NIOSH Mining Program Technical Report

Advancing Self-escape Training:

A Needs Analysis Based on the National Academy of Sciences Report "Improving Self-Escape from Underground Coal Mines"

Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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May 2023

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NIOSH [2023]. Advancing self-escape training: a needs analysis based on the National Academy of Sciences report, "Improving Self-escape from Underground Coal Mines." By Hoebbel CL, Bellanca JL, Ryan ME, Brnich MJ. Pittsburgh PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2023-134, https://doi.org/10.26616/NIOSHPUB2023134.

DOI: https://doi.org/10.26616/NIOSHPUB2023134

DHHS (NIOSH) Publication No. 2023-134

May 2023

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Acknowledgments

The authors wish to thank the following personnel of the National Institute for Occupational Safety and Health (NIOSH) for their contributions to the work described within this report or its content: Timothy J. Bauerle, James Boyd, Brittney W. Bragg, Jessica L. Cohen, Blaine P. Connor, Linda L. Chasko, Brendan Demich, Patrick Dempsey, Brianna Eiter, Audrey Glowacki, Emily J. Haas, William Helfrich, Carin Kosmoski, Brendan Macdonald, Launa Mallett, Susan M. Moore, Jason Navoyski, Mahiyar Nasarwanji, Timothy J. Orr, Nicole Ortiz, Elaine Rubinstein, Ted Scharf, Paul Schmidt, Jack Trackemas, Rich Unger, Dana Willmer, Candace Wolf, and Dave Yantek.

The research team also benefitted from the external expertise of Kwame Awuah-Offei, Mining Engineering Interim Chair, Mining & Explosives Engineering, Missouri University of Science & Technology; Denise A. Baker, Ph.D., Department of Psychological Science, Missouri University of Science & Technology; Nancy J. Cooke, Ph.D., Human Systems Engineering, Arizona State University; Todd Dewitt, CONSOL Energy; Jason Diamond, CONSOL Energy; David Leverknight, Mine Safety and Health Administration (MSHA); Joseph A. Sbaffoni, JAS Mine Consulting, LLC, Director, Pennsylvania Bureau of Mine Safety (Retired); Richard Stoltz, MSHA; and the late Marlon Whoolery, Principal, Whoolery Training and Consulting.

Finally, the authors would like to thank Jeffery L. Kohler, Ph.D., Emeritus Professor, Energy and Mineral Engineering, The Pennsylvania State University, for the initial scoping of this effort.

This technical report has been reviewed in draft form by the following individuals: Thomas Barrington, Donald Braenovich, Eric Gilson, Kenneth Helfrich, Megan Lavage, Shane McPherson, Thomas A. Morley, Joey L. Wolford, MSHA; Sekhar Bhattacharyya, Ph.D., Chair of Mining Engineering Program, The Pennsylvania State University; David Cliff, Ph.D. Professor of OHS in Mining, The University of Queensland, Australia; Joseph McGuire, Ph.D., Mine Safety and Health Educational Consultant; Susan M. Moore, Ph.D.; NIOSH National Personal Protective Technology Laboratory; Josh Roberts, Director of Occupational Health and Safety, United Mineworkers Association of America; and William C. York-Feirn, Mine Safety Program Director, Colorado Department of Natural Resources (Retired).

Although the individuals mentioned above contributed directly to the work described in this report and/or provided valuable feedback for its finalization, their review of documents and/or acknowledgment here does not constitute endorsement of its final content.

Acronyms and Abbreviations

AAR	After Action Report
ADDIE	analysis, design, development, implementation, evaluation
BOHSI	Board on Human-Systems Integration
CABA	compressed air breathing apparatus
CBT	computer-based training
CCER	closed-circuit escape respirator
CRM	Crew Resource Management
CTA	cognitive task analysis
DoD	Department of Defense
EGL	escape group leader
EMT	emergency medical technician
EPL	expected proficiency level
ERP	emergency response plan
FEMA	Federal Emergency Management Agency
FTA	formal task analysis
GAO	Government Accountability Office
HRPP	Human Research Protection Program
HSI	human-systems integration
IC	Information Circular
IRB	Institutional Review Board
ISD/SAT	Instructional Systems Development/Systems Approach to Training
ITS	intelligent tutoring systems
JAHSAAM	Joseph A. Holmes Safety Association Annual Meeting
KSA	knowledge, skills, and abilities
KSAO	knowledge, skills, abilities, and other attributes
MEET	Mine Emergency Escape Training
MINER Act	Mine Improvement and New Emergency Response Act of 2006
MSHA	Mine Safety and Health Administration
MSTTC	Mine Safety Technology and Training Commission
NAS	National Academy of Sciences
NDM	naturalistic decision-making

NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
NRC	National Research Council
OMB	Office of Management and Budget
PTA	preliminary task analysis
RA	refuge alternative
RP	responsible person
SCBA	self-contained breathing apparatus
SCSR	self-contained self-rescuer
SEM	social ecological model
SET	stress exposure training
SME	subject matter expert
SOW	statement of work
TACT	Team Adaptation and Coordination Training
TMT	Team Model Training
TNA	training needs analysis
TSM	training strategy matrix
USBM	United States Bureau of Mines
VE	virtual environment
VISLab	Virtual Immersion and Simulation Laboratory
VR	virtual reality
WBT	web-based training

Advancing Self-escape Training:
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Cassandra L. Hoebbel, Ph.D.;[1] Jennica L. Bellanca, M.S.;[2] Margaret E. Ryan, M.P.H.;[3] and Michael J. Brnich, Jr., C.M.S.P.[4]

Chapter 1: Overview

Underground coal miners face unique threats to their health and safety. Data from the National Institute for Occupational Safety and Health (NIOSH) indicate that 23 mine disasters[5] have occurred in U.S. underground coal mines since 1970, resulting in the deaths of 376 mineworkers [NIOSH 2019a]. Many more fatalities and serious injuries have resulted from lesser mining accidents. Increased scrutiny of U.S. mine safety practices resulted from a relatively rapid succession of large-scale emergencies in 2006 and 2007, beginning with the Sago mine disaster, and later in 2010, the Upper Big Branch mine disaster. Subsequent investigations into these two highly publicized events [e.g., MSHA 2007a,b; McAteer et al. 2011] suggest that both could have been averted or mitigated through better human-systems integration practices.

In direct response to the events of 2006, the U.S. Congress acted to strengthen existing safety and health training regulations and introduce new measures aimed at improving emergency preparedness and response in underground coal mines. The Mine Improvement and New Emergency Response ("MINER") Act of 2006 amended the Mine Safety and Health Act of 1977 "to require incident assessment and planning, harness new and emerging technology, enhance research and education, improve safety-related procedures and protocols, and increase enforcement (penalties) and compliance to improve mine safety" [MINER Act 2006].

These tragedies and resulting legislative changes prompted NIOSH and other industry stakeholders to engage in research and development activities to improve mine emergency preparedness and response. In 2011, NIOSH commissioned the National Academy of Sciences (NAS) to investigate the effectiveness of these efforts and to identify any areas still in need of improvement. This investigation led to the development of several recommendations for NIOSH, the Mine Safety and Health Administration (MSHA), and other interested parties to act upon to improve self-escape from underground coal mines [NRC 2013]. The full text of the resulting committee recommendations included in the NAS report, "Improving Self-escape from Underground Coal Mines," is included in Appendix A of this document [NRC 2013].

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[3] Columbia University/New York State Psychiatric Institute. All work for this report was completed as an Associate Service Fellow, Pittsburgh Mining Research Division, National Institute for Occupational Safety and Health.
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[5] A mining disaster is defined as an incident with 5 or more fatalities.

This report summarizes a needs analysis and actions taken by NIOSH based on the NAS recommendations specific to advancing self-escape training, with an emphasis on preparing rank-and-file mineworkers for self-escape. This report also provides the foundation for the practical guidance offered in its sister publication, the NIOSH Information Circular (IC) "Self-escape Core Competency Profile: Guidance for Improving Underground Coal Miners' Self-escape Competency" [NIOSH 2023], which offers an evidence-based self-escape competency framework derived from the results of this work.

Abbreviated versions of the four NAS recommendations discussed in this report are presented below in the order in which they were undertaken by NIOSH.

> **NAS Recommendation 7A:** To advance self-escape training, NIOSH should conduct or sponsor a formal task analysis and analysis of the knowledge, skills, abilities, and other personal attributes (KSAOs) for miners to self-escape effectively.
>
> **NAS Recommendation 7B:** Based on this analysis, NIOSH should identify training activities best suited for preparing mineworkers to self-escape effectively and identify existing gaps within the mining industry.
>
> **NAS Recommendation 5:** NIOSH should use current decision science research to inform the development of self-escape training materials for effective decision-making for the predictable components of self-escape.
>
> **NAS Recommendation 7C:** The Mine Safety and Health Administration (MSHA) and NIOSH should revise or develop training flows[6] to bring individual miners and mine management to mastery in critical self-escape KSAOs.

Although the NAS recommendations and needs analysis described herein are specific to underground coal mining, NIOSH believes that much of this content is also applicable to emergency response preparedness across all underground mining subsectors and other related industries.

Background

The mission of the NIOSH Mining Program is to eliminate mining fatalities, injuries, and illnesses through relevant research and impactful solutions [NIOSH 2022]. The program began in 1910 when Congress created the U.S. Bureau of Mines (USBM) to conduct mine safety and health research. Both the USBM and NIOSH, which acquired the USBM's health and safety research program following the Bureau's closure in 1996, have contributed to a dramatic and steady decline in catastrophic mining events and mineworker fatalities [NIOSH 2010a]. By the turn of the 21st century, it appeared that the threat of large-scale mining disasters had been effectually mitigated. However, a series of mine disasters in the first decade of the 21st century showed that perception to be incorrect: Brookwood in 2001 (13 fatalities), followed by Sago (2006, 12 fatalities), Darby (2006, 5 fatalities), Crandall Canyon (2007, 6 fatalities), and Upper

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[6] "Training flow" is a term used within the NAS report to describe systematic training procedures using a variety of training methods and consisting of several phases of instruction (e.g., classroom instruction, drills, and other hands-on practice).

