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 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 of 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 National Institute of 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 doesn't 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 (HSI), 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 underway, safety management before, during, and after an event are 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 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 level.

Appropriate staff from the National Institute of 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 of 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:

(1) verbal communication;
(2) positive pressure;
(3) facial hair,
(4) device weight and size minimization;
(5) device changeover or air replenishment in toxic environments;
(6) fit testing where applicable; and
(7) adequate vision through clearing or removal of condensation.

RECOMMENDATION 3: The National Institute of 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
- multi-function 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 of Occupational Safety and Health and the Mine Safety and Health Administration should re-examine 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 of 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 of 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 of 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...
improving their own safety cultures and identify strengths and weaknesses specific to their organizations.

B. The National Institute of Occupational Safety and Health 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 of 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 B. above, and using best practices within the training field, the Mine Safety and Health Administration and the
National Institute of Occupational Safety and Health 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 C. above and miners' retention of information learned under simulated emergency conditions.

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

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu
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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 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. Those briefings were provided during the committee’s four initial meetings and were given by: Tom Barczak, Director of the Division of Mining Science and Technology, NIOSH, Office of Mine Safety and Health Research; Michael Brnich, mining engineer, NIOSH, Office of Mine Safety and Health Research, Human Factors Branch; R.J. Matetic, Director of the Division of Mining Research Operations (DMRO) within NIOSH’s Office of Mine Safety and Health Research; Jeffery H. Kravitz Acting Director, MSHA Technical Support; John Urosek, Chief, Mine Emergency Operations, MSHA Technical Support; Kris Lilly, Redbone Mining; Joseph Sbaffoni, Director of Pennsylvania Bureau of Mine Safety; Kathleen M. Kowalski-Trakofler, Consultant John Wreathall, John Wreathall & Company, Inc.; and the following staff from the NIOSH Office of Mine Safety and Health Research: Rohan Fernando, Senior Research Engineer; Launa Mallett, Acting Team Leader, Training Research and Development Team and Joseph Waynert, Team Leader, Electrical Safety and Communication Team;
The committee participated in two site visits throughout the course of the study. The committee would like to thank the staff and leadership at 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). Tours and exercises at these facilities were assisted by the following individuals: Eric Schubel, General Superintendent, Consol Energy; Joshua Caldwell, WVU Director, Academy for Mine Training and Energy Technologies; Thomas Hall, WVU Extension Agent; Randy Long, Laboratory Instrumentation Specialist, WVU; Steven Perkins, WVU Extension Agent; Henry Pisegna, WVU Part-Time Instructor; George Rannenburg, WVU Extension Agent; and Jay Cole, WVU Chief of Staff, President’s Office. 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 A. Wanchisen and Melissa Welch-Ross who provided oversight and support of the study. Julie Anne Shuck, 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, and Kirsten Sampson Snyder, who managed the report review process. Additional research and technical assistance was provided by Matthew Von Hendy, Research Librarian, and Ellen Reid, our 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, Division of Neuroergonomics, Department of Neurology, The 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.

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Toby Warden, Study Director
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