscious control a person has over what he is doing. For instance, knowledge refers to an activity where a high degree of conscious attention needs to be used to make decisions or perform an activity. This might be the case when a new miner initially learns to don an SCSR. With practice, however, this activity should ideally progress to a rule and then a skill where it can be completed largely outside of conscious control.

This classification can be useful to help diagnosis errors. For instance, an error in donning an SCSR that occurs because the miner automatically skips a step is quite different from not knowing the steps in the first place. By understanding different forms of errors, training practices can be developed to target specific mistakes (see Reason, 1990). This classification model can also be used to help determine when externalized information about completing particular skills—such as checklists or acronyms (see Gawande, 2009)—may be most effective (e.g., if miners repeatedly skip steps, an acronym that includes all the steps could be useful).

In summary, the goal is to train miners to a level where they can use necessary breathing apparatus automatically, even though they hardly ever use it. In Chapter 6, we talk in detail about what decision science research says about how to train procedural memory. One theme is the idea that repetition in itself does not ensure adequate proficiency. Rather, mastery, or a demonstration of that proficiency is needed.

Miners also have to know when to use breathing apparatus. This needs to be trained to automaticity so that a miner, in the moment, does not have to make decisions when working memory might be compromised (either by stress, CO, or both). For habitual reaction, the miner has to have thorough expectations for what donning and using an SCSR is like, and the miner has to trust in the equipment. The miner also has to have experience problem solving on the fly so that dealing with unexpected events also becomes second nature. Research demonstrates that when tasks have become proceduralized, people have thinking and reasoning resources left to devote to other issues (Beilock et al., 2002). Proceduralizing the components of donning breathing apparatus, and when to don it, leaves valuable cognitive resources necessary to solve unexpected problems in the moment.

Miners also have to have adequate knowledge about how other safety technology in the mines work. This includes gas-monitoring devices, communication systems, lifelines, and refuge chambers. One way to acquire this type of knowledge is through emergency drills and protocols that spell out, in a step-by-step way, all the information about the mine that might aid in self-escape.

Finally, it is important to note that miners also need to be trained in terms of the limitations of the technology they use. They need to know what signs to look for if their equipment is not working or if it needs to be replaced. A thorough understanding of the limitations of the technology and equipment will help prepare the miners to make optimal decisions in an emergency.

Knowledge of the Mine

Well-practiced primary and secondary escape routes are important for successful self-escape in the event of a mine emergency. Ideally, miners should have memorized how to get to an escape route such that they can walk out of a mine in situations where there is limited visibility or in situations where stressful conditions make reasoning or navigating difficult.

This knowledge is especially important in situations where the escapeway map on the section is not visible.

In addition to rote knowledge of escapeways, it is also important for miners to have detailed knowledge of the spatial layout of the mine as a whole—otherwise known as a cognitive map of the mine. A cognitive map (or mental map) is an internal memory representation of the layout of the mine (Tolman, 1932). Cognitive maps allow a person to visualize the layout of a particular place in one's "mind's eye." Importantly, a cognitive map preserves spatial relations and distances from one landmark to another (Kosslyn, 1994) and thus can play an essential role in helping miners use a landmark to determine the best route for exiting a mine in the event of an emergency. Cognitive maps should not be limited to primary escapeways but should also include basic knowledge of the ventilation system (and how it could change during a mining emergency), caches for breathing apparatus, lifelines, communication systems, and refuge chambers. Miners should also know how to use the environment to find information needed to self-escape (e.g., use lifelines to determine the location of cache).

Cognitive neuroscience research has determined that cognitive maps are derived using visual imagery and many of the same visual processing areas in the brain involved in actually perceiving information in the world are used when people invoke visual images (Kosslyn, 1994). Knowing that visual images share many features with perception lends insight into how mental maps of the mine can be committed to memory. Specifically, miners should not just be given verbal or written information about the layout of the mine but should actually use visual information (maps) to memorize important information. Research also shows that movement through an environment can help people understand distances and spatial layouts (Burgess, 2006) and that active exploring and having to make decisions about which direction to go in a training situation (Bjork, in press), as opposed to just following someone else out of the mine during training, can also be beneficial for learning spatial layouts. Requiring individual and groups of miners to walk escape routes and make decisions about possible paths to safety in training exercises will likely be beneficial for miners developing a thorough understanding of the mine layout.

Locations of caches, refuge chambers, and other key places can serve as important landmarks, providing miners with information about where they are in the mine. Route knowledge is thought to develop by registering one's actions with a set of landmarks in the environment (Siegel and White, 1975). Explicitly teaching miners to think about mine landmarks with respect to particular ways out of the mine could prove beneficial for learning the layout of the mine and for coming up with novel escape paths in the event that self-escape in a mine emergency necessitates changes from practiced escape routes. Landmarks are a way to “off-load” navigation onto the environment (Waller and Lippa, 2007)—as long as these landmarks do not move. For instance, if a miner is aware that a belt line (a landmark) leads out of the mine, the miner can follow the belt line in the event of an emergency with limited visibility. This form of cognitive off-loading may be especially important in stressful situations where effective decision making, planning, or navigation abilities are stunted. Following a belt line or some other stable external landmark limits the need to navigate and reason on one’s own. The lifeline represents one form of cognitive off-loading already in place. Miners can use the lifelines to determine the locations of the nearest escapeway and SCSR cache.

Knowledge of What to Do to Self-Escape

Successful self-escape in an underground coal mine emergency involves (a) detection, (b) assessment, and (c) escape phases (see Figure 1-1).

Detection involves developing conceptual knowledge of common problems indicators. This is akin to how experts build up a rich semantic knowledge base in their domain of expertise (Chi et al., 1981; Lesgold et al., 1988). This knowledge allows miners to classify the problem appropriately (Chase and Simon, 1973; Ericsson and Polson, 1988) and then to assess the problem, which includes identifying possible solutions. Finally, the escape phase involves the development of “if, then” rules. If a particular scenario occurs, then take a particular course of action. These “if, then” rules can also be considered as procedural knowledge that is enacted fairly automatically once the problem has been identified (Anderson, 1993). As an example, in the physics work mentioned above (Chi et al, 1981), it was found that expert physicists actually spent more time than novices analyzing a problem in order to decide what kind of problem it was but less time actually solving the problem. Once experts had categorized the problem, they automatically activated the procedural knowledge needed to solve it and solved it very quickly.

These findings are consistent with research on expertise showing that the first option experts generate is usually the best one (Klein et al., 1995; Gigerenzer and Goldstein, 1996; Johnson and Raab, 2003). Finally, these findings are consistent with the idea that sometimes the best action is to pause before a decision is made (Kowalski-Trakofler et al., 2010). Specifically, in an escape situation, it is important for miners to make sure they are aware of all the available information before they act. Making sure that all the available information is collected and used in the decision process is especially important for group leaders in emergency situations. Research has shown that pausing to assess a situation and gather new information can allow individuals to come up with the most appropriate response or see a situation in a new way (Wiley, 1998).

A basic premise of most human-systems integration approaches is that changes in one part of the system can have an impact on another part of the system. For instance, organizational demands regarding productivity can impact a miner's bias for determining whether some environmental indicator is a sign of a real emergency that requires self-escape is a false alarm. Together, the different parts of a system can often serve to prevent weaknesses in one part, but sometimes these weaknesses align and adverse events occur. As talked about more in Chapter 5, this aligning of weaknesses is often referred to as the "Swiss cheese model." The idea is that when holes in different parts of a system line up, unanticipated adverse events can occur (see Reason et al., 2001).

Anticipatory Thinking and Heuristics

Successful self-escape also involves flexible or anticipatory thinking. Anticipatory thinking is the process of imagining unexpected events and how they may affect plans and practices (Klein et al., 2010). It is a hallmark of expertise. For instance, expert chess masters are able to plan out several moves ahead in a game situation, and down several possible move trees, to determine whether a particular move will be successful (Chase and Simon, 1973). Importantly, anticipatory thinking is not mere prediction but involves actively interpreting the environment for information that might change a potential course of action. For instance, it has been shown that expert drivers constantly scan the environment for possible hazards in a way that novices do not (Pradhan et al., 2005).

Anticipatory thinking allows miners to adapt to changing emergency situations by understanding the consequences of potential decisions and how they need to be altered in the event of changing factors in the environment. It also allows them to adapt to a situation in which several factors come together to lead to unpredictable consequences. Anticipatory thinking, fueled by expertise in self-escape, may also help miners avoid common mistakes that tend to happen in stressful situations when working memory is compromised.

Thought patterns known as heuristics are short-cut strategies for solving problems, which can be useful when decision time is short and reasoning compromised (Sternberg, 2003). Such short-cuts can be especially useful in situations where the decision maker is dealing with large amounts of information. For example, if a miner has a heuristic for donning an SCSR that smoke = donning, then there does not need to be time taken or cognitive resources spent on considering the pros and cons of donning—especially when such time could be used to gather important information about the emergency situation at hand. However, some heuristics can lead to biases and ultimately poor decisions. These potential mistakes include, but are not limited to, (a) sunk costs, (b) backup avoidance, and (c) confirmation bias.

Sunk costs occur when a person follows through on a decision initially made even if there are signs that this decision should be reevaluated or changed (Thaler, 2000). Making a commitment pushes people to resist revaluation.

Backup avoidance is when people do not want to consider an option that will take them further away from their goal at first—even though it may be the best option (Anderson, 2005). This avoidance may have occurred during the Aracoma Alma mine fire where miners went forward rather than backward in an attempt to escape (U.S. Department of Labor, 2007b). Perhaps considering going backwards to avoid smoke would have been beneficial, similar to how airline attendants routinely urge passengers to recognize that, in the event of an emergency, the nearest exit may be behind them.

Confirmation bias involves looking for information that confirms the story a person has built instead of looking for information that might disconfirm it (Galotti, 2008). People have a tendency to want to search out meaningful patterns and make sense of experiences and thus they look for information to confirm their initial predictions and tend to ignore factors that could disconfirm it. This means that people may be less likely to pay attention to the environment cues that do not confirm initial assumptions and, as a result, less likely to update erroneous assumptions. And, in many domains, novices tend to do this more than experts (Lesgold et al., 1988). A related idea is illusory correlations, where two events occurring together in time are seen as causally connected even though they are independent (Chapman and Chapman, 1967). Building on these sorts of mistakes in training and educating miners that they may occur can be a powerful way to create the knowledge they need to effectively self-escape in a mining emergency.

COMMUNICATION

Communication is at the heart of behavioral elements that are fundamental to self-escape, such as organizing, gathering information, decision making, creating group cohesion, providing guidance, maintaining motivation, and informing and directing effort. This section discusses communication between escaping miners, and communication between miners underground and key support personnel on the surface.

Between Miners

As noted in Chapter 3, most escapes occur in groups with miners collecting together to move to a place of safety. Sometimes the group represents an intact work team or section crew, but in other situations an escape group is formed by individual miners with varying roles who happen to be nearby at the time of the emergency. Within any group of miners there could be a wide range of experience, expertise, knowledge, and ideas. These are resources, held by members of the escaping group, which should be mobilized to solve the escape problem.

In situations where SCSRs are worn or verbal communications is otherwise prevented, communication between miners is reduced to rudimentary, nonverbal signals and/or writing notes. The mining community has developed a series of hand and headlamp signals (Kosmoski et al., 2012). This approach seems adequate for issuing commands, such as evacuate, go this way, slow down, yes, no, etc.; however, it cannot support questions, detailed statements of information, explanations, or any notion of a conversation. Although this may be marginally useful for a designated leader, it leaves a poor set of options for followers. Miners are limited in their ability to ask questions, relay a particular piece of important information, or report any physical failings. If a miner believes that the group is going in the wrong direction, the choices are (a) keep silent and moving in what one believes to be the wrong direction, or (b) remove an SCSR to talk and risk toxic inhalation, (c) leave group and turn in another direction alone without explanation, or (d) try to communicate with gestures, taps, and mumbles. The miner might be able to communicate on the tagline[1] by shaking it or by grunting out loud, but this type of communication is lacking in terms of the richness of information it can convey.

A nonverbal scenario forces an escape group to rely almost exclusively upon the knowledge and decisions of only one person. Recent research has demonstrated that groups of individuals working together make the best decisions when there is a high level of collective intelligence (known as the “c factor” [Woolley et al., 2010]). Collective intelligence is not strongly related with the maximum intelligence or knowledge of individual group members (i.e., with what one person knows) but rather with the ability of a group to communicate (e.g., take turn in conversations, exchange information). Thus, the ability to communicate within a group of miners in an emergency situation seems highly beneficial for successful self-escape—especially when there are changing circumstances that require the reevaluation of initially chosen options.

When verbal communication and ongoing exchange of information is possible between miners, the members of the escape group are able to participate in all of the fundamental behavioral elements of self-escape discussed earlier. Miners will differ in experience and knowledge, but the resources that exist within the group now can be mobilized. Verbal communication enables miners to contribute information about a fire or other hazards and the locations and status of personnel and to suggest courses of action, weigh options, ask questions, give opinions, sound objections and explain them, and so forth. With verbal ability, what would otherwise be a collection of individuals now has the potential of becoming an effective escape team or group. Interventions designed to improve team effectiveness, such as leadership and followership training, can now be useful. Improving team communication is critical given that people have an egocentric bias to think others understand what they have communicated, even when others do not (Chang et al., 2010). Training that allows miners to develop accurate communication strategies—verbal and nonverbal—would be an essential component of successful self-escape.

Between Miners and Surface Personnel

The surface communication center, the responsible person, and the immediate support team can be significant resources to miners, particularly when verbal communication is possible.[2] As with the case of communication between miners underground, any constraints on communications with the surface limit important coordination and information exchange between the personnel on the surface and underground escape groups.

The surface communication center can play an integral part in the exchange of critical information from first alert to any time that the escape groups are able make contact. Surface personnel obtain information from the miners and provide other information back to them. The information obtained by the responsible person is routed to other surface personnel for decision making with respect to locations, firefighting, aiding escape, and rescue. It will include such information as locations of the fire and the miners, health status of the miners, availability and usability of breathing apparatus, presence and density of smoke, and miners' intentions. Some of the information obtained from one escape group is also subsequently routed back down to other groups when they contact the surface for information. The information obtained from the surface by the miners is used to make decisions, such as route choice, wayfinding, the status of other miners, and entering or not entering a refuge.

Given that the responsible person and team may need to simultaneously obtain and provide valid information to disparate groups of miners underground and to other personnel on the surface under stress and time pressure, it raises issues related to communication, such as: How should the responsible person support team and its task be structured? How many people are necessary to do the job? How should they divide their roles? What training should be provided to them? As these issues are addressed, modifications to current arrangements should be directed at clarifying roles and simplifying the significant communication responsibilities that the responsible person carries.

IDENTIFYING SELF-ESCAPE COMPETENCIES

Decision science research has provided insight on the types of information miners might miss and the common mistakes that may be made in emergency situations (see Box 4-1). This research has helped identify cognitive competencies necessary for the self-escape task and as such can inform the development of emergency protocols and training procedures. This section briefly discusses five critical competencies—detecting hazards, using equipment and technology, wayfinding, understanding stress, and team functioning. We note, however, that this list of competencies is drawn from the discussion in this chapter but is notably incomplete. As discussed in Chapter 3, a full critical incidents analysis and task analysis would be necessary before a complete list of competencies could be identified.

> **Detecting Hazards:** Miners have to constantly draw distinctions between routine hazards and those that require self-escape. To do this, miners must have knowledge of environmental conditions that require self-escape and/or use of personal protection equipment. Miners also have to understand how biases (e.g., an organizational culture that implicitly discourages false alarms or their own lack of trust in safety equipment) might impact their decision to label something as an emergency. Miners need to develop a rich knowledge base that allows them to automatically know which environmental cues mean they should don their breathing apparatus and what self-escape procedures should be enacted.
>
> **Using Equipment and Technology:** Miners need to be able to automatically (without thinking in detail) don breathing apparatus and switch from one to another. They also have to have very clear expectations for what donning is like. They have to be able to fluently use other technology relevant for self-escape (these include, but are not limited to, communication devices and gas monitors).

BOX 4-1
Examples of Psychological Factors That Can Affect Effective Self-Escape

Optimism bias—The human bias to initially assume that nothing is wrong. In the context of a mining emergency, this may involve ignoring initial signs of fire or roof falls.

Cultural or organizational bias not to false alarm—Tacit pressure from an organization not to behave as if self-escape is required (e.g., not donning self-contained self-rescuer [SCSR] when environmental cues such as smoke indicate otherwise because a miner is hesitant to use an expensive piece of equipment).

Compromised thinking and reasoning under stress—The decrease in a person’s cognitive capacity, the ability to think and reason systematically, which is often compromised under stress. Recognizing this can aid decision making.

Emotion-driven decision processes—A person’s tendency to allow emotions to dictate decisions. May result in putting additional people in danger.

Backup avoidance—The tendency to not want to go away from one’s goal. This tendency may result in miners not considering escape routes that initially take them farther from a place of safety but are ultimately the best choice.

Confirmation bias—The tendency to only look for information that confirms what one believes (e.g., about the cause of an emergency situation) and thus not update one’s notion of what has happened and what needs to be done to effectively self-escape.

Egocentric communication bias—One’s bias to assume that others understand what one has said, even when they have not, which may increase in times of stress.

Sunk costs bias—The tendency to continue following through on a decision initially made even if there are signs that the decision should be reevaluated or changed.

Wayfinding: Miners need to have adequate awareness of their environment. This knowledge includes mental maps of how to get to escapeways, how landmarks can help them determine where they are in the mine, and how they should travel out in addition to utilizing current lifeline symbols.

Understanding Stress: Miners need to have awareness of how stress impacts decision making (e.g., how the brain and body changes in stressful situations) and the types of decision-making mistakes and potential pitfalls that are likely to occur in mine emergency situations.

Team Functioning: The ability to function as an effective member within a team is also a fundamental competency that emerges in self-escape. Although the ability to self-escape alone has to be supported, most escapes occur in work groups. To escape, these work groups must transform themselves into teams in which members have roles and responsibilities, share the common goal of escape, share a common mental model or understanding of how an escape team should function, and work to enable the team to be successful. Toward this end, a team member must understand the various ways in which one can contribute (e.g., providing information to leader or group), when to communicate and when to listen or encourage others to speak (e.g., detecting situational cues), and when to be a leader and when to be a follower (e.g., delegating and accepting tasks). With respect to working with surface personnel, communication skills are obviously important (e.g., passing along facts and flagging opinions as such).

RECOMMENDATION

The findings from research in the field of decision science, which can broadly be defined as the investigation of decision processes and communication strategies within and across people, is increasingly recognized as important for understanding human behavior across a variety of fields. To effectively self-escape in the event of a mine emergency, miners need to have more than knowledge of their equipment and surroundings; they must also have the psychological tools to make effective decisions and communicate successfully. Decision science research helps identify common thinking and reasoning pitfalls that can occur in stressful situations (see Box 4-1) and also informs the training that miners take part in as a means to ensure successful self-escape.

> **RECOMMENDATION 5: The National Institute for Occupational Safety and Health should use current decision science research to inform development of self-escape training, protocols, and materials for training for effective decision making during a mine emergency. Miners and mine operators should be knowledgeable of typical warning signals and able to determine if a true emergency exists and decide how to respond appropriately. All miners should be trained using standard protocols developed for predictable components of self-escape. This will allow miners to devote adequate attention to unexpected events and enhance situational awareness.**

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[1] A tagline is a long heavy-duty rope with tethers spaced at even intervals, designed to link members of a mine crew together in the event of an emergency, particularly in dense smoke and little or no lighting.

[2] Texting possibilities exist in the absence of verbal communication that may permit limited text communication between surface communication centers and miners underground. However, the number of mines with this capability is relatively few, and the speed and depth of communication is limited.