Big Branch (2010, 29 fatalities). These events reminded the mining industry and NIOSH of the critical need to balance investments in resources and training to reduce the risk of low-probability/high-severity events with those that focus on more frequent but less severe injuries and illnesses. To help achieve this balance, additional emphasis was placed on adequately preparing individual mineworkers to perform the non-routine tasks required to effectively respond to mine emergencies.

Specifically, a number of investigations and reports resulting from the Sago mine disaster emphasized the need for renewed focus on mine emergency preparedness and response through better human-systems integration practices [e.g., McAteer et al. 2006a,b; Mine Safety Technology and Training Commission (MSTTC) 2006; MSHA 2007a,b; West Virginia Mine Safety Technology Task Force 2006; U.S. Government Accountability Office (GAO) 2007]. This emphasis prompted NIOSH to engage in wide-ranging research efforts to characterize, assess, and improve the mine emergency escape system, which includes components such as refuge alternatives (RAs), safety culture, and mineworker KSAOs[7].

In an effort to improve self-escape training and move the industry in the direction of developing a definition of minimum self-escape proficiency, NIOSH also focused investigations on self-escape competency characterization and improved miner training while simultaneously commissioning reviews of mine emergency response training and best practices around the world [e.g., Galvin 2008; Wu and Gray 2008]. As a result of these activities, three areas of critical importance were identified:

- evaluation of competencies,
- new training content, and
- improved training methods.

The renewed focus on self-escape competency identification and improved miner training resulted in the development and dissemination of 14 new NIOSH training packages between 2008 and 2012. Additionally, NIOSH researchers compiled a list of self-escape knowledge, skills, and abilities (KSAs) based upon a review of mine safety training regulations, available literature, and input from mine safety and training experts [Peters and Kosmoski 2013], which served as the basis for a small-scale study designed to identify gaps in self-escape KSAs. In this study, NIOSH researchers interviewed mine safety and health trainers to gain their perspective on the effectiveness of existing self-escape training and mineworker competence [NIOSH 2015a]. Based on personal experiences, interviewees consistently pointed to perceived deficiencies in the following content areas: (1) general escapeway training and alternate escape routes, (2) reading a mine map, (3) understanding how the mine's ventilation system works, (4) barricading, (5) refuge alternatives, and (6) communication systems. All six of these areas are currently included in the mandated minimum training requirements for underground coal miners, as outlined in Table 1. Importantly, participants in the NIOSH interviews also emphasized the lack of competency standards and assessment strategies in existing self-escape training protocols.

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[7] NIOSH researchers focused on critical knowledge, skills, and abilities (KSAs) required for effective self-escape, placing less emphasis on trainees' other attributes (Os) which are less malleable and amenable to training.

Table 1. Minimum federal training requirements for all miners related to self-escape competencies

Minimum Training Requirements
Annual refresher training [30 CFR 48.8] • Transportation controls and communication systems • Barricading • Refuge alternatives • Roof or ground control; ventilation, emergency evacuation; and firefighting plans • First aid • Self-rescue and respiratory devices [hands-on donning and transferring] • Mine gases • Such other courses as may be required by the District Manager based on circumstances and conditions at the mine.

MINER Act [MINER Act 2006]
• Quarterly mine emergency evacuation training and drill
  o Review of maps and emergency plans
  o Location and use of lifelines, tethers, SCSRs[8] (self-contained self-rescuers), refuge alternatives, fire suppression and firefighting equipment and other materials
• Annual expectations training for SCSRs and refuge alternatives

Concurrent with these exploratory efforts, NIOSH entered into a research contract with the National Academy of Sciences (NAS) to better characterize effective “self-escape” within the context of underground coal mining. Specifically, under the oversight of the National Research Council’s (NRC) Board on Human-Systems Integration (BOHSI), the Committee on Mine Safety: Essential Components of Self-escape was convened. The committee carefully reviewed and synthesized relevant literature and other existing data to develop a set of recommendations presented in the NAS report, “Improving Self-escape from Underground Coal Mines” [NAS 2013].

Specific to self-escape training, this report focuses on NAS Recommendations 7A, 7B, 5, and 7C, which were borne out of the following conclusion by the committee: “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” [NRC 2013 p. 116]. The NAS committee

[8] While SCSR is the terminology commonly used in the mining industry for these devices, it is important to note that they are also known as closed-circuit escape respirators (CCER) in accordance with 42 CFR Part 84 Subpart O.

further stated, “In training, miners seldom have to demonstrate mastery of a skill, but only have to be in attendance” [NRC 2013 p. 116] and recommended that NIOSH undertake a number of research activities to focus on the development of self-escape competency standards. The committee believed that these competency standards should be utilized in a “train-to-mastery” system in lieu of the hours-based system currently required by law. “Mastery” has been defined as “the ability to perform the task instinctively, regardless of the conditions” [TRADOC 350-70 2017, p. 147] and is the desired level of proficiency for evaluating task readiness within the U.S. Department of Defense (DoD). While clear differences in job duties, as well as time and training resource availability between the mining industry and the DoD are evident, the authors believe a shift toward competency-based emergency response training and evaluation is possible.

Although the MINER Act calls for some measure of evaluation of trainee learning and performance, the regulation does not specify competency standards, performance criteria, or methods for assessment. Both the NAS report and prior NIOSH research emphasize the need for definitions and standards for determining successful completion of mandated training similar to those prevalent in Australia [e.g., Commonwealth of Australia 2020, Queensland Government 2012], the United Kingdom [Health and Safety Executive 2015], and South Africa [South African Government 1998] beginning with the development of “a comprehensive listing of competencies for miners, foremen, managers, and responsible persons” [NIOSH 2010b, p 43] and procedures for assessing critical self-escape competencies [Peters et al. 2010]. Therefore, the aim of the work described within this report is to address some of these deficiencies and to continue movement in the direction of standardized self-escape training and assessment in the U.S. mining industry. This work aligns with the NIOSH Mining Program’s Strategic Goal 3.4 to reduce the risk of mine disasters and improve the post-disaster survivability of mineworkers [NIOSH 2019c].

Framing the Research Approach

In order to frame the research activities described in this report, it was necessary to examine the problem through a combination of human-systems integration, social ecology, instructional systems design, and the Federal Emergency Management Agency (FEMA) Preparedness Cycle.

Human-Systems Integration

Recognizing the myriad factors that influence individual mineworkers’ capability to self-escape from underground coal mines, the NAS committee developed a human-systems integration (HSI) model of self-escape, depicted in Figure 1, stating the following:

> Human-systems integration examines the interaction of people, tasks, and equipment/technology in the pursuit of some goal . . . in this case self-escape. The interaction occurs within, and *is influenced by* [emphasis added], the broader organizational and environmental context where human capabilities and limitations are considered in the context of a dynamic system that may change based on both external and internal factors [NRC 2013 p. 16–17].

Figure 1. The NAS human-systems model of self-escape. This model illustrates how individual differences (e.g., in cognitive and physical capabilities) influence how miners approach tasks and interact with equipment and technology, while also being influenced by the broad environment. Adapted from NRC [2013].

The HSI model provides a framework by which NIOSH's "Improving Self-escape from Underground Coal Mines Training Initiative" project research [NIOSH 2018] was designed. It stresses the importance of considering the interactivity of an entire system. Despite a strong focus on training and individual components of the system, self-escape tasks, equipment, and organizational context cannot be dissociated from self-escape competency.

Some examples of specific self-escape HSI system success factors include organizational support (e.g., policies, provision of resources, safety climate), human-centered design of self-escape tools and technology (e.g., self-contained self-rescuers [SCSRs], communication systems), individual and group performance (self-escape competence), education and training (effective training flows), and external factors (e.g., MINER Act provisions).

Social Ecology

Similar to the systems thinking of the HSI framework, it is also helpful to contextualize individual factors (e.g., mineworker competence) within a broader ecological model that also guided the development of this research project. As defined in Stokols et al. [2013], "the term, ecology, refers to the study of the interrelationships between organisms and their environment". In the current study, this would apply to mineworkers and their environments. The field of social ecology emerged in the 1960s, giving more attention to social and cultural environmental factors that could affect these relationships than did earlier models. Using the social ecological model (SEM), the reciprocal relationships between the individual mineworker and his or her physical and social environment are more easily illustrated and understood (Figure 2). The mineworker exists within this context and is directly and indirectly affected by it.

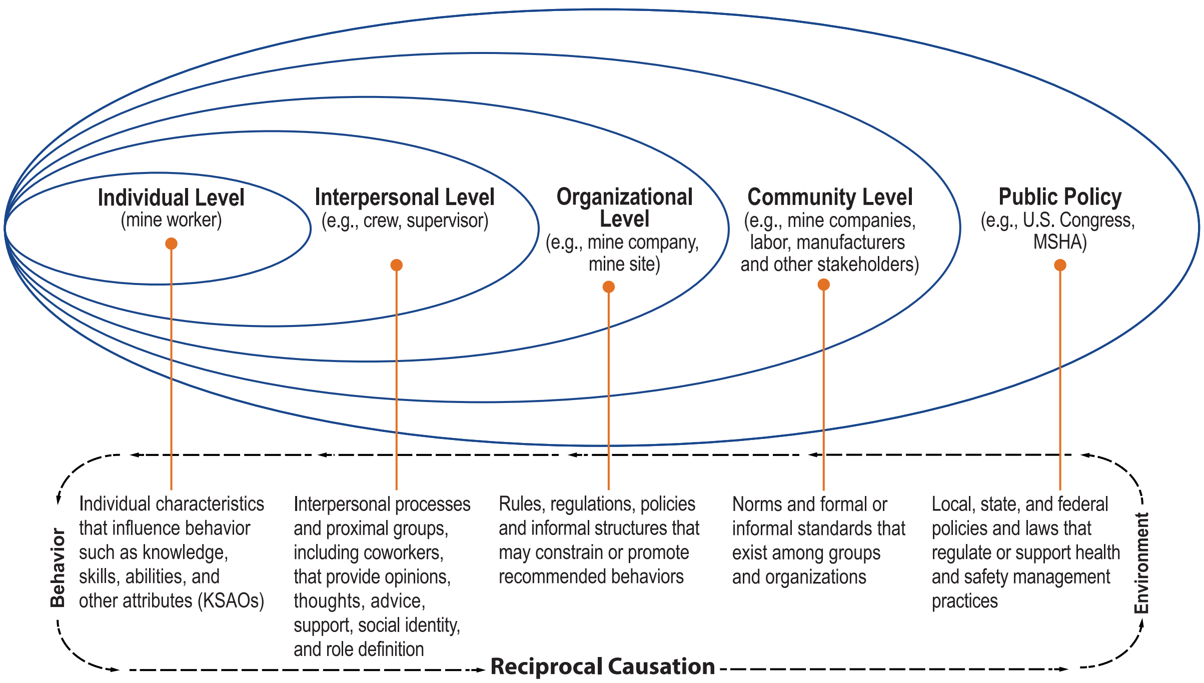

Figure 2. The social ecological model for improving self-escape from underground coal mines. This model depicts how individual mineworker characteristics both affect and are affected by multiple levels of influence, emphasizing the interaction between and interdependence of factors within and across all levels of emergency preparedness. Adapted from Glanz et al. [2002].

