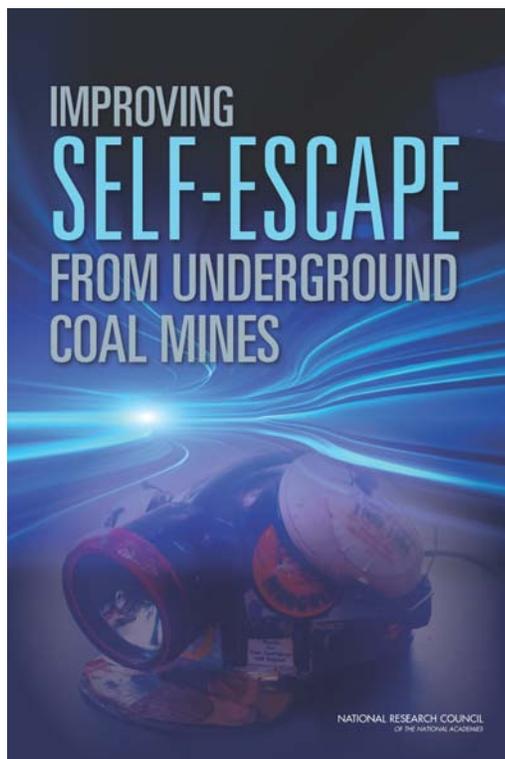


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BOARD ON HUMAN–SYSTEMS INTEGRATION

IMPROVING SELF-ESCAPE FROM UNDERGROUND COAL MINES



Although recent advances in mining research and practices have improved the safety and health of underground coal miners and extensive rescue strategies are in place, more coordinated planning and training are needed to better prepare miners to escape in the event of a mine emergency. Miners who need to evacuate a mine under life-threatening conditions must have working knowledge of their surroundings and the psychological tools to make decisions and communicate effectively. They also need to have reliable and uncomplicated equipment and technologies available.

At the request of the Office of Mine Safety and Health Research within the National Institute for Occupational Safety and Health (NIOSH), the National Research Council appointed a committee to examine the system in which miners work and propose ways to improve self-escape preparations for mining personnel. The committee's conclusions and recommendations are detailed in the report *Improving Self-Escape from Underground Coal Mines*.

The report considers human-systems and environmental factors, with specific focus on decision making under stress, technology development, safety culture, and training.

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HUMAN-SYSTEMS INTEGRATION APPROACH

A human-systems integration approach examines the relationships among people, tasks, the tools and equipment needed, and the environments within which they must operate. Self-escape is a task that involves multiple teams, acting before and during the escape, in a dynamic environment. Successful escape depends on available resources, actions of the organization and the miners, and the interactions between them. While the report's definition of self-escape references only actions taken after a mine emergency is underway, it is important to have a coordinated safety management system before, during, and after an event.

The report defines 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.

The committee recommends that emergency preparations such as escapeway drills be executed to incorporate and coordinate the varied roles of miners, other key personnel, the communications center, and stakeholders as deemed relevant to the escape scenario. These exercises should test interactions between persons involved and available tools and resources. In this way, human capabilities and limitations are considered in the context of a dynamic system that may change based on both external and internal factors. This leads to an understanding of how well one's emergency plans can be executed and an awareness of what improvements can be made. **Furthermore, mine operators, in collaboration with federal agencies, should make systematic, regular efforts to collect and analyze information from such drills and escape situations and make outcomes and lessons learned available in a way to promote future improvements.**

TECHNOLOGY DEVELOPMENT

Technologies and tools provide functional support to enhance individuals' capabilities and gather information. In mine emergency situations, the functionality that is needed includes supplied breathable air, communication between individu-

als and groups, atmospheric monitoring, tracking miners and hazards, using wayfinding and directional indicators, and vision enhancements.

The mining industry is already looking at needed upgrades to equipment and technologies used for emergencies, and cooperative efforts are underway that involve miner representatives, operators, technology providers, and the government. **The committee recommends that both NIOSH and the Mine Safety and Health Administration (MSHA) review their operational requirements for emergency supplies of breathable air, and that NIOSH allocate funds for research and development to improve the functionality of breathable air devices.** These improved devices should resolve problems with verbal communication, device weight and size, changeover or air replenishment in toxic environments, and vision.