5

Safety Culture

Specific to self-escape, a mine safety management system can be thought of as consisting of two broad domains: prevention and preparation. Prevention focuses on the policies, programs, and activities that seek to prevent adverse events and injuries from occurring. Actions within this domain generally follow the traditional hazard control hierarchy, which places primary emphasis on eliminating or controlling hazards in the work environment. Given the potentially catastrophic consequences of underground coal mine fires and explosions, priority should be placed on prevention through the use of redundant controls or what is sometimes referred to as defenses in depth (Rasmussen, 1997; Reason, 1997; Saleh and Cummings, 2011).

Preparation involves actions directed at avoiding or minimizing the adverse consequences of system failures once they occur or begin to occur. Escape training, personal protective equipment and communication technologies, equipment caches, refuge facilities, suppression systems, and lifelines and other wayfinding aids are all part of preparation. The goals here are to make self-escape unnecessary, or failing that, as safe and as simple as possible.

Discussions of safety management systems often invoke the concept of safety culture. The term “safety culture” first gained prominence in the aftermath of the Chernobyl disaster (Pidgeon and O’Leary, 2000). Indeed, a string of subsequent high-profile disasters served to focus both public and scientific attention on the role that a safety culture and other organizational factors play in the history and unfolding of such events (Weick et al., 1999).

Safety culture has been defined a number of ways, (see, e.g., Wiegmann et al., 2004; DeJoy, 2005), but most definitions highlight the shared norms, values, and assumptions pertinent to safety that exist within an organization and that serve to shape relevant attitudes and behaviors within the organization. At the very heart of safety culture is the relative importance of safety in comparison with other organizational priorities, such as production and cost control.

Safety culture forms the organizational context in which all safety-related actions take place. It provides the subtle and sometimes not so subtle cues about the importance of safety, the safety-related behaviors that are expected, the resources available to support safety, and the steps taken to identify, eliminate, or control hazards. As depicted in Figure 5-1, safety culture has general or global effects on how people in an organization receive and process information and think about safety-related matters. It also affects how the organization embraces and utilizes available hazard control technologies (i.e., operational hardware) and implements specific safety-related policies and procedures to minimize risks and maximize safety performance (operational software).

Safety cultures develop over time as organizations operate and adapt to local conditions, respond to events, and as a function of their leadership. In one more concise formulation (Schein, 2010), cultures evolve as organizations learn to cope with problems of external adaptation and internal integration. The safety culture of an organization can vary in terms of valence (positive to negative) and strength (strong to weak).

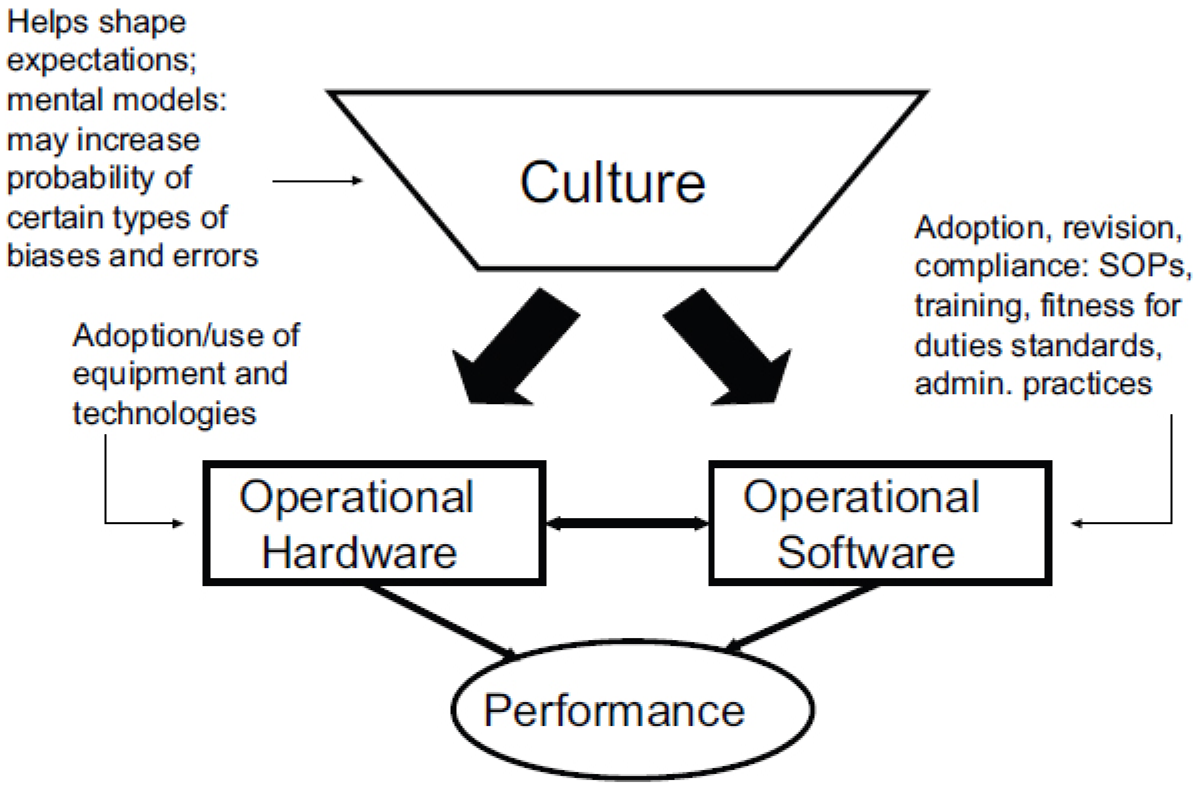

FIGURE 5-1 General model of safety culture influences on system performance.
NOTE: SOPs = standard operating procedures.
SOURCE: DeJoy et al. (2008).

BOX 5-1
Characteristics of a Positive Safety Culture

There would be general agreement throughout the organization that:

- safety is a clearly recognized value in the organization,
- accountability for safety within the organization is clear,
- safety is integrated into all activities in the organization,
- a safety leadership process exists within the organization, and
- safety culture is learning driven in the organization.

SOURCE: Adapted from International Atomic Energy Agency (2006, pp. 9-10).

A positive safety culture assigns high importance to safety, makes needed investments, takes appropriate actions, and closely monitors its performance with respect to safety. In a negative safety culture, safety has a relatively low priority and is often most likely to receive attention only after some type of adverse event has occurred. Such organizations frequently cut corners when it comes to safety and seek quick and inexpensive solutions.

Safety culture is defined above as involving shared norms, values, and assumptions. It is this shared notion that brings forth the idea of culture strength. A strong safety culture is one in which there is a high level of agreement about the importance of safety within and between work groups and other organizational divisions or units—from top to bottom. Where consensus is weak, absent, or highly variable across units, the safety culture is weak. Various attempts have been made to identify the core characteristics of a positive safety culture (see Box 5-1).

HIGH-RELIABILITY ORGANIZATIONS

Considerable attention within the safety literature has been given to so-called high-reliability organizations. These are organizations that routinely operate in dangerous, high-hazard environments but that maintain remarkably good safety records. Commercial aviation, aircraft carriers, and energy-generating facilities often qualify as high-reliability organizations. Such organizations are characterized by continuous and active engagement in safety that extends beyond controlling or mitigating untoward events and includes actively anticipating and planning for them (Roberts, 1990; LaPorte, 1996; Rochlin, 1999).

BOX 5-2
Attributes of High-Reliability Organizations

- Management commitment to safety
- Safety resources and incentives
- Open and candid communications
- Migration of authority based on functional skill
- Low frequency of unsafe behavior, even under production pressures
- Priority of safety, even at expense of production or efficiency
- Continuous safety mindfulness
- Openness about errors and problems, and errors reported
- Organizational learning

SOURCES: Adapted from Rochlin (1999) and Singer et al. (2003).

Box 5-2 summarizes the main attributes of high-reliability organizations. Many of these attributes resemble the characteristics of a strong, positive safety culture noted above (leadership and management support, learning orientation, etc.). Close attention to the attributes of high-reliability organizations, however, reveals a very strong focus on communication. Two of the attributes deal directly with communication—having open and candid communications about safety matters and having openness about safety problems and reporting. A third attribute—safety mindfulness—implies that a very high priority is assigned to emergency preparedness and plays out through communication.

High-reliability organizations are often described as being preoccupied with the idea that things could go seriously wrong at any moment; that risk and safety must always be uppermost in one’s thinking; and that error will seek out and find the complacent (Rochlin, 1993). High-reliability organizations can be described as having a continuous type of safety chatter that serves the important functions of keeping everyone in the organization alert and updated on system status and unfolding activities. This type of free flow of information is especially apparent during complex or critical operations. To a very considerable extent, maintaining a high level of safety performance is a social-communicative process.

SAFETY VOICE

The importance of communication has also been noted within the safety culture literature. For example, Reason (1997, p. 195) emphasizes the importance of “creating a safety information system that collects, analyses, and disseminates information from incidents and near-misses as well as from regular proactive checks on the system’s vital signs.” He also argues for the importance of free and open communication, especially the freedom to report safety problems without fear of blame or retribution.

More recent research has referred to this as “safety voice,” defined as behaviors that seek to improve safety by identifying shortcoming and possibilities for improved performance (Barton and Sutcliffe, 2009; Conchie et al., 2012). Having a learning orientation is a key element of a positive safety culture and high-reliability organizations. And having a learning orientation requires having timely access to relevant information and this involves free and open, two-way communication. This emphasis on learning was also highlighted by Galvin (2005) in an analysis of cultural maturity in the coal industry in Australia (see Figure 5-2).

Some high-hazard industries, such as firefighting and commercial aviation, have implemented near-miss reporting to expand the flow of information that might prove useful in preventing serious or deadly events in the future. Near misses are incidents or events that have the potential to result in injuries or other losses but do not (see Phimister et al., 2003). These incidents or events are reported voluntarily, and there are immunity policies for reporters. The reporting system is administered by a neutral party: for example, the Aviation Near-Miss Reporting System for the U.S. Federal Aviation Administration (FAA) is administered by the National Aeronautics and Space Administration. Reports are kept confidential. Most near misses represent errors or system failures or degradations that could have produced losses and may be predictive of more serious outcomes in the future. Near misses are generally considered to be much more frequent than actual loss-producing incidents and thus represent potentially important learning opportunities. Near-miss reporting systems may be particularly useful in work situations in which timely safety-related communications are logistically difficult or adversely sanctioned. The FAA’s near-miss reporting system is probably the best established near-miss reporting system in the United States.

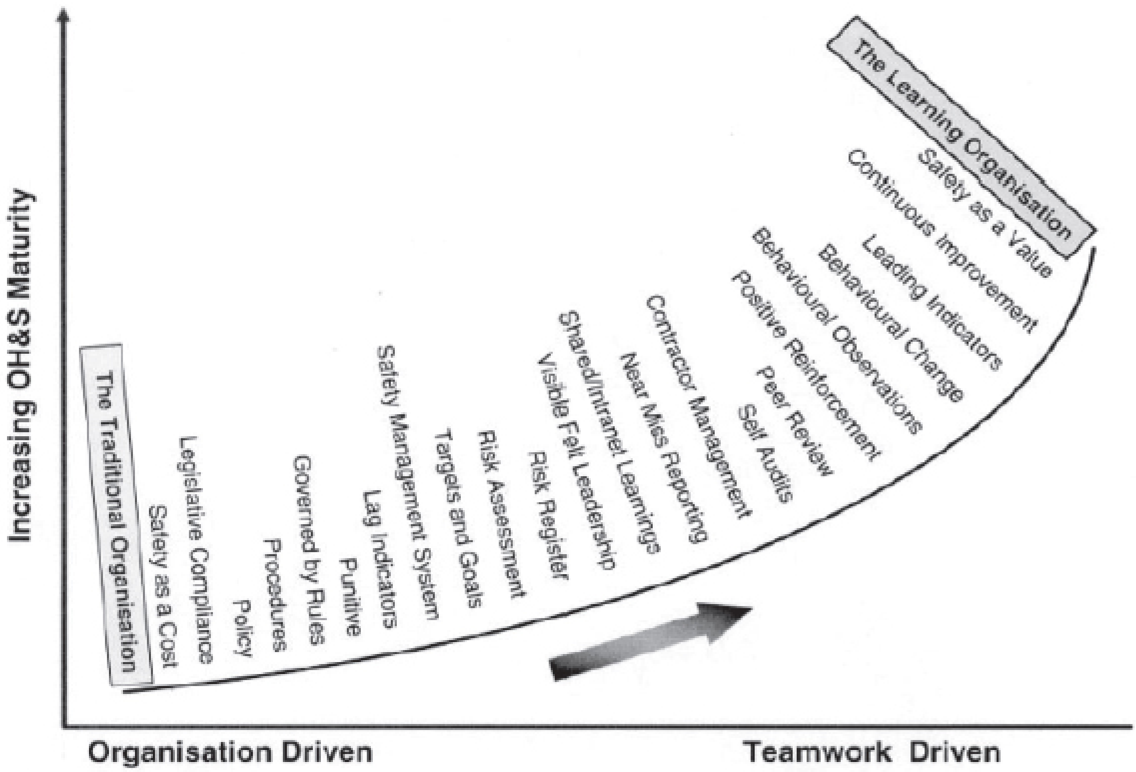

FIGURE 5-2 Australian mining: Changing OH&S behavioral culture.
NOTE: OH&S = occupational health and safety.
SOURCE: Galvin (2005, Figure 6). Reprinted with permission.

SYSTEM FAILURES

Any unintended emergency in an underground coal mine, regardless of magnitude, represents a systems-level (organizational) failure. This is especially so given the relative probability of serious consequences to workers and the likely complexity of successful escape. This characterization is a widely accepted premise of modern safety management.

Like other work systems, coal mines are not closed systems. Interactions within them can be influenced by external factors such as economic or market conditions, political actions and regulatory policies, scientific and technological advances, as well as various natural and societal or cultural factors. From a systems perspective, effective safety performance requires careful analysis of all possible interactions and the adoption of a multilevel perspective (Rasmussen, 1997; Leveson, 2011). For example, difficult market conditions can increase the likelihood of safety short-cuts or delay the purchasing of needed safety equipment. The sheer size and uniqueness of an industry can affect the development of new safety technologies or even the level of governmental oversight it receives. Regulatory requirements can serve to either stimulate or discourage technological innovations that could improve safety. A group culture of risk acceptance within an organization can influence safe work practices and operational safety and even discourage acceptance and adoption of available safety technologies. Unsafe working conditions, a culture that does not put safety first, and other systems-level malfunctions may predate an immediate emergency. In other words, it is not necessarily just one adverse event that leads to a mine emergency, but a series of events or failures that align to necessitate self-escape. In some circumstances, systems failures can predate the emergency by significant periods of time.

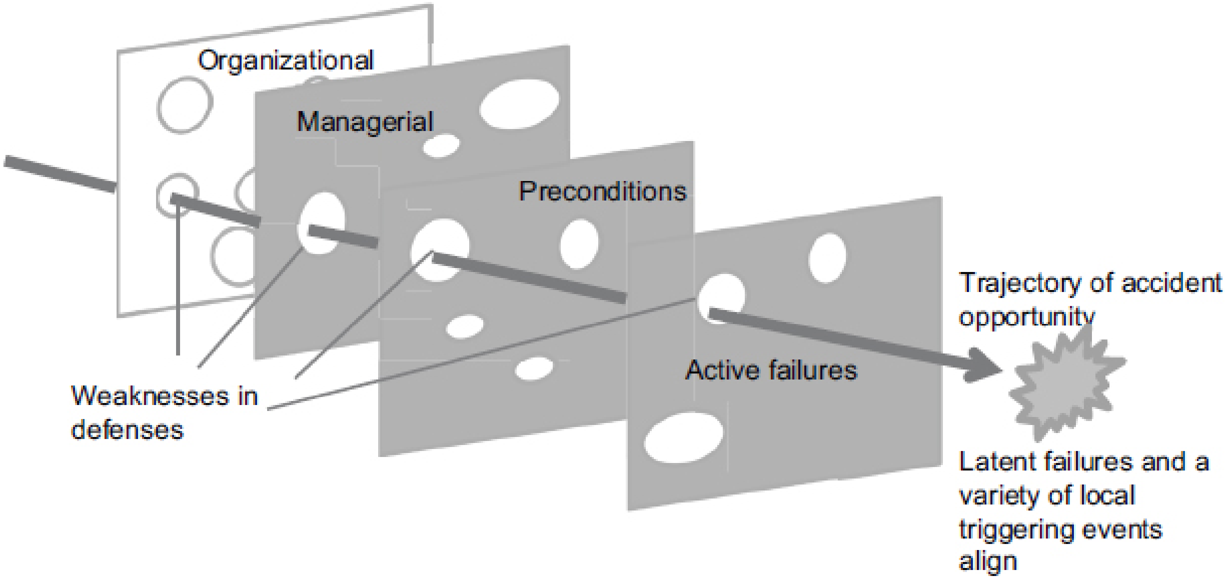

FIGURE 5-3 James Reason’s Swiss cheese model.
SOURCE: Adapted from Reason (1990, Figure 7.8).

This scenario follows the Swiss cheese model developed by Reason (1990) (see Figure 5-3). In the figure, there are different levels represented to provide safety barriers for potential hazards. The holes within each level represent weaknesses at different stages of the system and vary in size and position. The system as a whole fails when latent failures at the organizational and managerial levels line up with local failures and poor preconditions, allowing for (in Reason’s words) a “trajectory of accident opportunity.”

Systems problems require systems solutions; they cannot be shifted or relegated to human actions or heroics. As has been argued many times, work places and organizations are easier to change than the minds of individual workers (see, e.g., Reason, 1997). As with other high-hazard operational environments, first priority must be assigned to prevention. Error tolerance and resilience systems involve both humans and technology and equipment to enable systems to withstand some part of the system failing without complete failure. Much, but certainly not all of tolerance and resilience, focuses on pre-escape, prevention, and damage control. Building these qualities into the overall safety system should necessitate fewer escapes as well as more timely, efficient, and effective escapes. Primary attention is given to preventing such situations from occurring in the first place. There must also be continued safety mindfulness—conscious awareness that things can go very wrong at any time. This mindfulness is a key attribute of high-reliability organizations. Mindfulness also implies that a very high priority is assigned to emergency preparedness.

Miners are really the last line of defense in terms of promoting successful self-escape. Instead, factors in the system (e.g., communication systems, training, environmental support for escape, safety culture, external pressures) influence the likelihood of self-escape long before a miner or group of miners must act in the event of a mine emergency. When there is an alignment of deficiencies (or holes) in several different aspects of the system, successful self-escape is most at risk (Reason et al., 2001).

IDENTIFYING SAFETY PRACTICES

In a strong and positive organizational culture, safety is a clearly recognized value and there is a drive to increase learning to continuously enhance safety. Many unsafe work practices develop through preference, habit, or adherence to the status quo. It is important to have a systematic study of practices that will lead to the safest work environment possible and ensure these practices are consistently implemented throughout the work place. Integrating safe practices into all activities will help to mitigate potential emergencies that might necessitate self-escape and will help ensure the optimal self-escape practices once it is determined that a mining emergency has occurred and miners have to travel to a place of safety. Such practices of organizations with successful safety records include

Safety Culture: Creating a strong, positive safety culture that pervades an entire organization begins with senior management through actions more than words. Safety must be shown to be a key business and operational value; one that is adequately staffed and resourced. Safety performance goals extend beyond simple compliance with external standards and regulations. These goals should be continually monitored and updated as necessary. Monitoring and assessment feature both leading indicators (safety culture, safe work practices, hazard audits, near misses, etc.) and lagging indicators (accidents, injuries, other losses). Nothing short of continuous improvement is accepted.

Hazard Identification and Control: A fundamental element in successful safety management involves having a systematic program for identifying and assessing work-related hazards and for implementing and evaluating appropriate controls and other mitigation strategies on an ongoing basis. The primary emphasis is with preventing adverse events from occurring that might make mine escape necessary. However, this basic analytic process also can used to make mine escape and other emergency actions safer and more efficient.