The SEM has long been used in public health research and practice to identify targets and intervention leverage points in areas such as health behavior [e.g., McLeroy et al. 1988; Sallis et al. 2015; Stokols et al. 2013], chronic illness [e.g., Kazak 1989; Champaloux and Young 2015], violence prevention [e.g., Ali and Naylor 2013; Swearer and Hymel 2015], and community safety [Hanson et al. 2005]. This framework also emphasizes the reciprocity of the relationships between and among the various levels of influence. For example, the MINER Act was passed in reaction to multiple mineworker fatalities that were attributed to a number of systemic failures associated with training, response coordination, and mining technologies and equipment. Existing regulations were tightened and others were introduced as both a result of these failures and as an effort to prevent such failures in the future by targeting all levels of the social ecological model.

Based on prior NIOSH research conducted with mine safety and health professionals, Haas et al. [2014] suggested that effective execution of self-escape training research-to-practice (r2p) initiatives has the potential to affect every level of influence on mineworkers' self-escape competency. As the authors note, "Distinct interventions are needed at each level of the SEM to enhance individual and group behavior, and to modify organizational and training environments" [p. 124]. Positive outcomes of the current initiative could lead to more standardized training and assessment throughout the industry and could have significant policy implications for self-escape training requirements.

Instructional Systems Design

From an ecological perspective, all levels of influence must be represented through some or all of the stages of the research and/or implementation process. Therefore, research is often designed under an action-oriented design [Adelman 1993; Lewin 1946] utilizing a variety of methods similar to those used in Instructional Systems Development/Systems Approach to Training (ISD/SAT) [Branson 1977; Branson 1978; Branson et al. 1975]. Action research, which often relies on the expertise of practitioners and other stakeholders in repetitive cycles of planning, action, and evaluation, is widely used in the field of education and is particularly useful when performing pragmatic and solutions-driven research with direct relevance to practice [Levin and Greenwood 2001].

The ISD/SAT—an approach to training design developed by the U.S. Army and used by the U.S. DoD for training protocol development, implementation, and evaluation—is depicted in Figure 3, with each phase described in Table 2. A major emphasis of the ISD/SAT process is continuous improvement, and the steps include training analysis, design, development, implementation, and evaluation (ADDIE). The DoD also suggests that practitioners use the Shewhart Cycle (also known as “plan, do, check, act”) as part of the ISD/SAT for continuous improvement [DoD 2001]. This approach includes four basic steps: planning the approach, doing the activity, checking the results, and acting on the results.

Table 2. The ADDIE approach to instructional systems development, adapted from TRADOC [2017]

A	**Analysis**	The process that involves the detailed breaking down and examination of jobs, functions, tasks, objectives, and performance measures to determine requirements and how those requirements relate to one another. Analysis provides the foundation that justifies the continuation or termination of the ADDIE process.
D	**Design**	The process of translating analysis data into an outline for learning, creating a blueprint for learning product development, and determining the sequence and how to train.
D	**Development**	The process that is the act of taking design outputs and expanding on the learning activities, refining the course management plan, refining the resources, and creating the learning products. Development is the production phase of ADDIE.
I	**Implementation**	The process that is the conduct and delivery of the course/event in accordance with how the course/event was designed. Implementation includes student assessment to measure achievement of standards and course outcomes.
E	**Evaluation**	The quality control mechanism for learning and learning product development and implementation. Evaluation is a systematic and continuous method to appraise the quality, effectiveness, and efficiency of a program, process, product, or procedure. It provides the mechanism for decision-makers to ensure the application of consistent standards of quality.

As described in Table 2, the initial stages of the ADDIE process are typically exploratory and/or descriptive, and most of this research falls within these stages. Figure 3 demonstrates how evaluation is a central function of each phase, resulting in a systematic approach that is cyclical and iterative in nature. In keeping with this model, the results of the needs analysis described in this report have been synthesized to guide mine safety and health professionals and other stakeholders in the development and implementation of new and/or improved self-escape training and assessment activities.

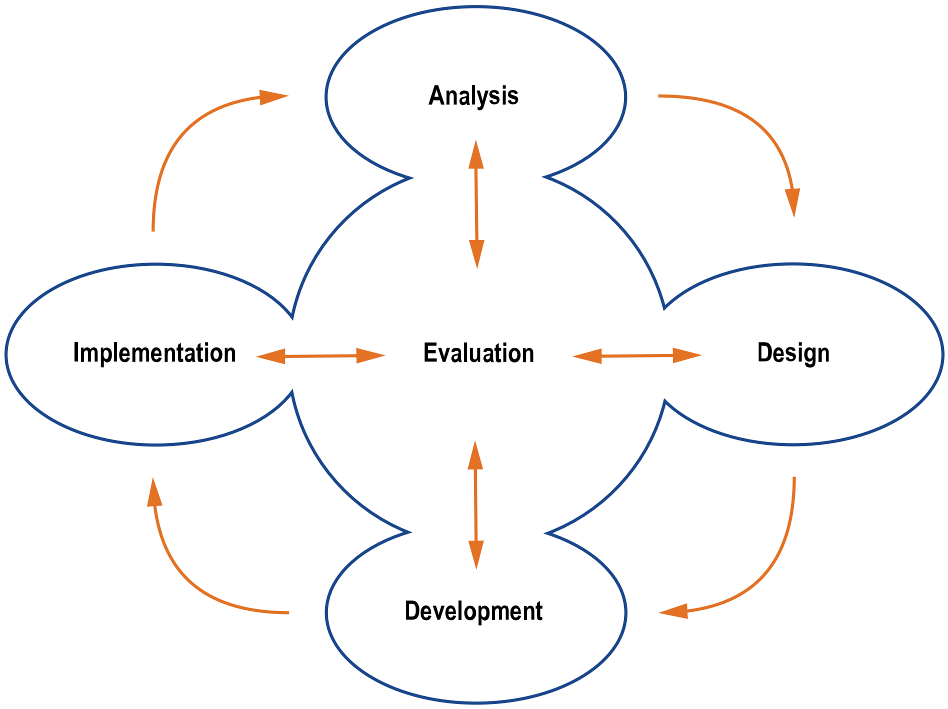

Figure 3. The ISD/SAT process, also referred to as ADDIE. ADDIE is an iterative cycle of analysis, design, development, implementation, and evaluation of instructional systems. Adapted from DoD [2001].

The Federal Emergency Management Agency Preparedness Cycle

Over the past several decades, the theory and practice of emergency management (EM) has been shifting from a largely reactive response command structure toward a more proactive structure that emphasizes the critical role preparedness plays in EM [Comfort 2007; Waugh and Streib 2006]. Preparedness is defined by FEMA [2019] as a scalable "continuous cycle of planning, organizing, training, equipping, exercising, evaluating, and taking corrective action in an effort to ensure effective coordination during incident response." The scalability of the process enables it to be readily applied to a broad spectrum of emergency preparedness efforts and provides the context for the competency framework development described within this report. It is also important to note the cyclical and iterative nature of the process, which allows room for "retrofitting" enhancements, as required once the framework and training flows have been developed (see Figure 4).

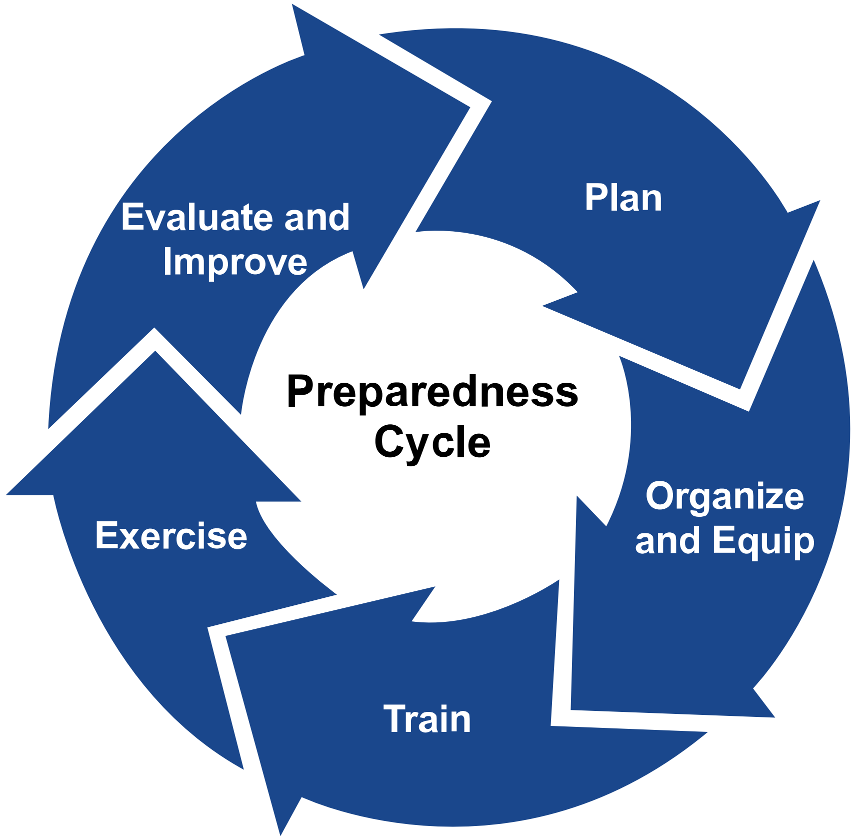

Figure 4. Representation of the FEMA Preparedness Cycle. This cycle represents a scalable and iterative process consisting of organizing, equipping, training, exercising, and the continuous evaluation and improvement of emergency response readiness.