Given the challenges that face miners under emergency situations, it is imperative that technology design consider miners' body space and strength to carry gadgets, natural behavior tendencies, and ease of use, in addition to the tasks required to self-escape. **The committee recommends that NIOSH and MSHA should accelerate efforts to develop other technologies, using human-centered design principles, that enhance miners' ability to escape. They should also re-examine their technology approval and certification process to ensure they are not deterring innovation in relation to self-escape technologies that are used in other industrial sectors and global markets.**

SCIENCE OF DECISION MAKING

Mine emergencies are stressful and complex events, often characterized by unanticipated conditions and the need for quick decision making, and complicated by hazards that vary widely from mine to mine. It is important to make miners aware of the warning signals most likely to occur in their mine environment so that appropriate early decisions can be made. It is also important to understand human biases and predispositions that could either help or hurt decision making.

Effective decision making is not based simply on in-the-moment choices but also on the long-term accumulation of knowledge and skills. For mine emergencies, miners need to have knowledge of

equipment and technology that they hardly ever use in daily work, and when they do need them, the conditions may not be optimal. Therefore, it is critical that miners be trained so that the use of these is automatic or habitual. If so, cognitive capacity can be preserved so that adequate attention can be directed at the unexpected events and conditions.

Miners also need to have rote knowledge of escapeways and the spatial layout of the mine as a whole. Requiring individuals and groups to walk escape routes and make decisions about possible paths will likely be beneficial for miners developing a thorough understanding of the mine layout. 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.

The committee recommends that NIOSH 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. With proper training, miners are more likely to learn what cues indicate real emergency situations and which do not and to gather the psychological tools necessary to make appropriate decisions.

SAFETY CULTURE

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. Preparation involves actions and resources directed at avoiding or minimizing the adverse consequences of system failures once they occur or begin to occur. Discussions of safety management systems often invoke the concept of safety culture.

Safety culture refers to the shared values pertinent to safety that 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 and develops over time as organizations operate and adapt

to local conditions, respond to events, and as a function of their leadership.

Integrating safe practices into all activities will help to mitigate potential emergencies and will help ensure optimal self-escape when necessary. Such practices include: creating a strong, positive safety culture that pervades an entire organization; having a systematic program for identifying and assessing work-related hazards and implementing controls; planning for and rehearsing actions that will be taken in emergency situations; maintaining open communication and a learning orientation about safety issues; and committing to training excellence and the use of best practices. Additionally, mine operators must ensure that everything to support escape is in place and available—from escape training to personal protective equipment to communication technologies to wayfinding aids.

There exists a repository of information on safety culture from other industries that can be reviewed for guidance relevant to the mining industry. The committee recommends that NIOSH, in coordination with mining stakeholders, 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. In addition, 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.

TRAINING

Training is a necessary step in preparing individuals and groups for self-escape. A systematic and industry-wide approach to self-escape training must be directed at two parties: (1) an individual miner alone and as a member of an escape group and (2) the responsible person team, which would consist of the responsible person (the person designated by the mine operator to take charge during mine emergencies), the people staffing the communication centers, and others designated to assist the responsible person. Separate training is required for each of these groups; however, coordinated training is also important to provide

an opportunity to exercise interrelated roles and identify ways to improve coordination and information exchange.

Because of the potential for shifting environmental conditions, every miner must be trained and prepared for conditions that warrant escape alone or with a group and with or without the ability to see and/or speak. They must also be trained to recognize when conditions change and how to mobilize the coping strategies and technologies best for each one. Training should be developed that emphasizes mastery with competency standards rather than durations and class time.

A variety of training tools could be arranged to form a sequence or flow of training experiences that leads to effective escape capability. Training flows in other industries begin with classroom procedure familiarization, move through technology

familiarization, advance into guided practice in the simulator, progress to independent practice with different scenarios, and conclude with a test of skills mastery.

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. Miners should have the opportunity to learn to perform necessary tasks under pressure and to practice managing their emotions before they have to face them under life-threatening conditions.

The committee recommends that NIOSH 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 order to guide the revision or development of training flows that bring miners, responsible persons, communication centers, and mine management to mastery in those KSAOs.

COMMITTEE ON MINE SAFETY: ESSENTIAL COMPONENTS OF SELF-ESCAPE

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FOR MORE INFORMATION . . . This brief was prepared by the Board on Human-Systems Integration (BOHSI) based on the report *Improving Self-Escape from Underground Coal Mine*. The study was sponsored by the Centers for Disease Control and Prevention through the Office of Mine Safety and Health Research at the National Institute for Occupational Safety and Health. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not reflect those of the sponsor. Copies of the report are available from the National Academies Press, 500 Fifth Street, NW, Washington, DC 20001; (800) 624-6242; <http://www.nap.edu> or via the BOHSI web page at <http://www.nationalacademies.org/bohsi>. Permission is granted to reproduce this document in its entirety, with no additions or alteration. Copyright © 2013 by the National Academy of Sciences.

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