Emergency Preparedness: An organization actively plans for and rehearses the actions that will be taken in emergency situations. Both managers and workers are involved in planning and executing practice activities. The formal emergency response plan is detailed, current, and customized to the specific characteristics of the work place. It is a proactive document, a “playbook” that is readily available and used. The emergency response plan also reflects a human-systems perspective that carries over into the design of safety-related training and adoption and use of available safety equipment and technologies.

Information Flow: Organizations are made up of individuals who must function together through effective communication. As with other organizational priorities, good communication is crucial to achieving safety goals and maximizing worker safety. All people in the organization have a “voice” and can speak up about safety issues without fear of retribution. Communication is central to successful emergency response, but it also has a crucial role in prevention and preparation activities.

Learning Orientation: In the most general sense, organizations with a learning orientation are open to new information, technologies, and ways of thinking and doing things. They realize the need to question, revise, and improve shared mental models that have become outdated, distorted, or inadequate based on new knowledge, emergent technologies, and/or the changing demands of the work situation.

Training Engagement: The term "engagement" reflects the fact that safe organizations, especially those in high-hazard industries, are committed to training excellence and the use of best practices. Training efforts extend beyond the passive and perfunctory transfer of information. Training experiences are provided that are experiential and competency based. Employees at all levels of the organization are involved in the design, implementation, and evaluation of safety training programs. Specific safety-related training might also be directed at senior managers to help them keep pace with overall safety needs and to help them be more knowledgeable and effective leaders of the entire safety effort.

RECOMMENDATIONS

A safety culture forms the organizational context in which all safety-related actions take place. It provides the subtle and sometimes not so subtle cues about the importance of safety, the safety-related behaviors that are expected, the resources available to support safety, and the steps taken to identify, eliminate, or control hazards. Safety cultures develop over time as organizations operate and adapt to local conditions and respond to events and as a function of organizational leadership. It is understood that mine operators have an obligation to comply with the law. However, to enhance self-escape capabilities, mine operators should also pursue efforts that create a strong, positive culture of safety. Safety needs to be recognized as a core value throughout the industry. There is a repository of information on safety cultures from other industries. The National Institute for

Occupational Safety and Health is to be recognized for recently initiating research on safety culture specific to underground coal mining.

RECOMMENDATION 6:

A. The National Institute for Occupational Safety and Health (NIOSH), in coordination with mining stakeholders, should compile the existing research and recommendations on safety culture from other high hazard and process industries and disseminate them to the mining industry. Such information would provide a useful resource that mine stakeholders could use to examine their own safety cultures and identify strengths and weaknesses specific to their organizations.

B. NIOSH should expand its safety culture research efforts to include a larger and more generalizable sample of mining organizations as well as to examine linkages between cultural attributes and safety performance, ideally using longitudinal data on safe work practices and accident and injury outcomes. NIOSH's current data base of qualitative and questionnaire data would appear to provide a strong basis for this expansion. Ultimately, the results from this research effort could be used to produce a set of safety culture tools that could be used by the entire mining community. This compilation of data collected using these tools could then be used for further analyses and benchmarking activities.

6

Training

Under threat-to-life conditions, a person wants to have a maximal chance of escaping alive. An important way to maximize those chances is by preparing the person to perform effectively and confidently under those conditions, and sound training is a key contributor to being well prepared.

Designing and delivering effective training is similar to shooting an arrow at a target: a person has to be able to see the target clearly; take into account the conditions that might affect the shot; select an arrow that fits the situation; fire the arrow at the target with good form; check to see how close your shot came to the bull's eye; and make corrections before the next shot. If one leaves out any of these steps, the person will shoot poorly or not hit the target at all. Similarly, in training, one has to have a clear and specific view of the goal of the training; take into account the conditions that might affect training; select the training methods that fit the training situation; deliver the training using best practices; verify how close the training came to having the training goal; and make any corrections necessary to improve the next training opportunity.

There are several excellent reviews of the training design and delivery process that provide a comprehensive discussion of these issues: see, especially, Noe (2010); Brown and Sitzmann (2011); and Cannon-Bowers and Bowers (2011). In this chapter, we discuss the processes that seem to be most relevant to the mine self-escape task. We also discuss aspects of training content and current industry practice that are relevant to self-escape.

CURRENT TRAINING IN THE MINING INDUSTRY

Required Training

Safety training in the U.S. mining industry is regulated by the Mine Safety and Health Administration (MSHA). Requirements set out which miners must be trained, how much training is required, who may provide the training, and the subject areas that need to be covered.[1] As noted earlier, much has changed in the training of miners, as well as the resources available to them, since the mandates of the 2006 MINER Act: quarterly hands-on training on the use of self-contained self-rescuers (SCSRs) and escapeway drills, the location of caches of additional SCSRs positioned along escapeways, and the availability of gas detectors, directional lifelines, refuge alternatives, and wireless communication and tracking systems.

The regulations on relevant training have been organized around new miners, experienced miners, and annual refresher training. New miners, before they start work duties, are required to receive no less than 40 hours of training. New miner training consists of instruction in 14 areas:

1. statutory rights of miners and authority and responsibility of supervisors,
2. self-rescue and respiratory devices,
3. mine transportation and communication,
4. work environment,
5. escapeways and emergency evacuation,
6. roof and ventilation plans,
7. health,
8. rock dusting,
9. hazard recognition,
10. electrical hazards,
11. first aid,
12. mine gases,
13. health and safety aspects of relevant tasks, and
14. other subjects required by the district MSHA manager based on mine conditions. (adapted from Title 30 CFR § 48.5)

Experienced miner training and annual refresher training cover many of the same areas. The regulations spell out when experienced miner training is required (see Appendix A). All employed miners are required to receive a minimum of 8 hours of annual refresher training.

Although all the training areas have the potential to increase miners' familiarity with mine-specific resources and protocols and as such equip miners with the knowledge necessary for self-escape, areas (2) and (5) have been recognized as most pertinent to self-escape. For area (2), miners are instructed on the use, care, and maintenance of self-rescue and respiratory devices. They must receive hands-on training in the complete donning of all types of devices used at the mine and in transferring between devices. For area (5), instruction is required to orient miners to the mine emergency evacuation and firefighting program approved by the district manager (under Title 30 CFR § 75.1502). Such instruction is supposed to include a review of the mine map and escapeway system, as well as methods for barricading when necessary.

As a result of the 2006 MINER Act, training on self-rescue, respiratory devices, escapeways, and emergency evacuation are now required quarterly as part of mine emergency evacuation training and drills (see discussion in Chapter 2). Instruction is now expected to emphasize the importance of not removing the SCSR mouthpiece, even to communicate, from respiratory devices. "Expectations training," which includes the donning and transferring of SCSRs in smoke or equivalent degraded environment and the use of training units that provide the sensation of SCSR airflow resistance and heat, is required annually. In the evacuation drills, miners are required to travel the entire primary or alternative escapeway and to physically locate lifelines, SCSR caches, refuge alternatives, and other self-escape resources.

In addition to knowing the location of refuge alternatives, miners are required to review quarterly the procedures to deploy and use refuge alternatives and their components as well as to be trained on the proper transportation of refuge alternatives and components. Annually, they are expected to experience the deployment and operations of refuge components. They are supposed to be instructed when to use refuge alternatives during an emergency, with emphasis on using as a last resort if escape is possible.

Training Gaps

Today's mine safety training programs appear to emphasize training duration and frequency rather than training to mastery. The committee heard from several stakeholders that current self-escape training is not satisfactory to meet the needs of miners. The Mine Safety Technology and Training Commission (2006), in its review of mine safety in underground coal mines, recognized that existing training requirements do not adequately address all areas needed to improve miners' ability to escape in mine emergencies: see Boxes 6-1 and 6-2. The commission acknowledged the mining industry would need to consider providing miners with additional training beyond what is required by law in order to adequately prepare them for emergency situations.

BOX 6-1
Self-Escape Skill and Knowledge Areas

- Knowledge of Escape/Rescue Technologies: Miners must be competent in the use of the technologies designed to assist them during an emergency situation. They must be proficient in the use of self-contained self-rescuers (SCSRs), directional lifelines, refuge chambers, gas-monitoring devices, and similar types of technologies. As a last resort, they must also be familiar with how to construct a proper barricade.
- Mine-Specific Knowledge: Miners must be intimately familiar with their mine's escapeways, ventilation system, mine map, SCSR storage locations, lifelines, escape capsules, communication networks, and other emergency systems. In addition, miners must be proficient in the specifics of their mine's emergency response/evacuation plan and related mine-rescue protocols.
- Escape/Rescue Conceptual Knowledge: A key escape/rescue competency often overlooked is the ability of miners to think and adapt to changing emergency situations. Miners must have effective problem-solving and decision-making skills. The ability

of miners to define the nature of their problem, identify alternative escape strategies, effectively use available technology, and execute their decisions all depends on their ability to think conceptually. Conceptual knowledge is a higher level of understanding. It is not gained by rote instruction alone. Instead, it is attained by exposing learners to good and bad examples of the concept they are trying to understand. Miners can better understand the concepts of self-escape if they are exposed to various types of mine disaster scenarios.*

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*Federal regulation currently requires coal mine operators to identify four different scenarios using fire, explosion, inundation of gas and water, in their mandatory Firefight Evacuation Plans. A different scenario is required for each 90-day Firefight Evacuation Drill.

SOURCE: Adapted from Mine Safety Technology and Training Commission (2006).

Across the mining industry, the capacity to provide adequate escape training seems to be inconsistent. A recent review by the U.S. Government Accountability Office (2007, p. 3) found

> Underground coal mine operators face significant challenges preparing for emergencies, including ensuring that miners receive realistic training and organizing mine rescue teams that satisfy new requirements. Mine operators recognized the importance of providing emergency training in a simulated environment. However, on the basis of our survey results, an estimate of 81 percent of mine operators considered the availability of special training facilities for providing such training as a challenge, and 70 percent considered the costs of providing simulated training as a challenge.

The committee was informed that despite training development done by the National Institute for Occupational Safety and Health, MSHA, some universities, and some mine operators, on the quality and quantity of escape training, there is still room for improvement to ensure that all mine personnel can effectively escape a mine emergency. This conclusion applies to almost every aspect of escape behavior training, from donning, removing, and exchanging SCSRs to working effectively as an escape group. Although there are exceptions, escape training programs in the industry seem to be oriented primarily toward “checking the box” of minimal compliance with federal and state training criteria.

BOX 6-2

Specific Training Elements to Maintain and Improve

- Self-contained self-rescuer (SCSR) Donning/Transfer: This is a fundamental escape skill. If miners do not have the ability to quickly don their SCSRs, they have no chance of successfully escaping through carbon monoxide (CO), smoke, or both. Miners need hands-on training in the SCSR donning (and transfer) procedure. In addition, SCSR training needs to be repeated frequently, or it tends to be forgotten.
- SCSR Expectations: SCSR expectations training involves having miners actually breathe through their SCSRs to provide them a realistic idea of what to expect from the device in an emergency.
- Simulated Smoke: Again, realistic experiences prepare miners for the sensations they may experience in emergencies.
- The Effects of CO: Increased training on the dangers posed by CO may encourage early donning of SCSRs and improve the ability of miners to self-escape.
- The Concept of Ventilation Leakage: Excess smoke in mine pathways may be the result of ventilation leakage and not specifically tied to the significance of an existing fire. Such smoke can be walked through. A better understanding of this concept may improve the problem-solving ability of miners confronted with such situations.
- Wayfinding: Wayfinding or being “mine wise” is a miner’s knowledge of alternative escape routes other than the primary escapeway. It also involves the ability to use alternative directional devices, such as track and belt lines to successfully exit a mine in limited visibility.

- Effective Warnings: Miners and responsible surface personnel need to know how to provide and receive accurate information as to the nature, location, and severity of a problem.
- Problem-Solving and Decision-Making Skills: Miners could benefit from additional training to develop their problem-solving and decision-making skills in emergency situations.

SOURCE: Adapted from Mine Safety Technology and Training Commission (2006).

The committee was told that miners seldom have to demonstrate mastery of a skill, but, instead, they just have to attend the required training. We also learned that programs for preparing and certifying self-escape trainers are few and of variable quality. According to the U.S. Government Accountability Office (2007), MSHA's monitoring of training and certified instructors is insufficient. Although MSHA has guidelines for the approval of new instructors, it allows variance in the processes for approval across districts. The report also notes that MSHA "does not have continuing education requirements for instructors … and does not ensure that they keep their knowledge and skills up to date. Further, MSHA does not adequately monitor instructors or evaluate training sessions, and does not assess how well miners are learning the skills being taught" (p. 4).

The number of training facilities capable of preparing miners and responsible persons in self-escape appears to be insufficient, especially with regard to facilities that have the capability of simulating mine fire conditions and providing integrated training between miners, responsible persons, and the surface communication centers. A recent inventory of coal mine rescue training capabilities and facilities (Bealko et al., 2009) found 12 facilities in the United States that offer what is considered real-life training activities or features that could enhance training. And of these, only eight are readily available public facilities. The other facilities are either government research, academic, or privately owned facilities. Only one of the public facilities was recognized as providing training to individual coal miners to respond to mine emergency conditions: most of the facilities were focused on preparing mine rescue teams. The inventory considered the provision of 11 basic features and training capabilities (e.g., firefighting, navigation in smoke, water rescue, incident command) and determined that comprehensive regional facilities do not exist in the United States. The inventory (Bealko et al., 2009) did acknowledge that existing facilities are providing some kinds of realistic and hands-on training experiences.

Currently, a source of best practices and sharing of training programs on mine health and safety is an annual mine instructors conference held by MSHA at the National Academy for Mine Health and Safety (in Beaver, West Virginia). The primary objective is to train and retrain the MSHA mine instructors; a secondary objective is to perform outreach to the mining industry as a part of the agency's Educational Field Service (EFS). At present, there are a very few programs at the annual conference on training miners to escape, and there are no programs that focus on the responsible persons and support to escaping miners.

The MSHA academy has the potential to expand escape training and offer programs on training in an integrated way. It could also be a venue for training on curricula developed by the National Institute for Occupational Safety and Health (NIOSH) on effective tools and their proper use. Other examples of existing sources of training include the many health and safety papers and presentations held in conjunction with the American Society of Safety Engineers, the International Society for Mine Safety Professionals, the Society for Mining, Metallurgy, and Exploration, the Joseph A. Holmes Safety Association,[2] vendor training programs, and various state coal mining institutes.

PRINCIPLES OF TRAINING DESIGN

There are a number of "best practice" principles and tools available through the work of both researchers and practitioners (for a thorough review, see Salas et al., 2012). The general principles apply regardless of whether the students are miners, members of a responsible person team, or trainers learning how to be better trainers. For discussion purposes, the rest of this chapter focuses on developing training for miners and members of responsible person teams.

One of the fundamental conceptual principles is that effective training is developed through a systematic process (Goldstein, 1986; Brown and Sitzmann, 2011; Salas et al., 2012). The essential elements include (1) conducting a training needs analysis that would include task, systems, and critical incidents analyses (see Chapter 3), (2) developing objectives and a design, (3) pilot testing that design, and (4) evaluating both the learners and the design. These steps are taken within the context of also considering how the learners will best absorb and retain what the training seeks to deliver, how the learners will accept or engage with the training, and how the training will facilitate transfer of the requisite knowledge, skills, abilities, and other personal attributes (KSAOs) back to the work environment.

As Brown and Sitzmann (2011) note, one key conclusion is to make training as similar as possible to what the learners will have to actually do on the job (Holton and Baldwin, 2003). This conclusion essentially captures the military doctrine of "train as you fight" and the importance of psychological similarity between the training experience and the actual application (i.e., escape under threat-to-life pressure and adverse conditions).

Training is but one intervention that may be called for to enhance success in escape scenarios. The scope of interventions that should be considered will be defined by a needs analysis. Once the needs analysis points to training as a key element, analyses of tasks, critical incidents, and the system in which escapes take place, are required to provide the basis for the content and design of the training needed. A task analysis and related training needs analysis make the target of your training clear and reveal priorities regarding what should be trained.

Research on training provides a number of evidence-based best practices for training design and delivery (Noe, 2010; Brown and Sitzmann, 2011; Salas et al., 2012) that can be key resources for mining industry personnel responsible for training or management. In particular, Salas and his colleagues (2012) not only list and review best practices, but they also provide tables and checklists for the pre-training, in-training, and post-training periods. Among those practices listed is the conduct of a training needs analysis. As part of that assessment, a task analysis, critical incidents analysis, cognitive task analysis, and team and system task analyses can specifically define the KSAOs that need to be trained, as well as relevant choice points, technologies, and conditions under which specific KSAOs should be demonstrated. For the task of self-escape, such an analysis would cover the tasks, behaviors, decision points, technologies, competencies, and conditions of the self-escape for miners.

Accompanying the task analysis would be a general analysis of the organizational climate and the extent of its readiness and support for this training. Organizational obstacles, negative supervisory attitudes, or lack of resources for effective training and its transfer would have to be resolved before expecting good training results. When organizational leaders support a particular training, the result of the training is improved (Salas et al., 2012). A similar outcome might be expected from support by union leaders, foremen, and formal and informal leaders among section crews in mines. To promote motivation and accurate perception of the training, Salas and colleagues (2012, p. 83) emphasize that "organizations should prepare and encourage supervisors, mentors, and team leaders to have effective conversations with trainees prior to training."

Lastly among the training analyses would be a work force analysis. A work force analysis will help the industry, and perhaps individual mines, determine whether the mode of training needs to accommodate changing employee demographics and any variations in miners' capacities to learn. As noted to the committee, the work force of the coal mine industry may be shifting, with an increase in younger workers as well as those with primary languages other than English. Several researchers make a case for training older workers differently than younger workers (Mayr and Kliegl, 1993; Mead and Fisk, 1998; Salas et al., 2012). As younger miners enter the work force, this population might be more engaged in training that is presented through computers, virtual reality formats, or the Internet. Although digital training should not replace high-fidelity simulation or hands-on experience in threat-to-life training, it might be appropriate and effective for portions of self-escape training, such as case-based decision making, problem detection and awareness, medical and refuge decision criteria, common wayfinding mistakes, and best practices, presented digitally prior to actual practice. Older employees may respond better to highly structured practice and traditional instructional materials (Salas et al., 2012).

Another important difference to keep in mind in assessing the work force is the difference between mine employees and contracted employees. Currently, about one-fifth (about 10,000) of the workers in underground mines are contractors. There is uncertainty about these workers in several regards: the training they have received; their familiarity with the layout of a particular mine; their skills for using available escape equipment and technologies; their knowledge of the authority for and in response to decisions; and group dynamics when contracted employees are part of a group in an emergency.

TRAINING MINERS FOR SELF-ESCAPE

A systematic and industry-wide approach to training for miners would be beneficial for the miners and the industry. Such an approach would focus on the two critical parties to mine self-escape: (1) an individual miner alone and as a member of an escape group, and (2) the responsible team, which consists of the responsible person, the people staffing the communications center at the mine site, and the other one or two people who are designated to assist the responsible person during the escape process. It is clear from the extensive list of tasks given to the responsible person (see Appendix A) that the person cannot perform the tasks alone: she or he will necessarily rely on other miners for assistance. Regardless of the composition of the team, or of other duties they perform when mine operations are nominal, each member of a responsible person team needs to be fully capable at all times for assuming the responsible person team role. Training is an important component in the preparation of the miners, the responsible person, and the responsible person team.