Relevant to this report, much like FEMA and other large entities, the mining industry continuously examines risks and evaluates mitigation efforts. Naturally, when perceived failures within a system arise, the system is re-examined to identify potential shortfalls. Although the "evaluate and improve" stage of this cycle is ongoing, the sense of urgency to evaluate and improve the process increases after catastrophic breakdowns in one or more components of the system (e.g., technological failure, human error). For example, the emergency events in 2006 resulted in legislative changes that touched all levels of the self-escape system. To meet these new requirements, the industry invested a great deal of time and resources to better "organize and equip," "train," and "exercise" miners for more effective mine emergency response. These efforts included, among others, the development of emergency response plans (ERPs), the increased availability of SCSRs, additional and improved SCSR training, installation of refuge alternatives, and required quarterly escape drills. The iterative FEMA process continues with the current NIOSH Mining Program effort to determine whether and how these efforts have been effective and how they might be improved.

Implementing the Research

In 2015, almost 10 years after the passage of the MINER Act and amid the building consensus that self-escape training in the U.S. left significant room for improvement, NIOSH researchers began work on the project, "Improving Self-escape from Underground Coal Mines Training Initiative" [NIOSH 2018].

Since not all mines have the capacity to conduct systematic training needs analyses (TNA) at the local level, industry-wide efforts to identify universal competency requirements, training objectives, and gaps are necessary. The objectives of this project were to better characterize the task of self-escape, further characterize potential gaps in self-escape training, and explore relevant individual and organizational characteristics in order to provide practical guidance to mine safety and health professionals for training and assessing mineworker self-escape competency. To meet these objectives, the project had five research aims, as follows:

1. To identify self-escape knowledge, skills, abilities, and other attributes (KSAOs) to characterize competence in the task of self-escape for rank-and-file mineworkers and those in self-escape leadership positions (mine management and responsible persons [RPs]).
2. To prioritize the knowledge, skills, and abilities (KSAs) that are critical to effective self-escape and amenable to training interventions.
3. To identify potential gaps in prioritized self-escape competencies and identify strategies to fill those gaps.
4. To create modifiable immersive mine environments suitable for self-escape training and behavioral research activities.
5. To provide a standardized, evidence-based framework for self-escape competency training and assessment to the mining industry.

Research Summary

The five research aims above were met through a combination of in-house efforts and contract work at NIOSH facilities, mine sites, and other training facilities. Aims 1–3 consisted largely of TNA activities. These efforts included formal hierarchical and cognitive task analyses to identify KSAOs across self-escape roles, the exploration of relationships between and among various individual and organizational characteristics, the identification of existing gaps in miner self-escape training and competence, and reviews of existing emergency training in mining and other high-risk industries and the knowledge base related to current decision science. Completion of these activities enabled the development of a structured, evidence-based training needs checklist. The checklist was reviewed and revised by several mine emergency subject matter experts (SMEs) to assist NIOSH in the development of a self-escape competency training and assessment framework for practical use in the mining industry, as detailed in the IC, "Self-escape Core Competency Profile: Guidance for Improving Underground Coal Miners' Self-escape Competency" [NIOSH 2023].

Parallel to the completion of the tasks designed to meet research Aims 1–3, NIOSH researchers addressed Aim 4 by using NIOSH's Virtual Immersion and Simulation Laboratory (VISLab) to develop a flexible virtual underground coal mine simulation environment platform (VR Mine) suitable for self-escape training and behavioral research activities. The flexibility of this simulated environment makes it suitable for experimental work—including the study of research topics such as situational awareness (SA), hazard recognition, and decision-making—and also allows mine-specific modifications (e.g., number of entries, crosscuts, locations of mine emergency response features and apparatus, etc.). The VR Mine can be used to create unique layouts quickly and easily for mine-specific training activities that can be incorporated into self-escape training flows. Effectively harnessed, this immersive, virtual reality (VR) platform can serve as a mechanism for delivery of content as well as provide opportunities for practice and assessment.

The outcomes of these research activities provide a solid framework from which enhanced self-escape training and assessment training flows can be developed or used by mine safety and health professionals. The outcomes are expected to contribute to an increased standardization of effective self-escape training and assessment and a more prepared workforce. Ultimately, these outcomes could also influence legislative and policy discussions related to self-escape training requirements in the U.S. mining industry.

Research Activities

NIOSH utilized in-house and non-governmental contractor expertise to perform the needs analysis described in this report. All activities were designed based on NAS Recommendations 5 and 7A-C and fit within the framework described in Chapter 1: Overview, above. Specifically, Table 3 demonstrates the alignment of the NAS recommendations, contract and NIOSH activities, the phases of ADDIE and the FEMA Preparedness Cycle, and the corresponding chapter from this report that covers these topics. Furthermore, NIOSH adopted the NAS definition of “self-escape,” as follows:

> 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 [NRC 2013 p. 13].

Using the NAS definition of self-escape, the activities contextualized in Table 3 were designed to consider both the need to escape as a group and the need to escape alone. Although the focus of this research is on identifying the training needs of individual mineworkers, it is important to note that the NAS committee’s definition of self-escape makes a distinction between self-escape by an individual and self-escape by a group (i.e., not aided externally). This differentiation has important implications for identifying both *what* KSAOs are required and *how* they might be trained. For example, ad hoc escape groups or “teams” of individual workers in close proximity to one another may form when confronted with an emergency. In these cases, factors such as communication, leadership, and other team based KSAOs are also critical and addressed in this report.

Many of the research activities summarized in Table 3 were executed simultaneously or overlapped considerably. For narrative purposes, the activities described in the following chapters are presented in the approximate chronological order in which they were undertaken.

Table 3. Activities undertaken or contracted by NIOSH based on the NAS report, "Improving Self-escape from Underground Coal Mines"

NAS Recommendation Summaries	Contractor* and NIOSH Research Activities	ADDIE Phase	Preparedness Cycle Phase	Technical Report Chapter
7A. To advance self-escape training, NIOSH should conduct or sponsor a formal task analysis and analysis of the knowledge, skills, abilities, and other personal attributes (KSAOs) for miners to self-escape effectively.	Preliminary Task Analysis (PTA)* Hierarchical Task Analysis (HTA)*	Evaluate Analyze	Evaluate/Improve Plan	Chapter 2: Analyzing the Task of Self-escape
7B. Based on this analysis, NIOSH should identify training activities best suited for preparing mineworkers to self-escape effectively and identify existing gaps within the mining industry.	Literature Review: Training and Assessment Strategies* Mineworker Self-report Survey	Design Evaluate	Evaluate/Improve Plan	Chapter 3: Identifying Effective Training Strategies and Existing Gaps
5. NIOSH should use current decision science research to inform the development of self-escape training materials for effective decision-making for the predictable components of self-escape.	Literature Review: Decision-making and Assessment Strategies* Cognitive Task Analysis (CTA)*	Analyze Design Evaluate	Evaluate/Improve Plan	Chapter 4: Preparing Miners for Decision-making Under Stress
7C. The Mine Safety and Health Administration (MSHA) and NIOSH should revise or develop training flows to bring individual miners and mine management to mastery in critical self-escape KSAOs.	Subject Matter Expert (SME) Validation and Consensus Building Focus Groups Creation of "Core Competency Profiles" for Miner Self-escape Virtual Reality Mine Design and Development	Design Develop Evaluate	Evaluate/Improve Plan Organize/Equip Train Exercise	Chapter 5: Developing Components for Self-escape Training Flows

* Contracted work carried out by the Group for Organizational Effectiveness, Inc., and its subcontractor, Aptima, Inc.

Other Documents Related to this Report

Contractor Reports

NIOSH responded to the NAS recommendations related to advancing self-escape training through a combination of in-house efforts and contract work as described in Table 3. After the tasks and subtasks necessary to carry out the work were identified, NIOSH contracted with a group of external subject matter experts to perform a detailed task analysis to identify and prioritize critical self-escape competency areas and KSAOs and to develop related training and assessment recommendations. This contractor, the Group for Organizational Effectiveness, Inc., and its subcontractor, Aptima, Inc.—hereafter referred to as "gOE/Aptima"—completed several activities that provided the foundation for the self-escape competency framework development detailed in this report.

During the first phase of this work, gOE/Aptima partnered with a mining SME and two participating mine sites to develop research protocols and data collection materials based upon contract specifications. These data collection protocols were approved by the NIOSH Institutional Review Board (IRB) (Protocol No. HSRB 14-OMSHR-10XP) and the Office of Management and Budget (OMB) (Control No. 0920-1081).

The later phases of the contract required written reports describing the methods and results of each research activity, which included a preliminary task analysis (PTA), a hierarchical task analysis (HTA), a cognitive task analysis (CTA), and other detailed TNA activities for training and assessing the critical physical and cognitive tasks associated with self-escape. The contractor report years and titles are as follows:

gOE/Aptima [2016a]. Emergency self-escape phase 2 report: Identify and categorize primary self-escape tasks.

gOE/Aptima [2016b]. Improving self-escape from underground coal mines training initiative: Training and assessment strategy recommendations.

gOE/Aptima [2017a]. Improving self-escape from underground coal mines training initiative: Decision-making.

gOE/Aptima [2017b]. Emergency self-escape phase 3 report: Hierarchical task analysis and recommendations.

gOE/Aptima [2017c]. Emergency self-escape phase 4 report: Cognitive task analysis and recommendations.