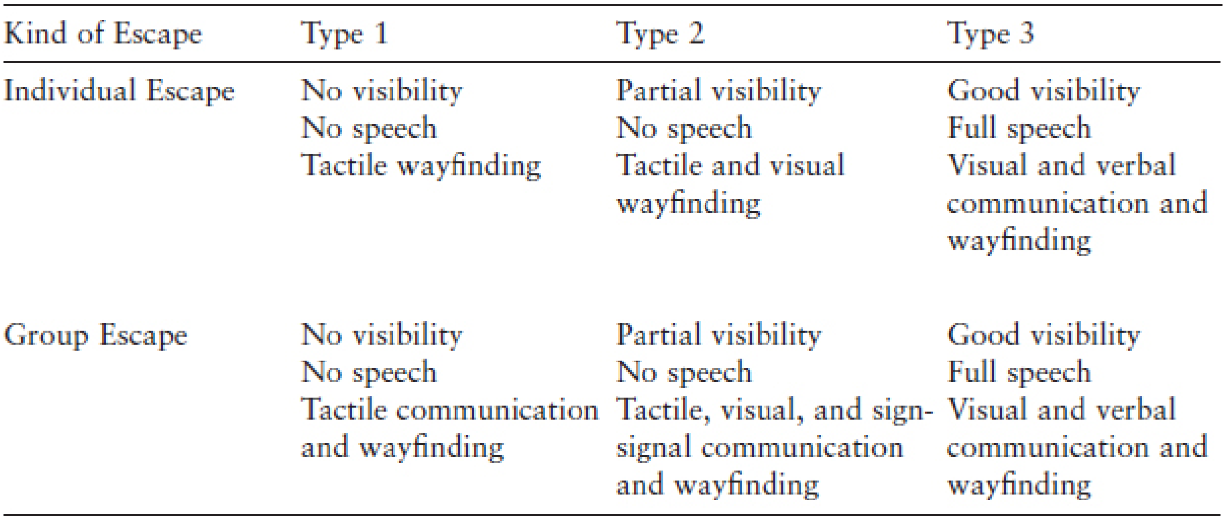
Across the mine industry as a whole, training for these critical groups appears to take place with little integration between them. Separate training is required for each of the groups; however, there seems to be few instances in which coordinated training occurs. The importance of integrated training is that it gives an opportunity for the groups to exercise their interrelated roles and identify opportunities to improve the way an escape is coordinated and information is exchanged. Although at times this may involve a mine-wide exercise, great gains also can be made using a responsible person team and only one work group of miners. Such a partial simulation would most benefit the surface personnel, who will have to periodically refresh their familiarity with escape procedures, and it is a good way to establish responsible person team procedures before applying them to mine-wide integrated drills. The ultimate goal for training, however, is a fully integrated emergency response drill among everyone who would be involved in an escape situation, conducted on a regular basis (see Recommendation 1 in Chapter 2).

Types of Escapes

Before an escape begins, the decision must be made as to whether the emergency can be resolved and so obviate the need to escape. The detection and evaluation of the emergency and the kinds of decisions required to stay and resolve the emergency would be important elements in any comprehensive training program. As a first and obvious step, safety values need to be in place as part of prevention so that miners take care to avoid any actions that could start a fire or cause another emergency.

As noted in previous chapters, the committee learned during its work that every mine and every emergency situation is unique. However, there are some fundamental similarities as well. In Chapter 3, an example of a preliminary self-escape task analysis for underground miners is illustrated. That task analysis was useful in highlighting escape behaviors and potential decision points as well as identifying conditions that characterize different types of escapes. Table 6-1 identifies six basic circumstances, based on way finding and communications implications of possible environmental conditions, under which mine escapes occur, regardless of variations in the mines or personnel. These basic circumstances are further defined by whether the escaping miner is alone or in a group. The environmental conditions determine the technology that will have to be used, as well as the functional limitations of the individual or group during the escape. Essential to wayfinding and decision making, sight and speech are key functional capabilities and may or may not be possible. These capabilities will be affected in part by smoke or limited lighting, which can restrict visibility, and the widely used SCSR technology, which limits speech. Therefore, miners must be trained to deal effectively with all six of the basic escape circumstances.

TABLE 6-1 Basic Circumstances of Escape and Their Wayfinding and Communication Implications



Kind of Escape	Type 1	Type 2	Type 3
Individual Escape	No visibility No speech Tactile wayfinding	Partial visibility No speech Tactile and visual wayfinding	Good visibility Full speech Visual and verbal communication and wayfinding
Group Escape	No visibility No speech Tactile communication and wayfinding	Partial visibility No speech Tactile, visual, and sign-signal communication and wayfinding	Good visibility Full speech Visual and verbal communication and wayfinding

During any specific escape, a miner is likely to experience more than one of these six circumstances over the course of the escape. A miner may be in thick smoke and with an SCSR and later come into fresh air, or vice versa; visibility may come and go as the escaping miner makes his way through escapeways; a miner also may begin in a group and then later become separated from that group, or vice versa.

Training Across Types

There will be important variances in a task analysis according to each circumstance and, consequently, variances in the specific training needed. For a complete picture, a task analysis is also needed for the job tasks of the responsible person and the responsible person team during an escape. We can see that teamwork training, discussed further below, will be necessary for miners in Type 2 and, especially, Type 3 conditions, as well as for the responsible person and his team in all instances.

Training designers should first address the worst-case scenario: an individual miner who is forced to escape by himself in thick smoke or darkness while wearing an SCSR that prevents speaking. Addressing the worst-case scenario first assures that all personnel in the mine share a common basic skill set and wayfinding ability. Comprehensive basic training will build confidence within the individual miner about leading a group out or following a leader on a tagline[3] under Type 1 conditions. It will also serve as a knowledge base from which each miner can contribute to group decision making if they are escaping under better conditions.

Because of the potential for shifting environmental conditions, individual miners have to be able to manage themselves and the appropriate technologies for each of these conditions. Thus, every miner must not only be trained and prepared for each of the six conditions but must also be trained to recognize when conditions change and how to mobilize the coping strategies and technologies best for each one. These needs require a flexible situational competency, in addition to the skills needed to deal with each of the basic conditions.

Specifically, miners have to have *situational awareness*. As discussed in Chapter 4, situational awareness is knowing what is around you, understanding it, and being able to project what might happen in the future (Endsley, 1988; Endsley and Garland, 2000). This type of awareness can be developed by training miners to see emergencies through the eyes of an "expert miner" (see Klein et al., 2013; see Chapter 4). By drawing on the knowledge base of highly experienced miners, one can learn what types of environmental cues these experts notice and the decisions and actions they might invoke in each situation. This knowledge can then be taught to less experienced miners. It should be noted that situational awareness is important not only for miners underground but also for surface personnel. Surface personnel could also be trained using the above-mentioned expertise approach, in terms of knowing what information is most important to communicate and receive from underground.

Regardless of the type of escape, miners will benefit from training on common decision-making pitfalls and mistakes that tend to occur in emergency situations. Chapter 4 discusses in detail how stressful situations can compromise miners' thinking and reasoning skills and outlines decision-making mistakes that are likely to occur during self-escape. These include following through on an initial decision rather than considering alternative options, particularly if conditions change (i.e., sunk costs), looking for information that confirms one's assumptions about the emergency situation rather than disconfirms them (i.e., confirmation bias), not thinking about options for self-escape in terms of routes outby that may be behind you (i.e., backup avoidance). Common biases that can occur include not acknowledging an emergency situation early enough and decisions that are driven by panic, emotion, or fear, rather than a thorough consideration of all the information at hand: these biases can also be addressed during training. Being informed about these decision-making issues and training in ways that allow miners to see the consequences of various decision paths—using past mine disasters or even fictitious scenarios—is likely to help miners act most appropriately during self-escape. This type of "mindset education," that is, educating miners about key psychological factors that can affect decisions about the implementation of self-escape, can be carried out through computer or virtual reality training.

Training needs to include correct self-location and wayfinding in the mine, procedures for using and changing breathing devices, and decision making with regard to use of refuges and other beneficial technologies in the mine. Under Type 1 conditions, current breathing technologies prevent group problem solving and increase the importance of passive, embedded wayfinding aids, whether individuals are escaping solo or in a group. Individual miners should be trained to demonstrate mastery of individual and group wayfinding aids, and refresher training needs to be provided on a regular basis to maintain skills and knowledge. As improved passive wayfinding and breathing technologies are put into place (see Chapter 3), self-escape training should be integrated with these aids and technologies.

With Type 1 training and technologies as a base, organizations can address training individuals and teams for the slightly better conditions associated with Type 2 escapes. In this situation, marginal visibility is present but breathing technologies prevent speech. With partial visibility, miners have some, although limited, ability to communicate through hand signs and headlamp signals. This ability enables some communication within the escape group, although no verbal contact with the responsible person team would be possible.

Thus, training needs to address this rudimentary form of communication. A close review of the sign signals that are currently taught—in conjunction with a careful study of escape tasks, decision points, and what comprises vital information in an escape group—might reveal that some of the current sign signals are more important than others and that ones of low importance could be dropped from training. Similarly, it may be found that by adding just a few carefully selected signs (e.g., question signs or escapeway designation signs), the exchange of critical information in a group could be greatly expanded.

Type 3 conditions of full sight and speech open up the possibility of training for effective decision making in groups of miners. Under emergency conditions, not every decision can or should be made as a group. However, with speech comes the option for leaders to explain their perception of the situation, describe a plan, consider information and alternatives offered by others, delegate some actions, call the responsible person team outside the mine and exchange information, and so forth. Other miners in the group can offer factual information, provide reminders, suggest alternative courses of action, volunteer for tasks, give opinions, and provide other informational support to the leader and other group members. With more information being shared throughout the escape process, either in an escape group or between an individual miner and the responsible person team, the chances are greater that the individual or group can choose better courses of action that fit the evolving conditions and particular difficulties encountered.

For miners who, in training, do not demonstrate competency at SCSR skills under Type 1 conditions, it cannot be assumed that they have the skills necessary to escape. Similarly, responsible persons and their teams who have not demonstrated team coordination competency under Type 3 conditions cannot be assumed to have the skills necessary to facilitate miners’ escapes.

Type 2 and Type 3 circumstances permit more knowledge to be shared through vision and within-group communication, in contrast with Type 1, in which the group will have to rely heavily on the knowledge of the leader. Type 3 conditions are well suited for training that covers leadership and followership behavior, maximizes the exchange of wayfinding and status information, and promotes effective courses of action. Also under Type 3 conditions, the responsible person and his delegates and the communication center have an opportunity to work as a team to solicit, discuss, and provide information with escaping miners.

Leaders and Followers

Both leadership and followership become important skills under any of the escape types. It is easy to understand how someone connected to a tagline and following a leader through thick smoke would want the leader to be fully and recently trained on wayfinding and making critical decisions about direction, resource locations, and refuges. Leaders on taglines must not only be well trained on these things must be visually identifiable as such, perhaps miners who have demonstrated competency in mine escape should be given a reflective helmet tag or some other identifiable symbol.

Since an escape group also is likely to encounter Type 2 or 3 conditions during its escape, leadership training needs to include verbal leadership skills, such as soliciting information and opinions from others, exchanging information with the responsible person team, delegating, decision making, laying out alternative courses of action, communicating intentions and rationale, setting up and managing a refuge group. The demands of escape conditions and the degree of time pressure will determine naturally the extent to which the group is able to discuss various alternatives. When there is time and the ability to speak, more group discussion and follower input can take place; when time is critically short, what is said must be concise and and clearly understood, and the leader needs to be able to be more autocratic. When to listen and when to dictate is an important decision requiring good judgment, so training for leaders also needs to include situational leadership.

Followership is equally critical to successful team functioning under stress. To promote escape success, the follower role includes providing factual data openly for the team and leader to consider, as well as providing one’s own recommendations, rationale, and reminders. In an escape situation, great responsibility is placed on the leader and followers to share information. Under Type 2 and 3 conditions, communication can be done with pointing, signals, signs, and language. When to speak and when to keep quiet and when to insist and when to defer are all part of both leadership and followership. During a Type 1 escape, reminders and guidance sometimes can be shared by mumbling through the SCSR and through shoulder taps and other tactile ways. Followership should be taught in conjunction with leadership.

Some rules for communication that could be useful in a mine emergency, especially between personnel on the surface and miners underground, are available from research on training:

- Repeat back key pieces of information to make sure it was understood correctly.

- Talk in “to do” statements rather than abstract statements (Chang et al., 2010).
- State key pieces of information stated first to ensure that receiver understands the context of what is being communicated (Bransford and Johnson, 1972).
- To the extent possible, having the same person(s) consistently on both ends can lead to a feeling of comfort and also less likelihood for misunderstandings (Gary Klein, MacroCognition LLC, personal communication).

Responsible Person and Team Training

Currently in the mine industry, attention seems to be on isolated training for an individual responsible person (U.S. Department of Labor, 2008). This is important of course, but the responsible person does not function alone during an escape. Under the current regulations, the responsible person must be trained to cover an enormous number of tasks in the event of a mine emergency. It is a bit unrealistic to expect one individual to meet all of these needs, especially when he/she may not be immediately available: if the responsible person is underground when an emergency begins, miners’ escape efforts may be unnecessarily delayed while the communications center tries to contact him or her. Even if the responsible person is in contact with the communication center, one may likely concentrate on assuring that all miners are evacuated safely to the surface then making decisions focused on addressing the hazard itself.

The responsible person needs to be aware of how decisions affect the self-escape efforts and must be trained to facilitate and aid the evacuation of miners. This must be a primary concern and anything done to mitigate the source of the emergency will, out of necessity, take a back seat to the escape under way. Therefore, it is important for other persons on the shift to be prepared to take over some of the secondary duties anticipated by the regulations. It is important to have a clear line of authority described for every mine regarding who assumes the responsible person role and the different responsible person team member roles under the various possible scenarios.

Under all conditions, the responsible person and the responsible person team would benefit from team coordination and decision-making training, such as crew-resource management training or one of its derivatives (Salas et al., 2012). This kind of training addresses effective team communication, situational awareness, detection of problems, and good team leadership and followership behavior. This training first requires that the responsible person team members be clearly distinguished and their roles be crisply defined. In this way, the functions of the team and its members are distinguishable from other incident response teams that may be involved in an emergency. In organizations that want to have a subsequent handover of responsible person responsibility to mine management or other personnel that arrive sometime later during the emergency, that transfer should be explicitly described in a mine's emergency response plan. Anyone—including higher management—that participates in tactical decision making pertinent to an escape also should undergo team coordination training.

A major review of research on team training (Cannon-Bowers and Bowers, 2011), which has primarily occurred in the military and aviation, identifies several things of particular interest to mine escape teams and responsible person teams. One is that teams under time pressure rely on existing, shared knowledge or shared mental models of the situation and of each other. Thus, training to build shared team knowledge of what to do under different escape conditions and circumstances would be beneficial for both in-mine and above-ground teams. Among the many aspects of team training reviewed, scenario-based training and team coordination and adaptation training appear to be particularly suited to both miner and responsible person team preparation for escape.

Since there is little history of formal responsible person team training in the mining industry, team coordination and adaptation training could build on the considerable knowledge of current responsible persons. Responsible person teams would also need refresher training to keep their shared knowledge current, as well as the understanding of everyone's roles and role boundaries during self-escape and, if applicable, rescue.

Cannon-Bowers and Bowers (2011) also point out that there is significant evidence from learning research to support scenario-based training. They provide specific guidelines for team training and for the transfer of team training to the work setting.

Basic team coordination training is a tool that also should be considered for miner escape groups and responsible person teams. As discussed above, with improved escape conditions, opportunities for miners to communicate increase. Although Type 1 circumstances require a group to rely heavily on the knowledge of the leader, Type 2 and Type 3 circumstances permit more knowledge to be shared through improved vision and within-group communication. Type 3 circumstances are well suited for training in leadership and followership skills, maximizing the exchange of wayfinding and status information, and promoting effective courses of action. Also under Type 3 circumstances, the responsible person, delegates, and the communication center have an opportunity to work as a team. There is a natural opportunity here to improve their coordination and effectiveness, as well as their communication with miner escape teams, through team training.

TRAINING TOOLS

There are a large number of training tools, methods, and strategies available and described in the research on training that are suited for individual miners and responsible person teams (e.g., Gagne et al., 1988; Noe, 2010). These include, but are not limited to, classroom lectures, rote physical drills, mentoring, modeling, part-task trainers, full-task trainers, team and crew-resource management training, integrated simulations, computer-based training, virtual reality, environmental simulators, remote online training, and in-mine simulations.

A training designer should select the tools that are most appropriate to achieve the training objectives and to maximize transfer of learning back to the task. Any method by itself will not fully address a training task rather a combination of tools and methods, combined with specific content, will form the best training strategy (Cannon-Bowers and Bowers, 2011). When the goal of training is effective performance under life-threatening conditions, the training designer should select the tools that lead to rapid detection of trouble, automatic actions, effective use of available information, and good decision making. The various training tools should be mixed, modified, and arranged to form a sequence of training experiences that leads to effective in-mine escape capability. The sequential arrangement of these experiences constitutes the escape training flow or program.

Currently, classroom lectures are widely used in the corporate training environment and in annual SCSR refresher training for miners. This tool is suitable for the presentation of overview information, general concepts, background, and historical and technical information, as well as for introductory familiarization to hardware and procedures. However, this type of training does not yield learning that lasts particularly long by itself, and it does not transfer well to a life-and-death escape situation. As a tool to introduce the SCSR and familiarize miners with its parts, procedures, and function, classroom training is potentially useful; however, by itself it does not adequately prepare a miner to be able to use the SCSR under actual escape conditions. Therefore, classroom training needs to be used in combination with other training tools in order to ensure proficiency under actual escape conditions.

Escape performance in a real mine emergency will be improved to the extent that miners and the responsible person teams have been trained under realistic conditions and scenarios. This is the “train as you fight” maxim that is supported by training research and practiced by a number of high-risk, high-stakes industries, such as the military and the space industry. Hands-on, experiential training in a simulator brings workers close to the actual experience they must master and is essential training for threat-to-life situations. The psychological fidelity of the training experience in this approach is also higher than in classroom training as environmental conditions, scenarios, difficulties, time pressure, and other aspects are similar to the actual escape. Workers not only learn to perform necessary tasks under pressure but are also able to practice managing their emotions.

The use of high-fidelity simulators are likely to be useful in training for the types of emergencies faced by individual miners and teams. Simulators could be mounted on trucks and periodically taken to mining sites for initial training and follow-up practice, so that each locale need not develop and program its own equipment. An example of this is a mobile fire escape simulator used extensively by West Virginia University in SCSR expectation training at mine sites (Bealko et al., 2009). Note, however, that when training is done in high-fidelity simulators, emergency conditions that produce high levels of stress may interfere with learned responses. The use of work aids that miners could carry with them as a quick reference to decision rules and strategies could be useful in training and subsequently in emergencies as reminders of what to do.

The U.S. Navy, the U.S. Army, the National Aeronautics and Space Administration, and offshore oil drilling companies conduct training in simulators for pilot and passenger escape from helicopters and jets that have to ditch at sea. A helicopter that goes down in the sea will often roll over and submerge before anyone can get out, and such an accident can occur during day or night. To train for these escape situations, trainees are strapped into a “dunker,” which is usually a helicopter body complete with crew compartment, passenger compartment, doors, and windows. The dunker is then dropped into water, fills up and rolls over, and the trainees must extract themselves while upside down and submerged. Trainees first do this with their eyes open; they then do it with no vision while wearing blackened swim goggles. A high level of motivation is provided by the lack of oxygen, and the trainees have to demonstrate that they are able to escape unaided in order to be certified as competent in this skill.

For miners, even the current classroom SCSR training could be improved if the trainees were required to open, activate, don, and transfer SCSRs repeatedly under eyes-open and then no-vision conditions. Rote learning of SCSR use under the no-vision condition leads to confidence and automatic behavior during an actual fire or other emergency, freeing a miner to be assessing his situation, the threat, his fellow miners, and what action should be taken next. This kind of augmented classroom experience would be considered a “part-task trainer” because the training focuses solely on SCSR skills, which are only one part of the integrated skill set that must be mastered to self-escape.

In psychology and related motor-learning fields, there has been extensive research on understanding optimal practice conditions for the long-term retention of information. For instance, repeatedly practicing the same skill (massed practice) leads to less successful long-term retention than interspersing it with other skill practice or even separating that practice by time (distributed practice) (Proctor and Dutta, 1995; Schmidt and Lee, 2011). Massed practice (otherwise known as cramming) may give a miner the illusion, for example, of effectively donning an SCSR, when this is not the case. In more distributed situations, when the miner first practices donning, takes a break, and comes back and practices donning again, not only will the miner have a better understanding of what was remembered and what was not, but he/she will likely retain what was practiced for a longer period of time.

Practicing in one extended session without any breaks is also likely to lead to boredom, compared with distributing practice over time (Jarvis, 2006). This is important given concerns the committee has heard about some miners being complacent and reporting that training is uninteresting. Fostering more engagement and interest by trainees through distributed practice may not only enhance learning but also increase motivation during training.

There is a common belief that the more realistic training is the more effective it will be. It is certainly true that matching the conditions under which individuals are trained with those in which they will have to demonstrate their skills is beneficial for performance (for a general review, see Galotti, 2008). It may also be the case that technology-infused training that capitalizes on miners' (especially young miners') experience and positive attitudes toward video games or virtual reality can enhance engagement. However, as these technologies emerge, they need to be fully validated and tested demonstrating their appropriateness for use as a training tool. Furthermore, technology alone is not sufficient to ensure learning. It is still critical that the construction of training—from what specifically is trained to how it is trained (e.g., practice schedules)—is guided by the research on training and decision science. This is true regardless of the form of the training.

There are a number of ways to define and evaluate whether training has been effective and the relative advantages and disadvantages of different methods (see, especially, Cook and Campbell, 1979; Brown and Sitzmann, 2011). Evaluators can determine which methods are appropriate for the portions of the overall escape task that are being trained. However, Brown and Sitzman (2011) note that the pre-experimental designs, such as the post-test only and the pre- and post-test, are quite suitable for situations in which the main concern is whether or not the students have reached a particular level of competency on some task.

TRAINING IN OTHER INDUSTRIES

As mentioned above, industries outside of coal mining train and prepare individuals and teams to escape a confined work environment under dire circumstances. These industries include the military, firefighting, rescue, and space exploration. For our purposes, instances in which the physical environment, conditions and constraints on escape are similar to coal mining are termed here escape analogues. The jobs, work demands, personnel demographics, and other factors may differ substantially from those found in coal mining. However, key aspects are similar enough to provide ideas for improving training in the mining industry. They include the escape environment (e.g., highly confined work areas), emergency conditions (e.g., smoke in passageways), evacuation constraints (e.g., obstacles in passageways and restricted communication opportunities), escape equipment (e.g., respirators), personnel work units (e.g., teams), and requirements for successful escape (e.g., effective decision making and teamwork). Recognizing this, NIOSH conducted a literature review of other industries and found 18 articles from a number of analogues that appeared to be pertinent to mine escape (Harrald et al., 2008). These articles were identified for the mining community to use. A common theme that emerged was the need for more attention to organizational and behavioral issues.

All space-faring nations train their flight personnel to escape their vehicles under conditions of fire at different points in the launch, flight, and landing phases. For the flight phase, training focuses on first containing the fire. Training also includes escape to a waiting Soyuz capsule, in the event that containment should fail. In the case of a space station, such an escape would require people donning protective gear, moving through a number of modules to fight the fire, communicating with one another, and working systematically as a team.

Astronauts in training for missions aboard the International Space Station train for fire containment. European, Japanese, Canadian, Russian, and U.S. astronauts go through a comprehensive and systematic training procedure that entails five major phases:

1. classroom briefings that present the “big picture” of fire survival aboard the station, such as fire prevention, containment, and onboard resources;
2. a second round of classroom-based familiarization that focuses on firefighting procedures, why those procedures are written as they are, handling the hardware to be used, and donning and doffing breathing masks;
3. a walk-through of the procedures with an instructor inside a space station simulator, providing more familiarization with the equipment, gas sensor displays and where equipment is located; followed by a walk through with several different instructor-led scenarios in order to

understand how to respond to a variety of circumstances that are most likely to arise;

4. trainees' going through various scenarios in the station simulator in small teams; the instructor is observing and invokes "green cards" on trainees at various times with unexpected constraints or problems; and
5. multiple repetitions of the Phase 4 training with multiple unexpected scenarios to demonstrate mastery of the all the skills covered.

Separate similar training flows are followed for other emergency conditions, such as station depressurization and the release of toxins in the station atmosphere. In all cases, the flow is sequenced to begin with classroom procedure familiarization, move through hardware familiarization, advance into guided practice in the simulator, progress to independent practice with different scenarios, and conclude with a test of skills mastery. Demonstration of skills mastery is required before an astronaut is allowed to fly.

CONCLUSIONS AND RECOMMENDATION

Training is a necessary step in preparing individuals and groups to use available resources appropriately. Regulations relevant to training for self-escape appear to emphasize training duration and frequency rather than training to mastery. A detailed systematic task analysis would identify KSAOs critical to a successful self-escape. These KSAOs will provide a general blueprint for self-escape training programs and essential competencies.

Subsequent verification of training effectiveness would best be accomplished by NIOSH validating the entire training package so that operators do not have to do that. Those miners and responsible person team members who are trained to mastery could have a reflective symbol placed on their helmets so that in the event of an emergency other less trained individuals can immediately recognize those in their work groups with expertise at escaping and managing an escape. Refresher training should occur periodically according to NIOSH findings on training decay for the various elements. Individuals who retain their mastery should retain the helmet symbol.

Despite training developments by NIOSH, MSHA, and some universities and mine operators, the quality and quantity of escape training still falls far behind what is necessary to ensure that all mine personnel can effectively escape a mine emergency. This conclusion applies to almost every aspect of escape behavior training, from donning, doffing, and exchanging SCSRs under Type 1 conditions to miners' working effectively as a responsible person team.

As detailed above, effective training and transfer of what is learned in training to an actual emergency situation requires a supportive work climate. With only a few exceptions, most escape training programs in the industry are poorly designed, and many seem to be oriented primarily toward minimal compliance with federal and state training regulations. In training, miners seldom have to demonstrate mastery of a skill but only have to be in attendance. To ensure that miners can function effectively in an emergency, a train-to-mastery system with competency standards is needed, not time in class. Research will determine the minimum KSAO levels required to escape successfully under simulated crisis conditions and at various levels of reliability. The definition of mastery varies by what level of performance and reliability is acceptable: and increasing levels come with higher price tags of training time and general cost. The committee envisions that after step A. in Recommendation 7 below is completed, and the KSAOs are identified for self-escape, then a consensus group of stakeholders will meet to determine what level of performance is acceptable and define competency standards for those KSAOs. This meeting would include representatives from NIOSH, mine operators, and miner organizations.

The number of training facilities capable of preparing miners and responsible person teams in escape appear to be insufficient, especially those with the capability of simulating mine fire and other emergency conditions and providing integrated training between miners and responsible person teams. Programs for preparing and certifying self-escape trainers also are few and of variable quality.

For mines that cannot afford to send their miners long distances to available training facilities, there may be demand for portable training simulators to give miners the experience of donning an SCSR and wayfinding in a smoke-filled environment. Similarly, if multiple high-fidelity simulators are needed, mounting them on trucks may be a cost-effective way to make them available to all mines. Training center personnel can also facilitate small mine scenario exercises by helping design problems and supporting inexperienced management teams throughout the process. They can also provide important feedback to mines on their performance in the effort. This information can be stripped of mine identification information and then sent to NIOSH for inclusion into a self-escape database (suggested in Recommendation 1, see Chapter 2).

The West Virginia University facility, visited by the committee, is not currently designed to provide Type 3 or responsible person team training. However, it would be possible for this facility or others to be expanded to cover integrated Type 3 and responsible person team training with the addition of more tunnel complexity and with verbal team problem-solving scenarios for an escape group and the external responsible person team. Alternatively such integrated Type 3 training could be conducted in facilities suitable just for that purpose. Following classroom, part-task, integrated, and environmental simulation training, regular integrated simulations should be conducted at mine site, using the mine and its resources.

RECOMMENDATION 7: To advance self-escape training:

A. The National Institute for Occupational Safety and Health (NIOSH) should conduct or sponsor a formal task analysis and an analysis of the knowledge, skills, abilities, and other personal attributes (KSAOs) required for miners to self-escape effectively in coordination with the efforts of the responsible person, the communication center and mine management.

B. On the basis of these analyses and working with interested stakeholders, NIOSH should undertake the research required to identify the training modalities, techniques, and protocols best suited for those KSAOs as well as the interactions between miners, responsible persons, the communication center, and mine management. Thereafter, NIOSH should review current training and identify existing gaps within the mining industry.

C. On the basis of the research and review in step B. above, and using best practices within the training field, the Mine Safety and Health Administration (MSHA) and NIOSH should revise or

develop training flows that bring miners, responsible persons, communication centers, and mine management to mastery in those KSAOs, including interactions between those three groups.

D. NIOSH should conduct research to verify the effectiveness of training developed in step C. above and miners' retention of information learned under simulated emergency conditions.

E. In its current review of facilities supporting mine rescue training, MSHA should also evaluate whether these facilities could support self-escape simulation and scenario training.

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[1] Much of this summary draws on the regulations applicable to training for self-escape from underground coal mines, in Title 30 CFR Parts 46 and 48; see Appendix A for more details.

[2] The association, begun in 1916, is a private, nonprofit organization that recognizes achievements in mine safety; it gives annual awards and publishes a bulletin containing mine safety information. It includes representatives of federal and state governments, mining organizations, and labor unions.

[3] A tagline is a long heavy-duty rope with tethers spaced at even intervals, designed to link members of a mine crew together in the event of an emergency, particularly in dense smoke and little or no lighting.

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Appendix A

Regulations Relevant to Self-Escape

The text in this appendix is excerpted from the Code of Federal Regulations on mine emergencies and training. It is taken from two major sections of Part 30:

- 30 CFR § 75 sets forth safety standards compliance with which is mandatory in each underground coal mine subject to the Federal Mine Safety and Health Act of 1977. Some standards also are applicable to surface operations. Regulations and criteria supplementary to these standards also are set forth in this part.
- 30 CFR § 48 sets forth training and retraining of miners which includes new miner training; experienced miner training; annual refresher training; task training; and hazard training. Mine safety training in the United States is regulated by the Mine Safety and Health Administration (MSHA). Regulations mandate which miners must be trained; how much training is required; who may provide the training; and the subject areas that need to be covered by the training. They also require certification that training has been completed as well as impose record keeping requirements.

Topics covered in the following pages include

- escapeway requirements—number, location, size, conditions (p. 130)
- lifeline requirements (p. 131)

- primary escapeway conditions (p. 132)
- alternate escapeway (p. 133)
- mechanical escape facilities (p. 134)
- responsible person duties during emergency evacuations (p. 136)
- emergency preparedness program (p. 137)
- quarterly evacuation drills (p. 139)
- escapeway maps (p. 142)
- refuge alternatives (p. 142)
- communications (p. 148)
- training of new miners (p. 149)
- experienced miner training (p. 152)
- annual refresher training (p. 154)

[ESCAPEWAY REQUIREMENTS—NUMBER, LOCATION, SIZE, CONDITIONS]

§ 75.380 Escapeways; bituminous and lignite mines.

(61 FR 9829, Mar. 11, 1996; 61 FR 20877, May 8, 1996, as amended at 61 FR 55527, Oct. 25, 1996; 69 FR 17530, Apr. 2, 2004; 71 FR 12269, Mar. 9, 2006; 71 FR 71452, Dec. 8, 2006; 73 FR 80613, Dec. 31, 2008)

(a) Except in situations addressed in § 75.386, at least two separate and distinct travelable passageways shall be designated as escapeways and shall meet the requirements of this section.

(b)

(1) Escapeways shall be provided from each working section, and each area where mechanized mining equipment is being installed or removed, continuous to the surface escape drift opening or continuous to the escape shaft or slope facilities to the surface.
(2) During equipment installation, these escapeways shall begin at the projected location for the section loading point. During equipment removal, they shall begin at the location of the last loading point.

(c) The two separate and distinct escapeways required by this section shall not end at a common shaft, slope, or drift opening, except that multiple compartment shafts or slopes separated by walls constructed of noncombustible material may be used as separate and distinct passageways.

(d) Each escapeway shall be—

(1) Maintained in a safe condition to always assure passage of anyone, including disabled persons;
(2) Clearly marked to show the route and direction of travel to the surface;
(3) Maintained to at least a height of 5 feet from the mine floor to the mine roof, excluding the thickness of any roof support, except that the escapeways shall be maintained to at least the height of the coalbed, excluding the thickness of any roof support, where the coalbed is less than 5 feet…. When there is a need to determine whether sufficient height is provided, MSHA may require a stretcher test where 4 persons carry a miner through the area in question on a stretcher;
(4) Maintained at least 6 feet wide [with some exceptions where no less than 4 feet wide is allowed];
(5) Located to follow the most direct, safe and practical route to the nearest mine opening suitable for the safe evacuation of miners; and
(6) Provided with ladders, stairways, ramps, or similar facilities where the escapeways cross over obstructions.

[LIFELINE REQUIREMENTS]

(7) Provided with a continuous, durable directional lifeline or equivalent device that shall be—

(i) Installed and maintained throughout the entire length of each escapeway as defined in paragraph (b)(1) of this section;
(ii) Flame-resistant in accordance with the requirements of part 18 of this chapter upon replacement of existing lifelines; but in no case later than June 15, 2009;
(iii) Marked with a reflective material every 25 feet;
(iv) Located in such a manner for miners to use effectively to escape;
(v) Equipped with one directional indicator cone securely attached to the lifeline, signifying the route of escape, placed at intervals not exceeding 100 feet. Cones shall be installed so that the tapered section points inby;
(vi) Equipped with one sphere securely attached to the lifeline at each intersection where personnel doors are installed in adjacent crosscuts; and

(vii) Equipped with two securely attached cones, installed consecutively with the tapered section pointing inby, to signify an attached branch line is immediately ahead.

(A) A branch line leading from the lifeline to an SCSR [self-contained self-rescuer] cache will be marked with four cones with the base sections in contact to form two diamond shapes. The cones must be placed within reach of the lifeline.

(B) A branch line leading from the lifeline to a refuge alternative will be marked with a rigid spiraled coil at least eight inches in length. The spiraled coil must be placed within reach of the lifeline.

(e) Surface openings shall be adequately protected to prevent surface fires, fumes, smoke, and flood water from entering the mine.

[PRIMARY ESCAPEWAY CONDITIONS]

(f) Primary escapeway.

(1) One escapeway that is ventilated with intake air shall be designated as the primary escapeway. The primary escapeway shall have a higher ventilation pressure than the belt entry unless the mine operator submits an alternative in the mine ventilation plan to protect the integrity of the primary escapeway, based on mine specific conditions, which is approved by the district manager.

(2) Paragraphs (f)(3) through (f)(7) of this section apply as follows—

(i) To all areas of a primary escapeway developed on or after November 16, 1992;

(ii) Effective as of June 10, 1997, to all areas of a primary escapeway developed between March 30, 1970, and November 16, 1992; and

(iii) Effective as of June 10, 1997, to all areas of the primary escapeway developed prior to March 30, 1970, where separation of the belt and trolley haulage entries from the primary escapeway existed prior to November 16, 1992.

(3) The following equipment is not permitted in the primary escapeway —

(i) Mobile equipment hauling coal except for hauling coal incidental to cleanup or maintenance of the primary escapeway.
(ii) Compressors [with exceptions].
(iii) Underground transformer stations, battery charging stations, substations, and rectifiers [with exceptions].
(iv) Water pumps [with exceptions].

(4) Mobile equipment operated in the primary escapeway, except for continuous miners and as provided in paragraphs (f)(5), (f)(6), and (f)

(7) of this section, shall be equipped with a fire suppression system installed according to §§ 75.1107-3 through 75.1107-16 that is—

(i) Manually operated and attended continuously by a person trained in the systems function and use, or
(ii) A multipurpose dry chemical type capable of both automatic and manual activation.

(5) Personnel carriers and small mobile equipment designed and used only for carrying people and small hand tools may be operated in primary escapeways if—

(i) The equipment is provided with a multipurpose dry chemical type fire suppression system capable of both automatic and manual activation, and the suppression system is suitable for the intended application and is listed or approved by a nationally recognized independent testing laboratory, or

(ii) Battery powered and provided with two 10 pound multipurpose dry chemical portable fire extinguishers.

(6) Notwithstanding the requirements of paragraph (f)(3)(i), mobile equipment not provided with a fire suppression system may operate in the primary escapeway if no one is inby except those persons directly engaged in using or moving the equipment.

(7) Notwithstanding the requirements of paragraph (f)(3)(i), mobile equipment designated and used only as emergency vehicles or

ambulances, may be operated in the primary escapeway without fire suppression systems.

(g) Except where separation of belt and trolley haulage entries from designated escapeways did not exist before November 15, 1992, and except as provided in § 75.350(c), the primary escapeway must be separated from belt and trolley haulage entries for its entire length, to and including the first connecting crosscut outby each loading point except when a greater or lesser distance for this separation is specified and approved in the mine ventilation plan and does not pose a hazard to miners.

[ALTERNATE ESCAPEWAY]

(h) Alternate escapeway. One escapeway shall be designated as the alternate escapeway. The alternate escapeway shall be separated from the primary escapeway for its entire length, except that the alternate and primary escapeways may be ventilated from a common intake air shaft or slope opening.

[MECHANICAL ESCAPE FACILITIES]

(i) Mechanical escape facilities shall be provided and maintained for—

(1) Each shaft that is part of a designated escapeway and is greater than 50 feet in depth; and
(2) Each slope from the coal seam to the surface that is part of a designated escapeway and is inclined more than 9 degrees from the horizontal.

(j) Within 30 minutes after mine personnel on the surface have been notified of an emergency requiring evacuation, mechanical escape facilities provided under paragraph (i) of this section shall be operational at the bottom of shaft and slope openings that are part of escapeways.

(k) Except where automatically activated hoisting equipment is used, the bottom of each shaft or slope opening that is part of a designated escapeway shall be equipped with a means of signaling a surface location where a person is always on duty when anyone is underground. When the signal is activated or the evacuation of persons underground is necessary, the person shall assure that mechanical escape facilities are operational as required by paragraph (j) of this section.

(l)

- (1) Stairways or mechanical escape facilities shall be installed in shafts that are part of the designated escapeways and that are 50 feet or less in depth, except ladders may be used in shafts that are part of the designated escapeways and that are 5 feet or less in depth.
- (2) Stairways shall be constructed of concrete or metal, set on an angle not to exceed 45 degrees from the horizontal, and equipped on the open side with handrails. In addition, landing platforms that are at least 2 feet by 4 feet shall be installed at intervals not to exceed 20 vertical feet on the stairways and equipped on the open side with handrails.
- (3) Ladders shall be constructed of metal, anchored securely, and set on an angle not to exceed 60 degrees from the horizontal.

(m) A travelway designed to prevent slippage shall be provided in slope and drift openings that are part of designated escapeways, unless mechanical escape facilities are installed.

§ 75.381 Escapeways; anthracite mines.

(61 FR 9829, Mar. 11, 1996, as amended at 71 FR 12269, Mar. 9, 2006; 71 FR 71452, Dec. 8, 2006; 73 FR 80614, Dec. 31, 2008)

(a) Except as provided in §§ 75.385 and 75.386, at least two separate and distinct travelable passageways shall be designated as escapeways and shall meet the requirements of this section.

(b) Escapeways shall be provided from each working section continuous to the surface.

(c) Each escapeway shall be—

- (1) Maintained in a safe condition to always assure passage of anyone, including disabled persons;
- (2) Clearly marked to show the route of travel to the surface;
- (3) Provided with ladders, stairways, ramps, or similar facilities where the escapeways cross over obstructions;
- (4) Maintained at least 4 feet wide by 5 feet high. If the pitch or thickness of the coal seam does not permit these dimensions to be maintained other

dimensions may be approved in the ventilation plan; and
(5) Provided with a continuous, durable directional lifeline or equivalent device that shall be.

(d) Surface openings shall be adequately protected to prevent surface fires, fumes, smoke, and flood water from entering the mine.

(e) Primary escapeway. One escapeway that shall be ventilated with intake air shall be designated as the primary escapeway. The primary escapeway shall have a higher ventilation pressure than the belt entry unless the mine operator submits an alternative in the mine ventilation plan to protect the integrity of the primary escapeway, based on mine specific conditions, which is approved by the district manager.