Within this technical report, NIOSH researchers have synopsized key findings from the contractor reports and described how they were used to inform the development of subsequent research activities and the resulting self-escape competency framework. The full contractor reports are available upon request from mining@cdc.gov.

NIOSH Information Circular: Self-escape Core Competency Profile: Guidance for Improving Underground Coal Miners' Self-escape Competency

This report's sister publication, the NIOSH IC "Self-escape Core Competency Profile: Guidance for Improving Underground Coal Miners' Self-escape Competency" [NIOSH 2023], was developed based on the totality of internal and external research and validation efforts described in this technical report. The IC is intended to serve as the competency framework for mine safety and health professionals to use in the development of new or improved self-escape training flows. The IC includes a validated checklist of core competencies and performance criteria, which can serve as measurable learning objectives for self-escape training and assessment activities.

Chapter 2: Analyzing the Task of Self-escape

This chapter details how NIOSH contracted with gOE/Aptima to analyze the self-escape task based on the NAS report recommendation 7A, summarized as follows:

> **Recommendation 7A**. To advance self-escape training, NIOSH should conduct or sponsor a formal task analysis and analysis of the knowledge, skills, abilities, and other personal attributes (KSAOs) for miners to self-escape effectively.

Training needs analysis is "a systematic process that applies work analysis techniques and procedures to identify and specify training requirements that have been linked to deficiencies in individual, team, or organization performance to develop learning objectives to address the identified deficiencies" [Surface 2013 p. 437]. TNA is a critical first step in developing effective training programs [Ostroff and Ford 1989]. One TNA methodology is a task analysis.

Task analysis is a widely accepted empirical approach to developing comprehensive and measurable training objectives and is often the first step in ISD (the "A" of ADDIE). Standard methods for performing task analyses include hierarchical task analysis (HTA) [Drury 1983; Hackos and Redish 1998; Stanton 2006] and cognitive task analysis (CTA) [Crandall et al. 2006, Militello and Hutton 1998]. Stanton [2006] describes how HTA techniques have been successfully used to design and develop training, perform team task analysis, and determine appropriate allocation of function—i.e., whether a particular task should be performed by a person or persons, technology, or some combination of the human-technology system. Similarly, CTA has been used to identify cognitive requirements in command-and-control systems, decision-making, situational assessments, and response planning and execution [Crandall et al. 2006].

Although the NAS report called for a formal task analysis to examine the KSAOs required for effective self-escape, the focus of this report is on preparing mineworkers to effectively self-escape through improved training. Therefore, the required critical "knowledge" and "skills" (KSs) will be emphasized. However, some "abilities" (As) that could be practiced during self-escape training drills (e.g., the ability to speak loudly and clearly) are included, and other personal attributes (Os) (e.g., experience, motivation to learn, self-efficacy) that have been found to be associated with training and performance outcomes in general will be briefly discussed. While it is important to acknowledge the relationships between and among all the KSAOs relevant to self-escape, distinctions have been made so that the focus can be placed on the KSAs that are most malleable and amenable to training. Some of these relationships and distinctions are discussed further in the following sections of this chapter, but the task demands associated with most abilities will receive only cursory treatment within this report.

Scoping the Work

In order to ensure the comprehensive identification of all tasks critical to successful self-escape for all underground coal miners, NIOSH provided gOE/Aptima with a statement of work (SOW) detailing a specific set of criteria on which to base the formal task analysis. The SOW required the analysis of self-escape tasks across four self-escape roles (inby worker,[9] outby worker, responsible person [RP][10], and escape group leader [EGL][11]) and four emergency scenarios (fire, explosion, impoundment/gas or water inundation, and rock burst/roof fall). It was also required that the contractor secure the participation of a mining subject matter expert (SME) and at least two underground coal mines representing a large mine, a small mine, and two different mining methods (continuous and longwall). Appendix B contains a detailed description of the participating mines. In general, the formal task analysis was also bounded between (a) miners making the decision on their own or based on notification by coworkers or mine management of the need to escape, and (b) completed self-escape at the exit of an underground mine. However, researchers additionally included preparedness tasks (e.g., establishing situational awareness, ensuring a serviceable[12] SCSR is on one's belt) because SMEs identified a number of critical daily tasks that are necessary for effective emergency preparation. Ultimately, the identified self-escape tasks were organized into four categories: *general preparedness*, *orientation to and preparation for escape*, *meeting at designated gather space*, and *escape.*

Identifying and Prioritizing Critical Tasks

A preliminary task analysis (PTA) is required to generate a comprehensive list of all tasks that could be required to complete any given job (e.g., self-escape). Initial identification of tasks can be done in a number of ways, but in general, SMEs are individually interviewed or participate in focus groups facilitated by task analysts. Both methods were utilized during this phase of the work to identify the tasks that underground coal miners might need to effectively complete during the task of self-escape and prioritize them based on criticality and amenability to training and assessment activities [gOE/Aptima 2016a]. The protocol for the focus groups and the four emergency scenarios, and specification of the four worker roles for each are in Appendix C, and the initial mine leadership safety management interview guide can be found in Appendix D. A brief summary of the analysis and results is provided below and the full contractor report, "Emergency self-escape phase 2 report: Identify and categorize primary self-escape tasks," is available upon request from mining@cdc.gov.

Purpose of Identifying and Prioritizing Self-escape Tasks

In order to identify and prioritize initial self-escape tasks, task analysts had three goals:

1. To ensure that the designated self-escape roles and mine operations at the proposed mines converged with NIOSH-provided specifications, and to gain an initial understanding of the responsibilities of these roles during self-escape.

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[9] *Inby* and *outby* are mining terms that refer to opposite directions within the mine from one's current location. All locations deeper into the mine toward the working face are "inby" one's location in the mine, and all areas toward the mine entrance/egress and thus further from the working face are "outby."

[10] For each shift that miners work underground, mine operators are required by law to designate a *responsible person* to take charge during mine emergencies.

[11] Although not formally required by law, the section foreman is usually expected to serve as the *escape group leader* and may or may not also be the designated responsible person.

[12] Serviceable is defined by the manufacturer and may be different for different SCSR models.

2. To identify and categorize an exhaustive set of self-escape tasks required for all four self-escape roles across four emergency scenarios.
3. To prioritize self-escape tasks to establish a set of critical self-escape tasks for further analysis.

Methods and Materials

Participants

To confirm the relevance of the specified self-escape roles and determine the suitability of the participating mines for conducting the analysis, initial interviews (n = 6) as described in Appendix D were conducted by gOE/Aptima with personnel from a large mine and small mine. From the large mine, a mine foreman, assistant day shift manager, and safety manager participated; from the small mine, participants included the mine superintendent, president, and mine foreman. Thereafter, mine management was asked to identify mineworkers who met the criteria for participation in focus groups (Appendix C), which included a thorough understanding of the mine layout and operations; experience in the tasks, procedures, and technology required for self-escape; and at least five years of experience in underground coal mining.

Following the initial interviews, 11 participants from the two mine sites participated in the focus groups. From the large mine, volunteer participants were a longwall shearer operator, two belt cleaners (both also shift foremen), and a motorman (n = 4). From the small mine, volunteer participants were two beltmen, two mechanics (one outby), a supervisor, a roof bolter, and a surface/outby worker (n = 7). All met the study criteria for participation. In total, 17 SMEs participated in either the initial interviews or the PTA focus groups.

Lastly, one of the mines' safety directors and the contracted SME reviewed the identified tasks to determine which tasks would be further examined during the hierarchical and cognitive task analyses that followed.

Informed Consent

The project purpose and process were thoroughly explained to each interviewee and focus group participant. Each participant was provided an informed consent document approved by the NIOSH Institutional Review Board (IRB; Protocol #14-OMSHR-10XP). All participants were informed that their participation was voluntary and were given the opportunity to ask questions and/or withdraw their consent at any time, with no penalty. Participants provided their oral consent, and no one refused to participate in the research.

Semi-structured Interviews

Researchers from gOE/Aptima conducted initial interviews in above-ground facilities made available by mine management. Interview sessions followed a standardized process in accordance with the IRB-approved protocol. At least two researchers were present at all times, and both asked questions and recorded handwritten notes. To ensure confidentiality of the participants, recorded notes were assigned unique identification numbers rather than participant names.

Referencing the NIOSH-specified emergency scenarios and self-escape roles as described in Appendix C and in consultation with the subcontracted mining SME, gOE/Aptima researchers developed a number of questions that focused on four major areas: (1) self-escape processes and best practices; (2) greatest risk points; (3) training and preparation; and (4) ideas and suggestions. The questions were used to develop a semi-structured interview (Appendix D) to improve the understanding of self-escape processes and responsibilities by self-escape role. Individual interviews required approximately 1.5 hours of each participant's time.

Focus Groups

Researchers from gOE/Aptima conducted the focus group for each mine in an above-ground facility provided by management. The focus group started with position confirmation, where researchers worked with the participants to identify the possible positions at the mine as well as the general roles in self-escape. Next, gOE/Aptima researchers outlined the framework of the discussion by identifying the general phases of self-escape. Once the general framework was established, focus group participants were presented with one of the four NIOSH-provided emergency scenarios. To begin the process of developing a comprehensive list of self-escape tasks, participants were asked to identify all tasks that might be required, and by whom, to successfully navigate through each escape phase across all four escape scenarios, which allowed researchers to identify the greatest number of self-escape tasks. Researchers recorded all tasks in writing and asked participants for clarification as necessary. Focus group sessions required approximately 12 hours of each participant's time spread over multiple sessions. Each focus group lasted for approximately 2 hours.

Task Prioritization

After limited modification to reduce redundancy and increase clarity of task characterization between focus group sessions, gOE/Aptima researchers categorized the identified tasks by escape phase, escape role, and escape scenario for presentation to the SMEs in later focus group sessions. Defining a "critical" task as "one that without which the probability of self-escape could be seriously lowered" [gOE/Aptima 2016a p.16], these SMEs were asked to examine the list of tasks to determine criticality. Task "criticality" is a subjective judgment, and gOE/Aptima researchers worked with miners and the subcontracted mining SME and relied upon their own task analysis experience to derive criticality decisions. A final review of these judgments was made by the safety director from one of the participating mines.

Key Findings Based on Preliminary Task Analysis

The first major outcome of the PTA was the confirmation of the self-escape roles and the suitability of the participating mines for the formal task analysis. The four self-escape roles—inby worker, outby worker, RP, EGL—specified by NIOSH within the SOW were confirmed by SMEs to be appropriate for analysis and criticality determinations. Additionally, both participating mines were deemed appropriate for the analysis across roles and escape scenarios. Generally, the required tasks were similar across emergency scenarios and personnel from both the large and small mines. Some differences in state-specific regulations, responsibilities, seam height, modes of transportation, and potential distance to be traveled during escape were noted and would need to be covered in detail through mine-specific and task training as appropriate.

The second major outcome of the PTA was the development of a preliminary structure with which the KSAs of self-escape could be further deconstructed. After initial identification of 146 tasks relevant to at least one self-escape role across the four emergency scenarios, tasks were examined for criticality and categorized. Ultimately, the PTA resulted in a hierarchy of 21 critical task clusters (hereafter referred to as major self-escape “activities”), 37 general tasks (hereafter referred to as “competency areas”), and 75 subtasks, or KSAs, critical to at least one self-escape role. As shown in Table 4, critical KSAs were identified for all phases of self-escape as defined by the contractor, and the initial breakdown of critical KSAs by major self-escape activity is listed in Table 5. A detailed graphical example of these initial hierarchies is illustrated in Figure 5. The 75 critical KSAs retained for further analysis through HTA and CTA can be found in Appendix E. The contractor’s mining SME and a NIOSH panel reviewed the PTA results for final report acceptance prior to the start of the HTA and CTA.

Table 4. Number of initial tasks and critical tasks by escape phase

Self-escape Phase	Initial Tasks	Critical KSAs
General preparedness for self-escape	32	19
Orientation to and preparation for self-escape upon disaster event	47	25
Meeting at designated gathering space	24	9
Escape (moving away from gathering space)	43	22
Total	**146**	**75**

Table 5. Preliminary self-escape activities, competency areas, and critical KSAs

Major Self-escape Activities	Competency Areas	Critical KSAs
Accounting for personnel	2	3
Communicating nonverbally	1	5
Communicating verbally	4	5
Decision-making	3	7
Diagnosing	2	4
Directing and managing	2	4
Establishing and maintaining situational awareness	5	10
Firefighting	1	1
Leading	1	3
Moving	2	7
Operating communication technology	1	3
Post-mine exit activities	1	2
Supporting map usage	1	1
Treating injured miners	1	1
Using lifelines	1	2
Using mine maps	1	2
Using multigas detector	1	2
Using personal equipment	1	2
Using refuge alternatives	3	6
Using SCSRs	2	3
Using taglines/tetherlines	1	2
Total number of tasks selected for HTA	**37**	**75**

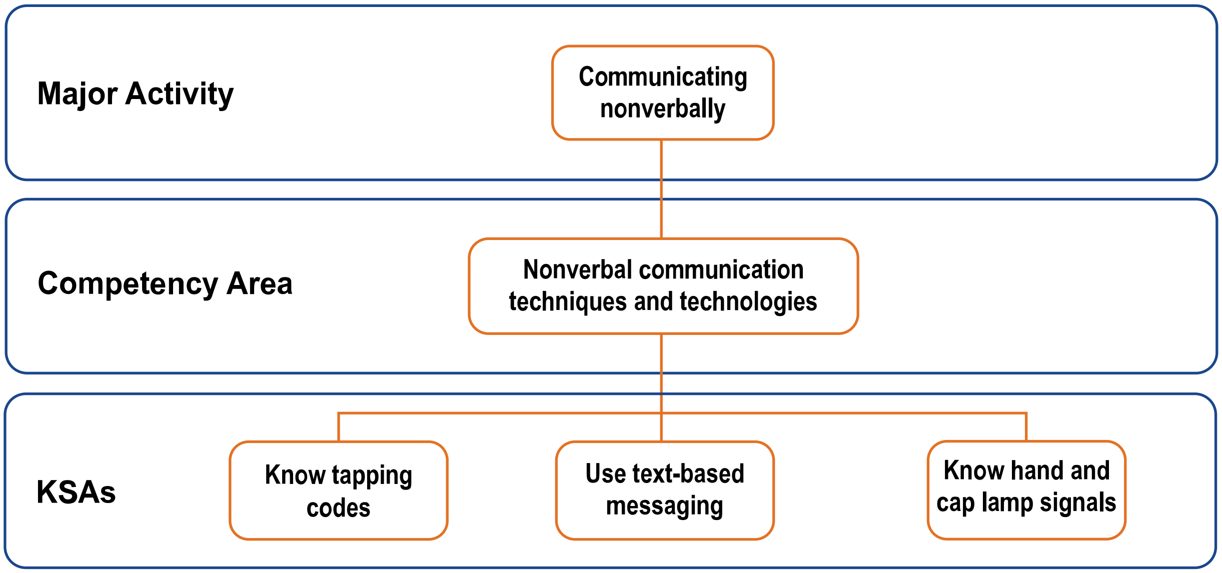

Figure 5. Example of one PTA task hierarchy showing one major self-escape activity, one required competency area, and critical subtasks (KSAs) used for HTA focus group discussions.

Detailing the Critical Tasks and Subtasks

Hierarchical task analysis (HTA) focuses on further dissection of prioritized tasks to arrive at a set of procedural steps or subtasks required for successful completion of each critical task. Traditionally, a task is viewed as something performed by a single person in a predictable sequence. For this analysis, gOE/Aptima researchers used a modified approach based on the unique nature of self-escape [gOE/Aptima 2017b]. Unlike many job tasks, in self-escape there is often a distribution of responsibility across roles (e.g., communicating with surface personnel, administering first aid). Sometimes, tasks may be required continuously or episodically throughout the process (e.g., maintaining situational awareness), while other tasks may be more discrete and have a clear procedure from beginning to end (e.g., donning an SCSR). A brief summary of the analysis and results is provided below and the full contractor report, "Emergency self-escape phase 3 report: Hierarchical task analysis and recommendations," is available upon request from mining@cdc.gov.

Purpose of Prioritizing Tasks for Training

To ensure a comprehensive list of all critical competency areas and KSAs and fully inform the development of appropriate training content and guidance to the industry, task analysts from gOE/Aptima had four goals:

1. To further deconstruct the competency areas to identify additional critical KSAs, subtasks, and/or required procedural steps.

2. To identify key decision points and other tasks with a substantial cognitive component for further analysis through CTA.
3. To identify innate abilities and other characteristics important to self-escape that could have implications for training.
4. To develop training recommendations based on results.

Methods and Materials

Participants

Four experienced miners (e.g., beltman, motorman, face worker, emergency medical technician [EMT], etc.) and a member of mine management from each mine (n = 10) participated in focus group discussions. The SME focus groups were designed to elicit further detail about specific KSAs and their criticality by self-escape role. At least one of the miners from each mine possessed current foreman certification and all had held a number of different mining positions throughout their careers.

Informed Consent

Researchers from gOE/Aptima conducted the focus groups in above-ground facilities provided by mine management. The project purpose and group process were thoroughly explained, and each participant was provided an Informed Consent document approved by the NIOSH Institutional Review Board (IRB; Protocol #14-OMSHR-10XP) and given the opportunity to ask questions and/or withdraw their participation at any time, without penalty. Participants provided their oral consent, and no one refused to participate in the research.

Focus Groups

Ranging between 3.5 and 6 hours a day over a two-day period, focus groups were formed at each mine. Participants were provided with handouts prepared by the gOE/Aptima research team based on the PTA results. Each handout contained the major activity, the competency area, and a list of associated KSAs. Figure 5 depicts an example handout of a PTA task hierarchy that the participants received. Participants reviewed each PTA task hierarchy and offered any other additional competency areas or KSAs required to successfully master each major activity, while researchers recorded handwritten notes.

Over the course of the focus groups, researchers collated all tasks, eliminated redundancies, edited for clarity, and assigned tasks to logical and distinct categories (e.g., communication techniques versus communication technologies) for review and approval by focus group participants and the subcontracted mining SME.

Key Findings Based on Hierarchical Task Analysis

Self-escape Preparedness Model

The first major outcome of the HTA was the development of the self-escape preparedness model. Used to frame the discussion of the findings, gOE/Aptima developed the model depicted in Figure 6 to illustrate the variables that were specifically considered in the subsequent development of training recommendations. At the center of the model are a number of human characteristics (knowledge, skills, abilities, and other individual factors such as motivation to learn, job experience/tenure, and age) that can relate to one another and to self-escape performance. To the left of the human characteristics are intervening variables (i.e., organizational safety climate, self-escape training, task design, and tools, technology, and equipment) that could be used to improve overall preparedness to self-escape.