(f) Alternate escapeway. One escapeway that shall be designated as the alternate escapeway shall be separated from the primary escapeway for its entire length.

(g) Mechanical escape facilities shall be provided—

(1) For each shaft or slope opening that is part of a primary escapeway; and
(2) For slopes that are part of escapeways, unless ladders are installed.

(h) Within 30 minutes after mine personnel on the surface have been notified of an emergency requiring evacuation, mechanical escape facilities shall be operational at the bottom of each shaft and slope opening that is part of an escapeway.

(i) Except where automatically activated hoisting equipment is used, the bottom of each shaft or slope opening that is part of a primary escapeway shall be equipped with a means of signaling a surface location where a person is always on duty when anyone is underground. When the signal is activated or the evacuation of personnel is necessary, the person on duty shall assure that mechanical escape facilities are operational as required by paragraph (h) of this section.

[RESPONSIBLE PERSON DUTIES DURING EMERGENCY EVACUATIONS]

§ 75.1501 Emergency evacuations.

(68 FR 53049, Sept. 9, 2003, as amended at 73 FR 7655, Feb. 8, 2008; 73 FR 80697, Dec. 31, 2008)

(a) For each shift that miners work underground, there shall be in attendance a responsible person designated by the mine operator to take charge during mine emergencies involving a fire, explosion, or gas or water inundation.

(1) The responsible person shall have current knowledge of the assigned location and expected movements of miners underground, the operation of the mine ventilation system, the locations of the mine escapeways and refuge alternatives, the mine communications system, any mine monitoring system if used, locations of firefighting equipment, the mine's Emergency Response Plan, the Mine Rescue Notification Plan, and the Mine Emergency Evacuation and Firefighting Program of Instruction.

(2) The responsible person shall be trained annually in a course of instruction in mine emergency response, as prescribed by MSHA's Office of Educational Policy and Development. The course will include topics such as the following—

(i) Organizing a command center;
(ii) Coordinating firefighting personnel;
(iii) Deploying firefighting equipment;
(iv) Coordinating mine rescue personnel;
(v) Establishing fresh air base;
(vi) Deploying mine rescue teams;
(vii) Providing for mine gas sampling and analysis;
(viii) Establishing security;
(ix) Initiating an emergency mine evacuation;
(x) Contacting emergency personnel; and
(xi) Communicating appropriate information related to the emergency.

(3) The operator shall certify by signature and date after each responsible person has completed the training and keep the certification at the mine for 1 year.

(b) The responsible person shall initiate and conduct an immediate mine evacuation when there is a mine emergency which presents an imminent danger to miners due to fire or explosion or gas or water inundation. Only properly trained and equipped persons essential to respond to the mine emergency may remain underground.

(c) The mine operator shall instruct all miners of the identity of the responsible person designated by the operator for their workshift. The mine operator shall instruct miners of any change in the identity of the responsible person before the start of their workshift.

(d) Nothing in this section shall be construed to restrict the ability of other persons in the mine to warn of an imminent danger which warrants evacuation.

[EMERGENCY PREPAREDNESS PROGRAM]

§ 75.1502 Mine emergency evacuation and firefighting program of instruction.

(71 FR 71452, Dec. 8, 2006, as amended at 73 FR 80697, Dec. 31, 2008)

Each operator of an underground coal mine shall adopt and follow a mine emergency evacuation and firefighting program that instructs all miners in the proper procedures they must follow if a mine emergency occurs.

(a) Program approval. The operator shall submit this program of instruction, and any revisions, for approval to the District Manager of the Coal Mine Safety and Health district in which the mine is located. Within 30 days of approval, the operator shall conduct training in accordance with the revised program.

(b) New or revised provisions. Before implementing any new or revised approved provision in the program of instruction, the operator shall instruct miners in the change.

(c) Instruction plan. The approved program shall include a specific plan designed to instruct miners on all shifts on the following—

(1) Procedures for—

(i) Evacuating the mine for mine emergencies that present an imminent danger to miners due to fire, explosion, or gas or water inundation;

(ii) Evacuating all miners not required for a mine emergency response; and

(iii) The rapid assembly and transportation of necessary miners, fire suppression equipment, and rescue apparatus to the scene of the mine emergency.

(2) The use, care, and maintenance of self-rescue devices, including hands-on training in the complete donning and transferring of all types of self-rescue devices used at the mine.

(3) The deployment, use, and maintenance of refuge alternatives.

(4) Scenarios requiring a discussion of options and a decision as to the best option for evacuation under each of the various mine emergencies (fires, explosions, or gas or water inundations). These options shall include—

(i) Encountering conditions in the mine or circumstances that require immediate donning of self-rescue devices;

(ii) Using continuous directional lifelines or equivalent devices, tethers, and doors;

(iii) Traversing undercasts or overcasts;

(iv) Switching escapeways, as applicable;

(v) Negotiating any other unique escapeway conditions; and

(vi) Using refuge alternatives.

(5) Location and use of the fire suppression and firefighting equipment and materials available in the mine.

(6) Location of the escapeways, exits, routes of travel to the surface, including the location of continuous directional lifelines or equivalent devices.

(7) Location, quantity, types, and use of stored SCSRs, as applicable.

(8) A review of the mine map; the escapeway system; the escape, firefighting, and emergency evacuation plan in effect at the mine; and the locations of refuge alternatives and abandoned areas.

(9) A description of how miners will receive annual expectations training that includes practical experience in donning and transferring SCSRs in smoke, simulated smoke, or an equivalent environment and breathing

through a realistic SCSR training unit or device that provides the sensation of SCSR airflow resistance and heat.
(10) A summary of the procedures related to deploying refuge alternatives.
(11) A summary of the construction methods for 15 psi stoppings constructed prior to an event.
(12) A summary of the procedures related to refuge alternative use.

(d) Instructors.

(1) The mine operator shall designate a person who has the ability, training, knowledge, or experience to conduct the mine emergency evacuation instruction and drills in his or her area of expertise.
(2) Persons conducting SCSR donning and transferring training shall be able to effectively train and evaluate whether miners can successfully don the SCSR and transfer to additional SCSR devices.

§ 75.1503 Use of fire suppression equipment.
(71 FR 71452, Dec. 8, 2006)

In addition to the approved program of instruction required by 30 CFR 75.1502, each operator of an underground coal mine shall ensure the following—

(a) Working section. At least two miners in each working section on each production shift shall be proficient in the use of all fire suppression equipment available on such working section, and know the location of such fire suppression equipment.
(b) Attended equipment. Each operator of attended equipment specified in 30 CFR 75.1107-1(c)(1), and each miner assigned to perform job duties at the job site in the direct line of sight of attended equipment as described in 30 CFR 75.1107-1(c)(2), shall be proficient in the use of fire suppression devices installed on such attended equipment.
(c) Maintenance shift. The shift foreman and at least one miner for every five miners working underground on a maintenance shift shall be proficient in the use of fire suppression equipment available in the mine, and know the location of such fire suppression equipment.

[QUARTERLY EVACUATION DRILLS]

§ 75.1504 Mine emergency evacuation training and drills.

(71 FR 71452, Dec. 8, 2006, as amended at 73 FR 80698, Dec. 31, 2008)

Each operator of an underground coal mine shall conduct mine emergency evacuation training and drills and require all miners to participate.

(a) Schedule of training and drills. Each miner shall participate in a mine emergency evacuation training and drill once each quarter. Quarters shall be based on a calendar year (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec). In addition —

(1) A newly hired miner, who has not participated in a mine emergency evacuation training and drill at the mine within the previous 3 months, shall participate in the next applicable mine emergency evacuation training and drill.
(2) Prior to assuming duties on a section or outby work location, a foreman shall travel both escapeways in their entirety.

(b) Content of quarterly training and drill. Each quarterly evacuation training and drill shall include the following—

(1) Hands-on training on all types of self-rescue devices used at the mine, which includes—

(i) Instruction and demonstration in the use, care, and maintenance of self-rescue devices;
(ii) The complete donning of the SCSR by assuming a donning position, opening the device, activating the device, inserting the mouthpiece, and putting on the nose clip; and
(iii) Transferring between all applicable self-rescue devices.

(2) Training that emphasizes the importance of—

(i) Recognizing when the SCSR is not functioning properly and demonstrating how to initiate and reinitiate the starting sequence;
(ii) Not removing the mouthpiece, even to communicate, until the miner reaches fresh air; and

    (iii) Proper use of the SCSR by controlling breathing and physical exertion.

(3) A realistic escapeway drill that is initiated and conducted with a different approved scenario each quarter and during which each miner—

    (i) Travels the primary or alternate escapeway in its entirety, alternating escapeways each quarter;
    (ii) Physically locates and practices using the continuous directional lifelines or equivalent devices and tethers, and physically locates the stored SCSRs and refuge alternatives;
    (iii) Traverses undercasts or overcasts and doors;
    (iv) Switches escapeways, as applicable; and
    (v) Negotiates any other unique escapeway conditions.

(4) A review of the mine and escapeway maps, the firefighting plan, and the mine emergency evacuation plan in effect at the mine, which shall include—

    (i) Informing miners of the locations of fire doors, check curtains, changes in the routes of travel, and plans for diverting smoke from escapeways.
    (ii) Locating escapeways, exits, routes of travel to the surface, abandoned areas, and refuge alternatives.

(5) Operation of the fire suppression equipment available in the mine and the location and use of firefighting equipment and materials.
(6) Reviewing the procedures for deploying refuge alternatives and components.
(7) For miners who will be constructing the 15 psi stoppings prior to an event, reviewing the procedures for constructing them.
(8) Reviewing the procedures for use of the refuge alternatives and components.
(9) Task training in proper transportation of the refuge alternatives and components.

(c) Annual expectations training. Over the course of each year, each miner shall participate in expectations training that includes the following—

(1) Donning and transferring SCSRs in smoke, simulated smoke, or an equivalent environment.

(2) Breathing through a realistic SCSR training unit that provides the sensation of SCSR airflow resistance and heat.

(3) Deployment and use of refuge alternatives similar to those in use at the mine, including—

(i) Deployment and operation of component systems; and

(ii) Instruction on when to use refuge alternatives during a mine emergency, emphasizing that it is the last resort when escape is impossible.

(4) A miner shall participate in expectations training within one quarter of being employed at the mine.

(d) Certification of training and drills. At the completion of each training or drill required in this section, the operator shall certify by signature and date that the training or drill was held in accordance with the requirements of this section.

(1) This certification shall include the names of the miners participating in the training or drill. For each miner, this certification shall list the content of the training or drill component completed, including the escapeway traveled and scenario used, as required in paragraphs (b) and (c) of this section.

(2) Certifications shall be kept at the mine for one year.

(3) Upon request, the certifications shall be made available to an authorized representative of the Secretary and the representative of the miners.

(4) Upon request, a copy of the certification that shows his or her own training shall be provided to the participating miner.

[ESCAPEWAY MAPS]

§ 75.1505 Escapeway maps.

(71 FR 71452, Dec. 8, 2006, as amended at 73 FR 80698, Dec. 31, 2008)

(a) Content and accessibility. An escapeway map shall show the designated escapeways from the working sections or the miners’ work stations to the surface or the exits at the bottom of the shaft or slope, refuge alternatives, and SCSR storage locations. The escapeway map shall be posted or readily accessible for all miners—

(1) In each working section;
(2) In each area where mechanized mining equipment is being installed or removed;
(3) At the refuge alternative; and
(4) At a surface location of the mine where miners congregate, such as at the mine bulletin board, bathhouse, or waiting room.

(b) Keeping maps current. All maps shall be kept up-to-date and any change in route of travel, location of doors, location of refuge alternatives, or direction of airflow shall be shown on the maps by the end of the shift on which the change is made.

(c) Informing affected miners. Miners underground on a shift when any such change is made shall be notified immediately of the change and other affected miners shall be informed of the change before entering the underground areas of the mine.

[REFUGE ALTERNATIVES]

§ 75.1506 Refuge alternatives.

(73 FR 80698, Dec. 31, 2008)

(a) Each operator shall provide refuge alternatives and components as follows—

(1) Prefabricated self-contained units, including the structural, breathable air, air monitoring, and harmful gas removal components of the unit, shall be approved under 30 CFR part 7; and
(2) The structural components of units consisting of 15 psi stoppings constructed prior to an event shall be approved by the District Manager, and the breathable air, air monitoring, and harmful gas removal components of these units shall be approved under 30 CFR part 7.
(3) Prefabricated refuge alternative structures that states have approved and those that MSHA has accepted in approved Emergency Response Plans (ERPs) that are in service prior to March 2, 2009, are permitted until Dec. 31, 2018, or until replaced, whichever comes first. Breathable

air, air-monitoring, and harmful gas removal components of either a prefabricated self-contained unit or a unit consisting of 15 psi stoppings constructed prior to an event in a secure space and an isolated atmosphere that states have approved and those that MSHA has accepted in approved ERPs that are in use prior to March 2, 2009, are permitted until Dec. 31, 2013, or until replaced, whichever comes first. Refuge alternatives consisting of materials pre-positioned for miners to deploy in a secure space with an isolated atmosphere that MSHA has accepted in approved ERPs that are in use prior to March 2, 2009, are permitted until Dec. 31, 2010, or until replaced, whichever comes first.

(b) Except as permitted under paragraph (a)(3) of this section, each operator shall provide refuge alternatives with sufficient capacity to accommodate all persons working underground.

(1) Refuge alternatives shall provide at least 15 square feet of floor space per person and 30 to 60 cubic feet of volume per person according to the following chart. The airlock can be included in the space and volume if waste is disposed outside the refuge alternative.

Mining Height (inches)	Unrestricted Volume (cubic feet) per Person*
≤36	30.0
>36-≤42	37.5
>42-≤48	45.0
>48-≤54	52.5
>54	60.0

*Includes an adjustment of 12 inches for clearances.

(2) Refuge alternatives for working sections shall accommodate the maximum number of persons that can be expected on or near the section at any time.

(3) Each refuge alternative for outby areas shall accommodate persons reasonably expected to use it.

(c) Refuge alternatives shall be provided at the following locations—

(1) Within 1,000 feet from the nearest working face and from locations where mechanized mining equipment is being installed or removed except that for underground anthracite coal mines that have no electrical face equipment, refuge alternatives shall be provided if the nearest working face is greater than 2,000 feet from the surface.

(2) Spaced within one-hour travel distances in outby areas where persons work such that persons in outby areas are never more than a 30-minute travel distance from a refuge alternative or safe exit. However, the operator may request and the District Manager may approve a different location in the ERP. The operator's request shall be based on an assessment of the risk to persons in outby areas, considering the following factors: proximity to seals; proximity to potential fire or ignition sources; conditions in the outby areas; location of stored SCSRs; and proximity to the most direct, safe, and practical route to an intake escapeway.

(d) Roof and rib support for refuge alternative locations shall be specified in the mine's roof control plan.

(e) The operator shall protect the refuge alternative and contents from damage during transportation, installation, and storage.

(f) A refuge alternative shall be removed from service if examination reveals damage that interferes with the functioning of the refuge alternative or any component.

(1) If a refuge alternative is removed from service, the operator shall withdraw all persons from the area serviced by the refuge alternative, except those persons referred to in § 104(c) of the Mine Act.

(2) Refuge alternative components removed from service shall be replaced or be repaired for return to service in accordance with the manufacturer's specifications.

(g) At all times, the site and area around the refuge alternative shall be kept clear of machinery, materials, and obstructions that could interfere with the deployment or use of the refuge alternative.

(h) Each refuge alternative shall be conspicuously identified with a sign or marker as follows—

(1) A sign or marker made of a reflective material with the word “REFUGE” shall be posted conspicuously at each refuge alternative.
(2) Directional signs made of a reflective material shall be posted leading to each refuge alternative location.

(i) During use of the refuge alternative, the atmosphere within the refuge alternative shall be monitored. Changes or adjustments shall be made to reduce the concentration of methane to less than 1 percent; to reduce the concentration of carbon dioxide to 1 percent or less and excursions not exceeding 2.5 percent; and to reduce the concentration of carbon monoxide to 25 ppm or less. Oxygen shall be maintained at 18.5 to 23 percent.

(j) Refuge alternatives shall contain a fire extinguisher that—

(1) Meets the requirements for portable fire extinguishers used in underground coal mines under this part;
(2) Is appropriate for extinguishing fires involving the chemicals used for harmful gas removal; and
(3) Uses a low-toxicity extinguishing agent that does not produce a hazardous by-product when activated.

§ 75.1507 Emergency Response Plan; refuge alternatives.
(73 FR 80699, Dec. 31, 2008)

(a) The ERP shall include the following for each refuge alternative and component—

(1) The types of refuge alternatives used in the mine, i.e., a prefabricated self-contained unit or a unit consisting of 15 psi stoppings constructed prior to an event in a secure space and an isolated atmosphere.
(2) Procedures or methods for maintaining approved refuge alternatives and components.
(3) The rated capacity of each refuge alternative, the number of persons expected to use each refuge alternative, and the duration of breathable air provided per person by the approved breathable air component of each refuge alternative.
(4) The methods for providing breathable air with sufficient detail of the component’s capability to provide breathable air over the duration stated

in the approval.

(5) The methods for providing ready backup oxygen controls and regulators.

(6) The methods for providing an airlock and for providing breathable air in the airlock, except where adequate positive pressure is maintained.

(7) The methods for providing sanitation facilities.

(8) The methods for harmful gas removal, if necessary.

(9) The methods for monitoring gas concentrations, including charging and calibration of equipment.

(10) The method for providing lighting sufficient for persons to perform tasks.

(11) Suitable locations for the refuge alternatives and an affirmative statement that the locations are—

(i) Not within direct line of sight of the working face; and

(ii) Where feasible, not placed in areas directly across from, nor closer than 500 feet radially from, belt drives, take-ups, transfer points, air compressors, explosive magazines, seals, entrances to abandoned areas, and fuel, oil, or other flammable or combustible material storage. However, the operator may request and the District Manager may approve an alternative location in the ERP if mining involves two-entry systems or yield pillars in a longwall that would prohibit locating the refuge alternative out of direct line of sight of the working face.

(12) The maximum mine air temperature at each of the locations where refuge alternatives are to be placed.

(b) For a refuge alternative consisting of 15 psi stoppings constructed prior to an event in a secure space and an isolated atmosphere, the ERP shall specify that—

(1) The breathable air components shall be approved by MSHA; and

(2) The refuge alternative can withstand exposure to a flash fire of 300 degrees Fahrenheit (°F) for 3 seconds and a pressure wave of 15 pounds per square inch (psi) overpressure for 0.2 seconds.

(c) If the refuge alternative sustains persons for only 48 hours, the ERP shall detail advanced arrangements that have been made to assure that persons who cannot be rescued within 48 hours will receive additional supplies to sustain them until rescue. Advance arrangements shall include the following—

(1) Pre-surveyed areas for refuge alternatives with closure errors of less than 20,000:1.
(2) An analysis to demonstrate that the surface terrain, the strata, the capabilities of the drill rig, and all other factors that could affect drilling are such that a hole sufficient to provide required supplies and materials reliably can be promptly drilled within 48 hours of an accident at a mine.
(3) Permissions to cross properties, build roads, and construct drill sites.
(4) Arrangement with a drilling contractor or other supplier of drilling services to provide a suitable drilling rig, personnel and support so that a hole can be completed to the refuge alternative within 48 hours.
(5) Capability to promptly transport a drill rig to a pre-surveyed location such that a drilled hole would be completed and located near a refuge alternative structure within 48 hours of an accident at a mine.
(6) The specifications of pipes, air lines, and approved fans or approved compressors that will be used.
(7) A method for assuring that within 48 hours, breathable air shall be provided.
(8) A method for assuring the immediate availability of a backup source for supplying breathable air and a backup power source for surface installations.