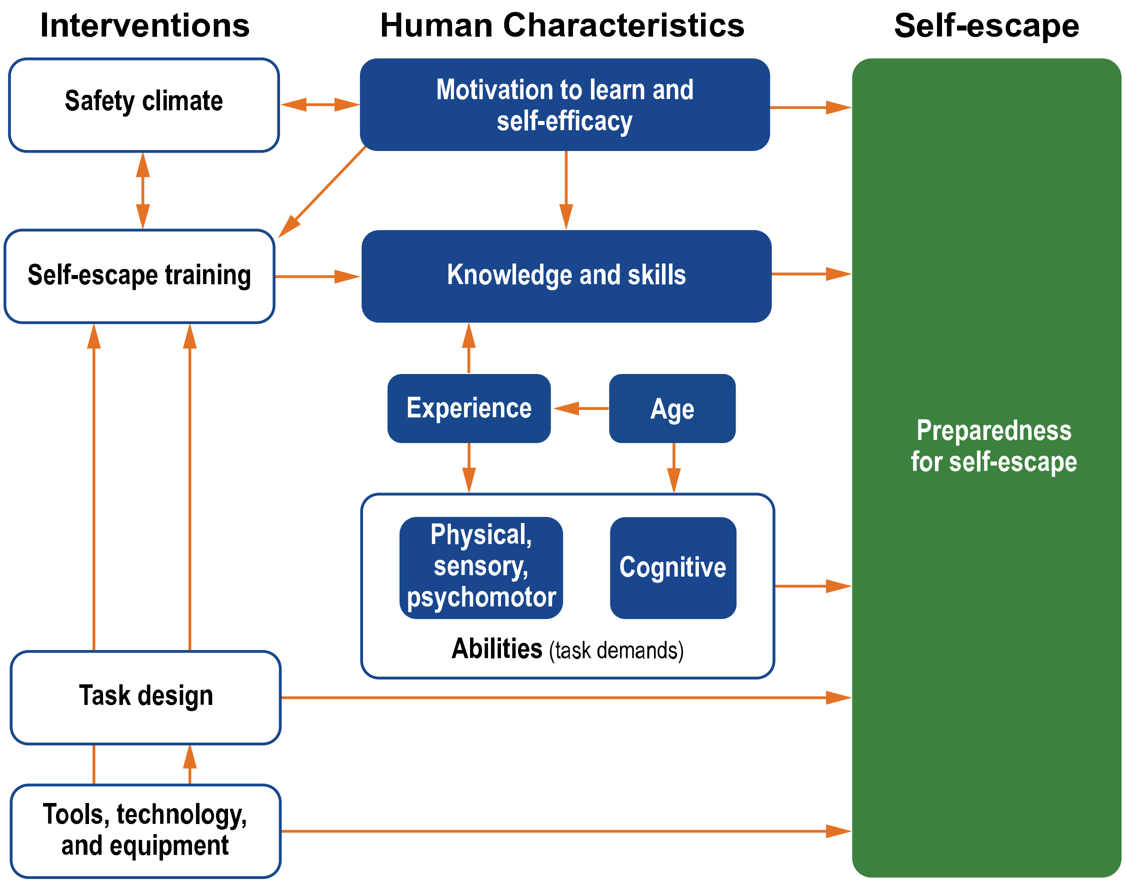

Figure 6. Self-escape preparedness model demonstrating the interplay between and among individual and organizational characteristics which have both direct and indirect relationships to mineworker preparedness. Adapted from gOE/Aptima [2017b].

The arrows within the model show both direct and indirect relationships between and among interventions, human characteristics, and self-escape preparedness. For example, "motivation to learn" and "experience" each have a direct effect on "knowledge and skills" and therefore an indirect effect on self-escape preparedness. "Task design" as well as "tools, technology, and equipment" (e.g., the tools, technologies, and equipment required by law) can have direct effects on "self-escape training", indirect effects on "organizational safety climate" as well as direct and indirect effects on preparedness for self-escape.

Acknowledging that there are a seemingly infinite number of variables or combinations of variables that could affect learning and retention, these variables were considered most germane to this effort and were selected based on existing literature supporting their relationships to learning and performance. Accordingly, NIOSH researchers added "self-efficacy" and "safety climate" to the model to demonstrate other established relationships. Furthermore, although all of these variables can contribute to performance outcomes, the results and subsequent recommendations focus on *self-escape training* for *knowledge, skills,* and those *abilities* (KSAs) deemed amenable to workplace interventions.

Identification of Critical KSAs

The second major outcome of the HTA was the confirmation or identification of all competency areas and associated critical KSAs. Researchers identified a total of 214 KSAs amenable to training and practice and critical to at least one self-escape role. With the exception of 22 tasks that were determined by gOE/Aptima task analysts to be specific to self-escape leadership roles, most tasks were identified as critical for all mineworkers in all self-escape roles. These 192 general tasks are the focus of the remainder of this technical report. These initial determinations can be found in Appendix F.

The majority of these subtasks are considered to be knowledge (e.g., "know locations of SCSR caches") or skills (e.g., "read and interpret mine and escapeway maps"), but several might also be considered abilities (e.g., "'go low' in smoke/explosion debris/difficult walking conditions"). Only the abilities considered critical to effective self-escape that could be covered or practiced during self-escape training (e.g., the ability to make decisions, the ability to speak loudly and clearly) are included. As recommended by NAS and the contractor, these results were later used by NIOSH researchers for expected proficiency-level consensus building activities and further role-specific task validation activities described in Chapters 3 and 4 of this report.

Abilities to Meet Task Demands

The third major outcome of the HTA was drawing the distinction between the identified 214 critical KSAs and other abilities that are less amenable to training but that still might be required to meet the demands of some self-escape tasks and thus be worthy of consideration.

"Task demands" are those demands placed upon the various dimensions of the human system (e.g., physical, mental, emotional) to successfully complete a given task. In the broadest sense, all required KSAs could be considered task demands. However, for this analysis, and consistent with standard job analysis approaches, knowledge and skills are generally considered separately from task demands. That is, knowledge and skills are learned, while abilities (e.g., manual dexterity) and other personal attributes and characteristics (e.g., job experience, general intelligence) are not learned but could also be important to or required for effective self-escape.

To identify the task demands relevant to self-escape, gOE/Aptima researchers utilized the U.S. Department of Labor's Occupational Information Network (O*NET) free online database of occupational categories and job descriptions [O*NET Resource Center 2016]. O*NET is widely used in research related to job characteristics [NRC 2010] and is useful for identifying specific job-related tasks and associated demands. It is widely acknowledged that, in general, the job tasks of underground coal miners can place substantial demands on the human system. Although O*NET does not currently include a profile for the "job" of self-escape, it does include profiles for specific mining positions (e.g., roof bolter, shuttle car operator). Many of the same task demands and abilities required for self-escape are seen in these job profiles (e.g., physical strength, manual dexterity), and it might be assumed that these demands are likely intensified during self-escape.

Although less mutable, and therefore not the focus of this effort, it is important for miners and mine safety and health professionals to be aware of broad abilities that are relevant to self-escape and defined by O*NET, as follows:

(1) *Cognitive*—abilities that influence the acquisition and application of knowledge in problem solving.

(2) *Psychomotor*—abilities that influence the capacity to manipulate and control objects.

(3) *Physical*—abilities that influence strength, endurance, flexibility, balance, and coordination.

(4) *Sensory*—abilities that influence visual, auditory and speech perception.

A more comprehensive breakdown of these abilities and relevant task demands can be found in Appendix G.

Additionally, it is also important to note that although some physical abilities, such as endurance, flexibility, and stamina, are all important for successful self-escape and more amenable to training than other innate abilities, these abilities might be better addressed through programs such as Total Worker Health® and other work-life balance efforts.

Other Characteristics

Similar to the distinction made for other abilities, the fourth major outcome of the HTA was the recognition of the importance of other characteristics apart from the critical KSAs. It is well established that some human characteristics, such as self-efficacy, motivation to learn, engagement, age, and experience, all relate to training outcomes but are less amenable to training. Specifically, human characteristics have been shown to be related to one another, to training effectiveness and performance [Christian et al. 2009; Denissen et al. 2007; Tziner et al. 2007], and to the supportiveness of the organizational safety climate [Parker et al. 2003; Tracey et al. 2001]. For example, it is widely accepted that levels of self-efficacy—belief in one's ability to successfully complete objectives—can predict performance [Bandura 1977, 1982; Gist 1987; Mathieu and Martineau 1993; Zimmerman 2000], and motivation to learn—the intensity and persistence of applied effort both during and after training [Tannenbaum and Yukl 1992]—is associated with measures of training effectiveness [Noe 1986; Noe and Schmitt 1986; Quiñones 1995].

Although some human characteristics (e.g., age and experience) cannot be overtly changed, their effects on training might still be mitigated through specific training interventions. Still other human characteristics, such as those relating to intellect (e.g., general intelligence) and personality (e.g., conscientiousness), also predict learning and transfer [Salas and Cannon-Bowers 2001], but they are less mutable and will not be addressed in this discussion. However, it is important to add that *transfer* of KSAs required for non-routine tasks (such as those associated with self-escape) is a complicated issue due to limited opportunities to use or practice such tasks [Bauerle et al. 2016a; Blume et al. 2010; Ford and Schmidt 2000]. This complexity should be considered when determining optimal frequency of and degree of realism required for some training activities (e.g., SCSR donning and switching/swapping).

Recommendations Based on Preliminary Task Analysis and Hierarchical Task Analysis

To begin to inform the *design* phase of ISD for self-escape training, recommendations based on the work accomplished during the PTA and HTA were generated by gOE/Aptima researchers. The section below presents the training recommendations proposed by gOE/Aptima researchers in the full contractor HTA report [gOE/Aptima 2017b]. These strategies address the human characteristics identified in the self-escape preparedness model (Figure 6) and the recommendations build upon or lead into results found in the contractor’s other related reports [gOE/Aptima 2016a,b; 2017a,c]. In some cases, NIOSH work relevant to the recommendations and published after the receipt of the contractor reports have been cited by the authors.

Motivation to Learn and Self-efficacy

Employing Learner-centered Training

Motivation to learn can partially be addressed through the improvement of the training type and design; namely, increasing the use of learner-centered training. Learner-centered training is where trainees are an active participant in training, making them more involved and engaged (e.g., via demonstration, hands-on practice, on-the-job training), such as in many of the knowledge and skills recommendations identified in the sections that follow. The two key features of learner-centered training are that the learners have significant control over their learning and that learning should be inductive (i.e., learners explore to infer the rules and principles) [Bell and Kozlowski 2009]. In learner-centered training, not only are trainees more engaged, but learner-centered training has also been found to be more effective than knowledge-centered (e.g., lecture-based) training because it can enhance trainee motivation and address individual differences [McCombs 2001; Gegenfurtner 2011]. It has also been shown to improve motivation in other industries such as pharmacy [Cheang 2009].

Ensuring Trainee Self-efficacy

When individuals have self-efficacy—believe themselves to be capable of high performance—they are more likely to work toward appropriate goals [Bandura 1986]. Therefore, it is important to design training that encourages these perceptions among trainees. For example, modeling and participation in realistic drills or exercises as a part of self-escape training has been shown to increase team efficacy [Hoebbel et al. 2015].