(d) The ERP shall specify that the refuge alternative is stocked with the following—

(1) A minimum of 2,000 calories of food and 2.25 quarts of potable water per person per day in approved containers sufficient to sustain the maximum number of persons reasonably expected to use the refuge alternative for at least 96 hours, or for 48 hours if advance arrangements are made under paragraph (c) of this section;
(2) A manual that contains sufficient detail for each refuge alternative or component addressing in-mine transportation, operation, and

maintenance of the unit;
(3) Sufficient quantities of materials and tools to repair components; and
(4) First aid supplies.

§ 75.1508 Training and records for examination, maintenance, and repair of refuge alternatives and components.

(73 FR 80699, Dec. 31, 2008)

(a) Persons examining, maintaining, or repairing refuge alternatives and components shall be instructed in how to perform this work.

(1) The operator shall assure that all persons assigned to examine, maintain, and repair refuge alternatives and components are trained.
(2) The mine operator shall certify, by signature and date, the training of persons who examine, maintain, and repair refuge alternatives and components.

(b) At the completion of each repair, the person conducting the maintenance or repair shall make a record of all corrective action taken.
(c) Training certifications and repair records shall be kept at the mine for one year.

[COMMUNICATIONS]

Subpart Q

§ 75.1600 Communications.

(Statutory Provisions)

Telephone service or equivalent two-way communication facilities, approved by the Secretary or his authorized representative, shall be provided between the surface and each landing of main shafts and slopes and between the surface and each working section of any coal mine that is more than 100 feet from a portal.

§ 75.1600-1 Communication facilities; main portals; installation requirements.

(38 FR 29999, Oct. 31, 1973)

A telephone or equivalent two-way communication facility shall be located on the surface within 500 feet of all main portals, and shall be installed either in a building or in a box-like structure designed to protect the facilities from damage by inclement weather. At least one of these communication facilities shall be at a location where a responsible person who is always on duty when men are underground can hear the facility and respond immediately in the event of an emergency.

§ 75.1600-2 Communication facilities; working sections; installation and maintenance requirements; audible or visual alarms.

(38 FR 29999, Oct. 31, 1973)

(a) Telephones or equivalent two-way communication facilities provided at each working section shall be located not more than 500 feet outby the last open crosscut and not more than 800 feet from the farthest point of penetration of the working places on such section.

(b) The incoming communication signal shall activate an audible alarm, distinguishable from the surrounding noise level, or a visual alarm that can be seen by a miner regularly employed on the working section.

(c) If a communication system other than telephones is used and its operation depends entirely upon power from the mine electric system, means shall be provided to permit continued communication in the event the mine electric power fails or is cut off; provided, however, that where trolley phones and telephones are both used, an alternate source of power for the trolley phone system is not required.

(d) Trolley phones connected to the trolley wire shall be grounded in accordance with Subpart H of this part.

(e) Telephones or equivalent two-way communication facilities shall be maintained in good operating condition at all times. In the event of any failure in the system that results in loss of communication, repairs shall be started immediately, and the system restored to operating condition as soon as possible.

§ 75.1600-3 Communications facilities; refuge alternatives.

(73 FR 80700, Dec. 31, 2008)

(a) Refuge alternatives shall be provided with a communications system that consists of—

(1) A two-way communication facility that is a part of the mine communication system, which can be used from inside the refuge alternative; and

(2) An additional communication system and other requirements as defined in the communications portion of the operator's approved ERP.

[TRAINING OF NEW MINERS]

30 CFR § 48.5 Training of new miners; minimum courses of instruction; hours of instruction

(a) Each new miner shall receive no less than 40 hours of training as prescribed in this section before such miner is assigned to work duties. Such training shall be conducted in conditions which as closely as practicable duplicate actual underground conditions, and approximately 8 hours of training shall be given at the minesite.

(b) The training program for new miners shall include the following courses—

(1) *Instruction in the statutory rights of miners and their representatives under the Act; authority and responsibility of supervisors.* The course shall include instruction in the statutory rights of miners and their representatives under the Act, including a discussion of section 2 of the Act; a review and description of the line of authority of supervisors and miners' representatives and the responsibilities of such supervisors and miners' representatives; and an introduction to the operator's rules and the procedures for reporting hazards.

(2) *Self-rescue and respiratory devices*. The course shall be given before a new miner goes underground and shall include—

(i) Instruction and demonstration in the use, care, and maintenance of self-rescue and respiratory devices used at the mine;

(ii) Hands-on training in the complete donning of all types of self contained self-rescue devices used at the mine, which includes assuming a donning position, opening the device, activating the device, inserting the mouthpiece, and putting on the nose clip; and

(iii) Hands-on training in transferring between all applicable self-rescue devices.

(3) *Entering and leaving the mine; transportation; communications.* The course shall include instruction on the procedures in effect for entering and leaving the mine; the check-in and checkout system in effect at the mine; the procedures for riding on and in mine conveyances; the controls in effect for the transportation of miners and materials; and the use of the mine communication systems, warning signals, and directional signs.

(4) *Introduction to the work environment.* The course shall include a visit and tour of the mine, or portions of the mine, which are representative of the entire mine. A method of mining utilized at the mine shall be observed and explained.

(5) *Mine map; escapeways; emergency evacuation; barricading.* The program of instruction for mine emergency evacuation and firefighting approved by the District Manager under 30 CFR 75.1502 or the escape and evacuation plan under 30 CFR 57.11053, as applicable, shall be used for this course. The course shall include—

> (i) A review of the mine map; the escapeway system; the escape, firefighting, and emergency evacuation plans in effect at the mine; and the location of abandoned areas; and
>
> (ii) An introduction to the methods of barricading and the locations of the barricading materials, where applicable.

(6) *Roof or ground control and ventilation plans.* The course shall include an introduction to and instruction on the roof or ground control plan in effect at the mine and procedures for roof and rib or ground control; and an introduction to and instruction on the ventilation plan in effect at the mine and the procedures for maintaining and controlling ventilation.

(7) *Health.* The course shall include instruction on the purpose of taking dust, noise, and other health measurements, and any health control plan in effect at the mine shall be explained. The health provisions of the act and warning labels shall also be explained.

(8) *Cleanup; rock dusting.* The course shall include instruction on the purpose of rock dusting and the cleanup and rock dusting program in effect at the mine, where applicable.

(9) *Hazard recognition.* The course shall include the recognition and avoidance of hazards present in the mine, particularly any hazards related to explosives where explosives are used or stored at the mine.

(10) *Electrical hazards.* The course shall include recognition and avoidance of electrical hazards.

(11) *First aid.* The course shall include instruction in first aid methods acceptable to MSHA.

(12) *Mine gases.* The course shall include instruction in the detection and avoidance of hazards associated with mine gases.

(13) *Health and safety aspects of the tasks to which the new miner will be assigned.* The course shall include instruction in the health and safety aspects of the tasks to be assigned, including the safe work procedures of such tasks, the mandatory health and safety standards pertinent to such tasks, information about the physical and health hazards of chemicals in the miner's work area, the protective measures a miner can take against these hazards, and the contents of the mine's HazCom program.

(14) Such other courses as may be required by the District Manager based on circumstances and conditions at the mine.

(c) Methods, including oral, written, or practical demonstration, to determine successful completion of the 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.

(d) A newly employed miner who has less than 12 months of mining experience and has received the courses and hours of instruction in paragraphs (a) and (b) of this section, within 36 months preceding employment at a mine, does not have to repeat this training. Before the miner starts work, the operator must provide the miner with the experienced miner training in § 48.6(b) of this part and, if applicable, the new task training in § 48.7 of this part. The operator must also provide the miner with annual refresher training and additional new task training, as applicable.

[EXPERIENCED MINER TRAINING]

30 CFR § 48.6 Experienced miner training.

(a) Except as provided in paragraph (e), this section applies to experienced miners who are—

(1) Newly employed by the operator;

(2) Transferred to the mine;

(3) Experienced underground miners transferred from surface to underground; or

(4) Returning to the mine after an absence of more than 12 months.

(b) Experienced miners must complete the training prescribed in this section before beginning work duties. Each experienced miner returning to mining following an absence of 5 years or more, must receive at least 8 hours of training. The training must include the following instruction—

(1) *Introduction to work environment.* The course shall include a visit and tour of the mine. The methods of mining utilized at the mine shall be observed and explained.

(2) *Mandatory health and safety standards.* The course shall include the mandatory health and safety standards pertinent to the tasks to be assigned.

(3) *Authority and responsibility of supervisors and miners' representatives.* The course shall include a review and description of the line of authority of supervisors and miners' representatives and the responsibilities of such supervisors and miners' representatives; and an introduction to the operator's rules and the procedures for reporting hazards.

(4) *Entering and leaving the mine; transportation; communications.* The course shall include instruction in the procedures in effect for entering and leaving the mine; the check-in and checkout system in effect at the mine; the procedures for riding on and in mine conveyances; the controls in effect for the transportation of miners and materials; and the use of the mine communication systems, warning signals, and directional signs.

(5) *Mine map; escapeways; emergency evacuation; barricading*. The program of instruction for mine emergency evacuation and firefighting approved by the District Manager under 30 CFR 75.1502 or the escape and evacuation plan under 30 CFR 57.11053, as applicable, shall be used for this course. The course shall include—

(i) A review of the mine map; the escapeway system; the escape, firefighting, and emergency evacuation plans in effect at the mine; and the location of abandoned areas; and

(ii) Methods of barricading and the locations of barricading materials, where applicable.

(6) *Roof or ground control and ventilation plans.* The course shall include an introduction to and instruction on the roof or ground control plan in effect at the mine and procedures for roof and rib or ground control; and an introduction to and instruction on the ventilation plan in effect at the mine and the procedures for maintaining and controlling ventilation.

(7) *Hazard recognition*. The course must include the recognition and avoidance of hazards present in the mine.

(8) *Prevention of accidents*. The course must include a review of the general causes of accidents applicable to the mine environment, causes of specific accidents at the mine, and instruction in accident prevention in the work environment.

(9) *Emergency medical procedures*. The course must include instruction on the mine's emergency medical arrangements and the location of the mine's first aid equipment and supplies.

(10) *Health*. The course must include instruction on the purpose of taking dust, noise, and other health measurements, where applicable; must review the health provisions of the Act; and must explain warning labels and any health control plan in effect at the mine.

(11) *Health and safety aspects of the tasks to which the experienced miner is assigned*. The course must include instruction in the health and safety aspects of the tasks assigned, including the safe work procedures of such tasks, information about the physical and health hazards of chemicals in the miner's work area, the protective measures a miner can take against these hazards, and the contents of the mine's HazCom program. Experienced miners who must complete new task training under § 48.7 do not need to take training under this paragraph.

(12) *Self-rescue and respiratory devices*. The course shall be given before the miner goes underground and shall include—

(i) Instruction and demonstration in the use, care, and maintenance of self-rescue and respiratory devices used at the mine;

(ii) Hands-on training in the complete donning of all types of self-contained self-rescue devices used at the mine, which includes

assuming a donning position, opening the device, activating the device, inserting the mouthpiece, and putting on the nose clip; and
(iii) Hands-on training in transferring between all applicable self-rescue devices.

(13) Such other courses as may be required by the District Manager based on circumstances and conditions at the mine.

(c) The operator may include instruction on additional safety and health subjects based on circumstances and conditions at the mine.
(d) The training time spent on individual subjects must vary depending upon the training needs of the miners.
(e) Any miner returning to the same mine, following an absence of 12 months or less, must receive training on any major changes to the mine environment that have occurred during the miner's absence and that could adversely affect the miner's health or safety.

(1) A person designated by the operator who is knowledgeable of these changes must conduct the training in this paragraph. An MSHA approved instructor is not required to conduct the training outlined in this paragraph.
(2) No record of this training is required.
(3) The miner must also complete annual refresher training as required in § 48.8, if the miner missed taking that training during the absence.

(f) Coal miners receiving training under this section shall participate in the next drill as required in § 75.383(b) or 75.1502(c) of this chapter, as applicable.

For more information: See MSHA's Program Policy Manual.

[ANNUAL REFRESHER TRAINING]

30 CFR § 48.8 Annual refresher training of miners; minimum courses of instruction; hours of instruction.

(a) Each miner shall receive a minimum of 8 hours of annual refresher training as prescribed in this section.

(b) The annual refresher training program for all miners shall include the following courses of instruction—

(1) *Mandatory health and safety standards.* The course shall include mandatory health and safety standard requirements which are related to the miner's tasks.

(2) *Transportation controls and communication systems.* The course shall include instruction on the procedures for riding on and in mine conveyances; the controls in effect for the transportation of miners and materials; and the use of the mine communication systems, warning signals, and directional signs.

(3) *Barricading.* The course shall include a review of the methods of barricading and locations of barricading materials, where applicable.

(4) *Roof or ground control; ventilation; emergency evacuation; and firefighting plans.* The course shall include a review of roof or ground control plans in effect at the mine and the procedures for maintaining and controlling ventilation. In addition, for underground coal mines, except for miners who receive this training under 30 CFR 75.1504, the course shall include a review of the emergency evacuation and firefighting program of instruction in effect at the mine.

(5) *First aid.* The course shall include a review of first aid methods acceptable to MSHA.

(6) *Electrical hazards.* The course shall include recognition and avoidance of electrical hazards.

(7) *Prevention of accidents.* The course shall include a review of accidents and causes of accidents, and instruction in accident prevention in the work environment.

(8) *Self-rescue and respiratory devices.* The course shall include instruction and demonstration in the use, care, and maintenance of self-rescue and respiratory devices used at the mine. In addition, except for miners who receive this training under 30 CFR 75.1504, the training for self-contained self-rescue (SCSR) devices shall include—

(i) Hands-on training in the complete donning of all types of self-contained self-rescue devices used at the mine, which includes assuming a donning position, opening the device, activating the device, inserting the mouthpiece, and putting on the nose clip; and

(ii) Hands-on training in transferring between all applicable self-rescue devices.

(9) *Explosives.* The course shall include a review and instruction on the hazards related to explosives. The only exception to this course component is when there are no explosives used or stored on the mine property.

(10) *Mine gases.* The course shall include instruction in the detection and avoidance of hazards associated with mine gases.

(11) *Health.* The course shall include instruction on the purpose of taking dust, noise, and other health measurements and any health control plan in effect at the mine shall be explained. The health provisions of the Act and warning labels shall also be explained.

(12) Such other courses as may be required by the District Manager based on circumstances and conditions at the mine.

(c) Refresher training may include other health and safety subjects that are relevant to mining operations at the mine. Recommended subjects include, but are not limited to, information about the physical and health hazards of chemicals in the miner’s work area, the protective measures a miner can take against these hazards, and the contents of the mine’s HazCom program.

(d) All persons employed as shaft or slope construction workers on June 28, 2006, must receive annual refresher training within 12 months of June 2006.

(e) Where annual refresher training is conducted periodically, such sessions shall not be less than 30 minutes of actual instruction time and the miners shall be notified that the session is part of annual refresher training.

Appendix B

Mine Accident, Injury and Illness Report

U.S. Department of Labor

Mine Safety and Health Administration

Mine Accident, Injury and Illness Report

U.S. Department of Labor
Mine Safety and Health Administration

• Section A - Identification D
Approved For Use Through 07/31/2014 OMB Number 1219-0007

MSHA ID Number
Contractor ID
Report Catagory ○ Metal/Nonmetal Mining ○ Coal Mining
☐ Check here if report pertains to contractor

Mine Name
Company Name

• Section B - Complete for Each Reportable Accident Immediately Reported to MSHA

1. Accident Code (circle applicable code - see instructions) ○ 01 - Death ○ 02 - Serious Injury ○ 03 - Entrapment
○ 04 - Inundation ○ 05 - Gas or Dust Ignition ○ 06 - Mine Fire ○ 07 - Explosives ○ 08 - Roof Fall
○ 09 - Outburst ○ 10 - Impounding Dam ○ 11 - Hoisting ○ 12 - Offsite injury

2. Name of Investigator
3. Date Investigation Started Month Day Year
4. Steps Taken to Prevent Recurrence of Accident

• Section C - Complete for Each Reportable Accident, Injury or Illness

5. Circle the Codes Which Best Describe Where Accident/Injury/Illness Occurred (see instructions)

(a) Surface Location: ○ 02 Surface at Underground Mine ○ 30 Mill, Preparation Plant, etc. ○ 03 Strip/Open Pit Mine ○ 04 Surface Auger Operation ○ 05 Culm Bank/Refuse Pile ○ 06 Dredge Mining ○ 12 Other Surface Mining ○ 17 Independent Shops (with own MSHA ID) ○ 99 Office Facilities
(b) Underground Location: ○ 01 Vertical Shaft ○ 02 Slope/Inclined Shaft ○ 03 Face ○ 04 Intersection ○ 05 Underground Shop/Office ○ 06 Other
(c) Underground Mining Method: ○ 01 Longwall ○ 02 Shortwall ○ 03 Conventional Stoping ○ 05 Continuous Mining ○ 06 Hand ○ 07 Caving ○ 08 Other

6. Date of Accident Month Day Year
7. Time of Accident • am • pm
8. Time Shift Started • am • pm

7
8

9. Describe Fully the Conditions Contributing to the Accident/Injury/Illness, and Quantify the Damage or Impairment

10. Equipment Involved
Type
Manufacturer
Model Number

10
MAN

11. Name of Witness to Accident/Injury/Illness
12. Number of Reportable Injuries or Illnesses Resulting from This Occurrence

13. Name of Injured/Ill Employee
14. Sex • Male • Female
15. Date of Birth Month Day Year

16. Last Four Digits of Social Security Number
17. Regular Job Title
• 18. Check if this Injury/Illness resulted in death. ☐
☐ • 19. Check if Injury/Illness resulted in permanent disability (include amputation, loss of use, & permanent total disability.

20. What Directly Inflicted Injury or Illness?
21. Nature of Injury or Illness

22. Part of Body Injured or Affected
23. Occupational Ilness (circle applicable code - see instructions) ○ 21 Occupational Skin Diseases ○ 22 Dust Diseases of the Lungs ○ 23 Respiratory Conditions (toxic agents) ○ 24 Poisoning (toxic Materials) ○ 25 Disorders (physical agents) ○ 26 Disorders (repeated trauma) ○ 29 Other

12
14
16
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18
19
20
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22
24

24. Employee's Work Activity When Injury or illness Occurred

Experience	Years	Weeks
25. Experience in This Job Title		
26. Experience at This Mine		
27. Total Mining Experience		

• Section D - Return to Duty Information

• 28. Permanently Transferred or Terminated (if checked, complete items 29,30, &31) ☐
29. Date Returned to Regular Job at Full Capacity (or item 28) Month Day Year
Answer 30 & 31 when case is closed
30. Number of Days Away from Work (if none enter 0)
31. Number of Days Restricted Work Activity (if none, enter 0)

Person Completing Form (name)
Title

Date This Report Prepared (month, Day, year)
Area Code and Telephone Number

For Official Use Only

Degree
Accident Type
Accident Class
Scheduled Charge
Keyword

MSHA Form 7000-1, Mar. 03 (revised)

MINE ACCIDENT, INJURY, AND ILLNESS REPORT MSHA FORM 7000-1

Section 50.20 of Part 50, Title 30, Code of Federal Regulations, requires a report to be prepared and filed with MSHA of each accident, occupational injury, or occupational illness occurring at your operation. The requirement includes all accidents, injuries, and illnesses as defined in Part 50 whether your employees or a contractor's employees are involved. A Form 7000-1 shall be completed and mailed within **ten working days** after an accident or occupational injury occurs, or an occupational illness is diagnosed.

This report is required by law (30 U.S.C. §813; 30 C.F.R. Part 50). Failure to report can result in the institution of a civil action for relief under 30 U.S.C. 9818 respecting an operator of a coal or other mine, and assessment of a civil penalty against an operator of a coal or other mine under 30 U.S.C. 9820(a). An individual who, being subject to the Federal Mine Safety and Health Act of 1977 (30 U.S.C. 9801 **at seq.**) knowingly makes a false statement in any report can be punished by a fine of not more than $10,000 or by imprisonment for not more than 5 years, or both, under 30 U.S.C. §820.(f). Any individual who knowingly and willfully makes any false, fictitious, or fraudulent statements, conceals a material fact, or makes a false, fictitious, or fraudulent entry, with respect to any matter within the jurisdiction of any agency of the United States can be punished by a fine of not more than $10,000, or imprisoned for not more than 5 years, or both, under 18 U.S.C. 91001.

REPORTING INSTRUCTIONS

Form 7000-1 consists of four sheets, an original (page 1) and three copies. The original will be mailed to MSHA, Denver Safety and Health Technology Center. The first copy (page 2) will be mailed to the appropriate local MSHA District or Subdistrict Office. Envelopes are included with the forms for mailing to those offices. If the mailed forms do not show return to duty information on an injured employee, complete and mail the second copy (page 3) to MSHA, Denver Safety and Health Technology Center, when the employee returns to regular job **at full capacity** or a final disposition is made on the injury or illness. The third copy (page 4) is to be retained at the mine for a period of **five years.** It is important to remember that a Form 7000-1 is required on each accident as defined in 30 CFR Part 50 whether any person was injured or not. A form is required on each individual becoming injured or ill, even when several were injured or made ill in a single occurrence. The principal officer in charge of health and safety at the mine or the supervisor of the mine area in which the accident, injury, or illness occurred shall be responsible for completing the Form 7000-1. Note: First aid cases (those for which no medical treatment was received, no time was lost, and no restriction of work, motion, or loss of consciousness occurred) need not be reported.

SPECIFIC INSTRUCTIONS

Detailed instructions for completing Form 7000-1 are contained in Part 50. A copy of Part 50 was sent to every active and intermittently active mine and independent mining contractor. If you do not have a copy, you may obtain one from your local MSHA Mine Safety and Health District or Subdistrict Office.

Section A- IDENTIFICATION DATA

Check the report category indicating whether your operation is in the metal/nonmetal mining industry or the coal mining industry. MSHA ID Number is the number assigned to the operation by MSHA. If you are unsure of your number assignment, contact the nearest MSHA Mine Safety and Health

District or Subdistrict Office. Reports on contractor activities at mines must include an MSHA-assigned contractor ID Number as well as the 7-digit operation ID.

Show mine name and company name. Independent contractors should provide the mine name and show the contractor name under “company name.”

Section B- COMPLETE FOR EACH ACCIDENT IMMEDIATELY REPORTABLE TO MSHA

Section B is to be completed **only** when your operation has an accident that must be reported **immediately** to MSHA. Circle code 02 “Serious Injury” only if the injury has a reasonable potential to cause death. For additional detail on those specific kinds of accidents see Section 50.10 of Part 50. When it is necessary to complete Section B, circle the applicable accident code; give the name of the investigator (the person heading the investigating team on the accident); show the date the investigation was started; and describe briefly the steps taken to prevent a recurrence of such an accident.

Section C- COMPLETE FOR EACH REPORTABLE ACCIDENT, INJURY, OR ILLNESS

Section C must be completed on each form submitted to MSHA.

Item 5. If you are reporting an occurrence at a **surface** mine or other **surface** activity, circle the code which best describes the accident location in (a). Surface Location; do not mark any codes in (b) or (c). If you are reporting an occurrence in an **underground** mine, circle the code which best describes the underground location in (b) Underground Location **and** in (c) Underground Mining Method.

Items 6, 7, and 8. Show the date and time of the occurrence and the time the shift started in which the accident/incident occurred or was observed.

Item 9. Describe fully the conditions contributing to the occurrence. Detailed descriptions of the conditions provide the basis for accident and injury analyses which are intended to assist the mining industry in preventing future occurrences. Please see Part 50 for detail on what your narrative should include.

Item 10. If equipment was involved in the occurrence, name the type of equipment, the manufacturer, and the model number of the equipment.

Item 11. If there was a witness to the occurrence, give the name of the witness.

Item 12. If the occurrence resulted in one or more injuries, report the number. A separate report must be made on each injured person.

Item 13. Show the name of the injured person. [Note: In these instructions, “injured person” means a person either injured or ill.]

Item 14. Indicate the sex of the injured person.

Item 15. Show the date of birth of the injured person.

Item 16. Show the last four digits of the injured person’s Social Security Number.

Item 17. Give the regular job title of the injured person at the time he was injured.

Item 18. Check this box if the injury or illness resulted in death.

Item 19. Check this box if the injury or illness resulted in a permanent disability. A permanent disability is any injury or occupational illness other than death which results in the loss (or complete loss of use) of any member (or part of a member) of the body, or a permanent impairment of functions of the body, or which permanently and totally incapacitates the injured person from following any gainful occupation.

Item 20. Name the object or substance that directly caused the injury or illness.

Item 21. Report the nature of injury or illness by naming the illness; or for injuries, by using common medical terms such as puncture wound, third degree burn, fracture, etc. For multiple injuries, enter the injury which was the most serious. Avoid general terms such as hurt, sore, sick, etc.

Item 22. Name the part of body with the most serious injury.

Item 23. Occupational illness is any abnormal condition or disorder, other than one resulting from an occupational injury, which falls into the following categories:

Code 21 - <u>Occupational Skin Diseases or Disorders</u>. Examples: Contact dermatitis, eczema, or rash caused by primary irritants and sensitizers or poisonous plants; oil acne; chrome ulcers; chemical burns or inflammations; etc.

Code 22 - <u>Dust Diseases of the Lungs (Pneumoconioses)</u>. Examples: Silicosis, asbestosis, coal worker's pneumoconiosis, byssinosis, and other pneumoconioses.

Code 23 - <u>Respiratory Conditions Due to Toxic Agents</u>. Examples: Pneumonitis, pharyngitis, rhinitis, or acute congestion due to chemicals, dusts, gases, or fumes; etc.

Code 24 - <u>Poisoning (Systemic Effects of Toxic Materials)</u>. Examples: Poisoning by lead, mercury, cadmium, arsenic, or other metals, poisoning by carbon monoxide, hydrogen sulfide, or other gases; poisoning by benzol, carbon tetrachloride, or other organic solvents; poisoning by insecticide sprays such as parathion, lead arsenate; poisoning by other chemicals such as formaldehyde, plastics, and resins; etc.

Code 25 - <u>Disorders Due to Physical Agents (Other than Toxic Materials)</u>. Examples: Heatstroke, sunstroke, heat exhaustion and other effects of environmental heat; freezing, frostbite and effects of exposure to low temperatures; caisson disease; effects of ionizing radiation (isotopes, x-rays, radium); effects of nonionizing radiation (welding flash, ultraviolet rays, microwaves, sunburn); etc.

Code 26 - <u>Disorders Associated with Repeated Trauma</u>. Examples: Noise-induced hearing loss; synovitis, tenosynovitis, and bursitis; Raynaud's phenomena; and other conditions due to repeated motion, vibration, or pressure.

Code 29 - <u>All Other Occupational Illnesses</u>. Examples: Infectious hepatitis, malignant and benign tumors, all forms of cancer, kidney diseases, food poisoning, histoplasmosis; etc.

Item 24. Describe what the employee was doing when he or she became injured or ill.
Items 25, 26, and 27. Show the number of weeks (or years and weeks) of experience of the injured person at the job title (indicated in Item 17), at your operation, and his/her total mining experience.

Section D - RETURN TO DUTY INFORMATION
<u>Section D</u> is to be completed in full when all return-to-duty information is available. If the information is not available within **<u>ten working days</u>** after a reportable occurrence, then the first two pages are sent to MSHA without Section D being completed; PAGE 3 is then mailed to DSHTC- with full information **<u>when the data are available</u>.** Until all the items are answered and the report sent to DSHTC-DMIS, the occurrence remains an open case.

Item 28. If the injured person was transferred or terminated as a result of the injury or illness, check the box and answer items **<u>29, 30, and 31</u>**.
Item 29. Show the date that the injured person returned to his regular job at full capacity or was transferred or terminated. This date should indicate when the count of days away from work and/or days of restricted work activity have stopped.
Item 30. Show the number of workdays 1/ the injured person did not report to his place of employment, i.e., number of days away from work.
Item 31. Show the number of workdays the injured person was on restricted work activity; do not include days away from work reported in Item 30.

At the bottom of the form, show the name of the person who completed the form; the date the report was prepared; and the telephone number where the person who completed the form may be reached.

1/ Note: The number of lost workdays should not include the day of injury or onset of illness, or any days on which the employee was not previously scheduled to work even though able to work, such as holidays or plant closures. Diagnosis of an "occupational illness or disease" under Part 50 does not automatically mean a disability or impairment for which the miner is eligible for compensation, nor does the Agency intend for an operator's compliance with Part 50 to be equated with an admission of liability for the reported illness or disease. If a chest x-ray for a miner with a history of exposure to silica or other pneumoconiosis-causing dusts is rated at 1/0 or above, utilizing the International Labor Office (ILO) classification system, it is MSHA's policy that such a finding is, for Part 50 reporting, a diagnosis of an occupational illness, in the nature of silicosis or other pneumoconiosis and, consequently, reportable to MSHA.

DEFINITIONS

(1) “Coal or other mine” means (a) an area of land from which minerals are extracted in nonliquid form or, if in liquid form, are extracted with workers underground, (b) private ways and roads appurtenant to such area, and (c) lands, excavations, underground passageways, shafts, slopes, tunnels and workings, structures, facilities, equipment, machines, tools, or other property including impoundments, retention dams, and tailings ponds, on the surface or underground, used in, or to be used in, or resulting from, the work of extracting such minerals from their natural deposits in nonliquid form, or if in liquid form, with workers underground, or used in, or to be used in, the milling of such minerals, or the work of preparing coal or other minerals, and includes custom coal preparation facilities. In making a determination of what constitutes mineral milling for purposes of this Act, the Secretary shall give due consideration to the convenience of administration resulting from the delegation to one Assistant Secretary of all authority with respect to the health and safety of miners employed at one physical establishment.

(2) “Operator” means any owner, lessee, or other person who operates, controls, or supervises a coal or other mine or any designated independent contractor performing services or construction at such mine.

(3) “Occupational injury” means any injury to a worker which occurs at a mine for which medical treatment is administered, or which results in death, loss of consciousness, inability to perform ail job duties on any day after an injury, or transfer to another job.

(4) “Occupational illness” means an illness or disease of a worker which may have resulted from work at a mine or for which an award of compensation is made.

(5) “Medical treatment” means treatment, other than first aid, administered by a physician or by a registered medical professional acting under the orders of a physician.

DIFFERENCES BETWEEN MEDICAL TREATMENT AND FIRST AID

Medical treatment includes, but is not limited to, the suturing of any wound, treatment of fractures, application of a cast or other professional means of immobilizing an injured part of the body, treatment of infection arising out of an injury, treatment of bruise by the drainage of blood, surgical removal of dead or damaged skin (debridement), amputation or permanent loss of use of any part of the body, treatment of second and third degree burns. Procedures which are diagnostic in nature are not considered by themselves to constitute medical treatment. Visits to a physician, physical examinations, x-ray examinations, and brief hospitalization for observations, where no evidence of injury or illness is found and no medical treatment given, do not in themselves constitute medical treatment. However, if scheduled workdays are lost because of hospitalization, the case must be reported. Procedures which are preventative in nature also are not considered by themselves to constitute medical treatment. Tetanus and flu shots are considered preventative in nature. First aid includes any one-time treatment and follow-up visit for the purpose of observation of minor scratches, cuts, burns, splinters, etc. Ointments, salves, antiseptics, and dressings to minor injuries are considered to be first aid.

(1) **Abrasions**

(i) First aid treatment is limited to cleaning a wound, soaking, applying antiseptic and nonprescription medication, and bandages on the first visit and follow-up visits limited to observation including changing dressing and bandages. Additional cleaning and application of antiseptic constitutes first aid where it is required by work duties that soil the bandage.

(ii) Medical treatment includes examination for removal of imbedded foreign material, multiple soakings, whirlpool treatment, treatment of infection, or other professional treatments and any treatment involving more than a minor spot-type injury. Treatment of abrasions occurring to greater than full skin depth is considered medical treatment.

(2) **Bruises**

(i) First aid treatment is limited to a single soaking or application of cold compresses, and follow-up visits if they are limited only to observation.

(ii) Medical treatment includes multiple soakings, draining of collected blood, or other treatment beyond observation.

(3) **Burns, Thermal and Chemical** (resulting in destruction of tissue by direct contact).

(i) First aid treatment is limited to cleaning or flushing the surface, soaking, applying cold compresses, antiseptics or nonprescription medications, and bandaging on the first visit, and follow-up visits restricted to observation, changing bandages, or additional cleaning. Most first degree burns are amenable to first aid treatment.

(ii) Medical treatment includes a series of treatments including soaks, whirlpool, skin grafts, and surgical debridement (cutting away dead skin). Most second and third degree burns require medical treatment.

(4) **Cuts and Lacerations**

(i) First aid treatment is the same as for abrasions except the application of butterfly closures for cosmetic purposes only can be considered first aid.

(ii) Medical treatment includes the application of butterfly closures for noncosmetic purposes, sutures (stitches), surgical debridement, treatment of infection, or other professional treatment.

(5) **Eve Injuries**

(i) First aid treatment is limited to irrigation, removal of foreign material not imbedded in eye, and application of nonprescription medications. A precautionary visit (special examination) to a physician is considered as first aid if treatment is limited to above items, and follow-up visits if they are limited to observation only.

(ii) Medical treatment cases involve removal of imbedded foreign objects, use of prescription medications, or other professional treatment.

(6) **Inhalation of Toxic or Corrosive Gases**

(i) First aid treatment is limited to removal of the worker to fresh air or the one-time administration of oxygen for several minutes.

(ii) Medical treatment consists of any professional treatment beyond that mentioned under first aid and all cases involving loss of consciousness.

(7) **Splinters and Puncture Wounds**

(i) First aid treatment is limited to cleaning the wound, removal of foreign object(s) by tweezers or other simple techniques, application of antiseptics and nonprescription medications, and bandaging on the first visit. Follow-up visits are limited to observation including changing of bandages. Additional cleaning and applications of antiseptic constitute first aid where it is required by work duties that soil the bandage.

(ii) Medical treatment consists of removal of foreign object(s) by physician due to depth of imbedment, size or shape of object(s), or location of wound. Treatment for infection, treatment of a reaction to tetanus booster, or other professional treatment, is considered medical treatment.

(8) **Sprains and Strains**

(i) First aid treatment is limited to soaking, application of cold compresses, and use of elastic bandages on the first visit. Follow-up visits for observation, including re-applying bandage, are first aid.

(ii) Medical treatment includes a series of hot and cold soaks, use of whirlpools, diathermy treatment, or other professional treatment.

PRIVACY ACT NOTICE FOR MINE ACCIDENT, INJURY AND ILLNESS REPORTS

GENERAL

This notice is given as required by Public Law 93-579 (Privacy Act of 1974) December 31, 1974, to the operators of mines providing personal information on injury and illness reports and accident investigations.

AUTHORITY

The authority to collect this information is Section 103 of Public Law 91-173, as amended by Public Law 95-164.

PURPOSE AND USE OF INFORMATION

The information collected will be used to help determine the cause of accidents, injuries, illnesses and fatalities associated with metal and nonmetallic and coal mining. the information will also be used with the intent to prevent and reduce future accidents, injuries, fatalities and illnesses.

EFFECTS OF NON-DISCLOSURE

You are required to furnish the information. Without it, MSHA may not be able to help prevent miners and other workers from becoming similarly hurt or ill in the future.

INFORMATION REGARDING PERSONAL IDENTIFICATION UNDER PUBLIC LAW 93-579 SECTION 7(b)

MSHA asks for the last 4 digits of the social security number under authority of Section 103 of Public Law 91-173, as amended by Public Law 95-164. This personal identification, which is not unique to any individual, helps MSHA establish the accuracy and usefulness of the information from injury and illness records.

BURDEN STATEMENT

Public reporting burden for this collection of information is estimated to average 30 minutes per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. This is a mandatory collection of information as required by 3 CFR 50.20. The information is used to establish injury, accident or illness files used to measure the levels of injury experience and identify those areas most in need of improvement. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, the the Office of Program Evaluation and Information Resources, Mine Safety and Health Administration, U.S. Department of Labor, Room 2301, 1100 Wilson Boulevard, Arlington, VA 22209-3939, and to the Office of Management and Budget, Paperwork Reduction Project (1219-0007), Washington, D.C. 20503.

Persons are not required to respond to this collection of information unless it displays a currently valid control number.

Appendix C

Biographical Sketches of Committee Members and Staff

WILLIAM S. MARRAS (*Chair*) is a professor of engineering and holds the Honda endowed chair in the Department of Integrated Systems Engineering at Ohio State University. He is also director of the Biodynamics Laboratory and holds adjunct appointments in the Departments of Orthopedic Surgery, the Department of Physical Medicine, and Biomedical Engineering, and executive director of the university's Institute for Ergonomics and director of its Center for Occupational Health in Automotive Manufacturing. His research applies quantitative engineering techniques to occupational surveillance, laboratory studies, and mathematical modeling. He has worked extensively on low back pain, both its occupational causality and techniques for its clinical assessment and treatment. He was awarded an honorary doctor of science degree from the University of Waterloo for his work on the biomechanics of low back disorders. He is a member of the National Academy of Engineering. He has a B.S. in systems engineering–human factors engineering, an M.S. in industrial engineering, and a Ph.D. in bioengineering and ergonomics.

DAVID BEERBOWER is principal at Beerbower Safety Associates, LLC. Previously, he was vice president for safety for Peabody Energy, a private-sector coal company, where he was responsible for corporate-wide safety policies and programs and compliance with mine safety and health laws and regulations for the company and its subsidiaries and affiliates worldwide.

Following a progression of coal mine operations management positions with several coal companies, Mr. Beerbower joined Peabody in 1991 as director of safety and health for Eastern Associated Coal Corporation in Charleston, West Virginia. The following year, he was named vice president of safety in the St. Louis headquarters where he continued to direct the company's health and safety efforts. He has served as chair of the health and safety committee at the Bituminous Coal Operators of America, vice chair of the health and safety committee at the National Mining Association, chair of the coal and energy division of the Society for Mining, Metallurgy, and Exploration. He is the recipient of the Lifetime Achievement Award from the National Mine Rescue Association and of the Robert Stefanko Distinguished Achievement Award in Mining Engineering from Pennsylvania State University. He holds a B.S. in mining engineering from Pennsylvania State University and an M.B.A. in manufacturing management from Washington University (St. Louis).

SIAN L. BEILOCK is a professor of psychology at the University of Chicago. Her work focuses on the cognitive science behind performance under stress. She explores what happens in the brain and body when people are in pressure-filled situations and unable to make appropriate decisions or perform skills they have executed flawlessly in the past. Using her findings, she also develops practice strategies and psychological techniques to ensure optimal performance under stress. She is a recipient of the Spence Award for transformative early career contributions from the Association for Psychological Science. In addition to her scholarly publications, she is the author of a bestselling book, *Choke: What the Secrets of the Brain Reveal About Getting It Right When You Have To.* She has a B.S. in cognitive science from the University of California, San Diego, and Ph.D.s in both kinesiology (sport psychology) and psychology (cognitive neuroscience) from Michigan State University.

DAVID CLIFF is a professor of occupational health and safety in mining and director of the Minerals Industry Safety and Health Centre at the University of Queensland in Australia. Previously, he worked as manager of mining research and as manager of occupational hygiene, environment, and chemistry at the Safety in Mines Testing and Research Station of the Queensland government. His work has been devoted to the areas of health and safety to the mining industry with particular expertise in fatigue management, occupational health and safety performance measurement, safety management systems, emergency preparedness, gas analysis, spontaneous combustion, fires, and explosions. He has attended or provided assistance in more than 30 mine emergencies. He has written on such topics as emergency management in underground coal mines, mine rescue guidelines, communications in difficult circumstances, and lessons from international mine safety incidents. He has an honors B.Sc. in chemistry from Monash University and a Ph.D. in physical chemistry from Cambridge University.

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