Enhancing Job Involvement

Employees with high job involvement are more motivated to learn and perform better in training and on the job [Kontoghiorghes 2004; Noe and Schmitt 1986]. Job involvement includes awareness of how an individual's job contributes to the organization as a whole and involvement in decision-making, as well as an organization's commitment to individuals. To enhance job involvement, mine management can communicate clearly to miners the ways in which management supports them and how the organization as a whole possesses values that are congruent with those of the workforce itself [Haas 2020; Haas et al. 2018; Rich et al. 2010].

Building Employee Trust

Research has indicated that training on the perception of risks and dangers tends to be more effective if the trainees trust their trainers as well as the organization as a whole [Siegrist and Cvetkovich 2000]. Trainers can emphasize their own expertise and the validity of the training content in order to foster trainee trust.

Knowledge and Skills

Empowering Miners to Communicate Perceived Risk before and during Self-escape

Since any miner may be the one who detects important events that either indicate the need to self-escape or provide important information during self-escape, miners should be encouraged to adopt the "see something, say something" mindset during training [McGuire et al. 2018]. Adoption of this mindset requires supervisor support and buy-in to distribute safety surveillance responsibilities across all workers. Ongoing NIOSH research has demonstrated that perceptions of supervisor support and communication, among other indicators, are predictive of individual safety performance [Haas 2020; Haas et al. 2017]. Therefore, training can emphasize individual responsibility to communicate.

Training Miners to Acknowledge Receipt of Critical Information

When critical information is communicated within the mine or between the mine workings and the surface, all parties should be able to indicate that the information was understood and received. This will reduce miscommunications and may involve repeating the information if time permits. Trainers may consider incorporating such tools as the Emergency Communications Triangle. This training tool is a 15-minute safety talk focused on the content of emergency warning messages [NIOSH 1999]. It presents a procedure, using mental cues that can be used by senders and receivers of emergency warnings, to ensure that critical information is communicated. The training materials also include graphics to be used during the talk and other references. Trainers should also consider ways to incorporate acknowledgment when responding nonverbally (e.g., "you indicated that all miners are accounted for and in your group; if that is correct, tap twice for "yes").

Training SCSR Use to Automaticity

Automaticity, which is acquired through practice and repetition, is the ability to perform actions correctly with little conscious thought. It is usually the result of learning, repetition, and practice and can reduce the cognitive load on escaping miners and minimize the sense of panic. Vaught, et al. [1993] found SCSR donning skills, specifically, degraded significantly after as little as 90 days following training. They recommended that “hands-on practice should be scheduled throughout the year,” and suggested that “training can be built into fire drills and other emergency preparedness routines” [p. 18]. Findings from that study were used, in part, to justify the MINER Act requirements for quarterly SCSR training. Trainers could take advantage of this mandated training to increase miners’ proficiency in SCSR use.

Expanding Expectations Training

Expectations training [Kowalski-Trakofler et al. 2008; NIOSH 2009] is used to create realistic expectations of escape group communication, coordination, movement speed, and other aspects of self-escape. Communications within an escape group are challenging, but proper expectations can help miners understand why certain communication KSAs (e.g., nonverbal communication techniques) are important. Similarly, moving in smoke, or moving through obstructions or an inundation could impede and slow a self-escape group. Developing appropriate expectations for travel speed and difficulty could support better self-escape performance. Presentation of facts, discussion of experiences, drills, and exercises, and debriefs could all be part of such expectations development.

Debriefing after Training Events, Simulations, and Drills

Debriefing has been shown to reliably increase performance [Tannenbaum and Cerasoli 2013]. Discussion can be stimulated by prompts such as: “How well did we work together during this event?”;“What problems did we encounter?”; “Did we have a clear idea of what to do at each stage of this event?”; “Were we well prepared by our training?”; “Were our communications effective?” Initial questions could be asked anonymously (e.g., on paper or via computer to yield more candid responses) and then discussed in a facilitated group.

Specific to mine self-escape training, NIOSH researchers Connor et al. [2016] described the value of debriefing after training events to identify gaps in prior learning and emphasized the importance of allowing trainees to make choices and experience consequences during simulated trainings for later review of actions taken, strategies used, and lessons learned. Citing previous research and meta-analyses [DeGrosky and Parry 2011; Johnson and Gonzalez 2008; Tannenbaum and Cerasoli 2013], Bauerle et al. [2016b] also describe the benefits of effective post-training review and feedback for trainees using computer-based simulation data generated during virtual exercises. These NIOSH researchers identified several key features of successful debriefs, such as data visualization of multiple information sources, flexibility, trainee interaction, contextualization of trainee actions and behavior, and the identification of performance gaps for targeted training efforts. Specific debrief opportunities, features, and suggestions related to the use of NIOSH’s Mine Emergency Escape Training (MEET) simulation are also discussed in the two papers [Bauerle et al. 2016b; Connor et al. 2016].

Abilities and Task Demands

Reviewing the Most Common Physical Demands across Tasks

Even though some aspects of preparedness may be difficult to attain (e.g., physical strength, endurance), it is possible that some miners would undertake actions to boost health and physical capabilities after this type of discussion. Regular reminders about maintaining general wellness and sensory abilities (e.g., protecting hearing, correcting vision) could prove to be beneficial to overall fitness and health as well as effective emergency response. While some abilities might be better addressed through programs such as Total Worker Health® and other work-life balance efforts, a number of free, convenient, and confidential health screenings for work-related illness and injury are often available through local resources as well as the NIOSH Enhanced Coal Workers' Health Surveillance Program (ECWHSP). This program provides miners with an easy way to check health status and radiographic evidence about their lung function.

Other Characteristics

*Augmenting NIOSH Age Awareness Training with O*NET Profiling*

It is important to appreciate the changes that occur with age as well as understand what can be done to reduce the risk of injury to help protect all workers. NIOSH Age Awareness Training for Miners [NIOSH 2008] supports these goals and can be enhanced by using O*NET to identify self-escape abilities susceptible to early age-related decline. Researchers have used O*NET abilities to profile various jobs to reveal their tendency to become more difficult over time due to aging [e.g., Belbase et al. 2017]. Naturally, this research indicates that manual blue-collar jobs, such as construction, are most susceptible to age-related decline. This can be similarly accomplished for self-escape by identifying important abilities based on the number of tasks to which they relate and their subjectivity to age-related decline. For example, flexibility, balance, and coordination abilities are demanded in at least five tasks each and are all susceptible to age-related decline [Belbase et al. 2015].

Assessing Generational Differences in Self-escape Attitudes

During interviews by gOE/Aptima researchers, it was sometimes mentioned that younger miners felt less concern about self-escape than older, more experienced miners. Whether this is true among the population of underground coal miners is an important research question. If there are differences in individual factors such as risk perception or risk tolerance) across age and/or experience variables, it is important to understand the direction of these relationships. If such differences do exist, it must be determined whether they are large and systemic enough that addressing them in training would be beneficial. For example, Haas et al. [2019] found risk tolerance to be a significant predictor of self-reported compliant and proactive safety behaviors among mineworkers in the U.S. and further research examining differences in the strength of these and other relationships across age and experience variables could have important implications for training mineworkers of different generations and/or levels of experience.

Ensuring Crews Have a Mix of Experience

Job experience and tenure can have both a positive and negative effect on abilities. Typically, experience and tenure have a positive effect on cognitive abilities [e.g., Hambrick and Engle 2002] but a negative effect on physical abilities [Margolis 2010]. As workers gain experience and expertise, they are better at decision-making and have improved situational awareness [Hutton and Klein, 1999]. On the other hand, tenure can lead to both acute and cumulative physical (e.g., lower back) and sensory (e.g., hearing loss) injuries to underground miners. According to some research [e.g., Schmidt et al. 1986], tenure has a strong and direct relationship between experience and job knowledge and a smaller effect on performance capabilities. Ensuring that crews have a good mix of experience levels is likely to provide the escape group with the necessary KSAO's.

Discussion of Preliminary Task Analysis and Hierarchical Task Analysis

Recognizing that a systematic analysis of the activities that comprise self-escape from the perspective of mineworkers themselves had never been done, the NAS recommended that NIOSH conduct or sponsor a formal task analysis to “crisply” define the concept of self-escape. Defining the task of self-escape is critical because, once defined, focus can shift to the identification of deficiencies in the self-escape system which could be targeted through improved training and preparation.

However, the PTA and HTA were not without limitations. The small number (one small and one large) and geographic location of the mines that participated in the task analyses could limit the generalizability of the results to all underground coal mines. With that being said, in most cases, it is sufficient to assume that the results of task analyses have a great degree of content validity based on the careful method by which they were constructed [gOE/Aptima 2017b; Lawshe 1975] and that critical self-escape tasks are likely to be similar across emergency scenarios and personnel in all underground coal mines. Despite these similarities, differences in mine characteristics, state-specific regulations, and mine-specific policies and procedures should be considered when developing mine-specific training flows. For example, the physical task demands of almost all of the tasks increase in a mine with a lower seam height. This is also reflected in the regulations, such as the fact that lower seam mines are required to have SCRSs located closer together because miners on average will take longer to crawl a distance and may use more oxygen [30 CFR § 75.1714-4].

Despite these limitations, the PTA and HTA described in this chapter provide a basis for understanding and exploring what is necessary to successfully and effectively escape from an underground mine. As expected, the number of critical self-escape tasks and subtasks (KSAs) resulting from the detailed task analysis was greater than the higher-level competencies identified in previous work [e.g., Commonwealth of Australia 2020; NRC 2013; Peters and Kosmoski 2013]. These detailed findings served as the foundation for further research and provided the content for further inquiry, examination, and validation of results through SME consensus building exercises. This solid, hierarchical foundation framed within the context of the gOE/Aptima model of self-escape preparedness, depicted in Figure 6, was critical to the success of later research activities described in the chapters that follow. These contract deliverables and resulting recommendations can also now aid mine safety and health researchers and other professionals in the development of specific self-escape training flows, training delivery, and continuous evaluation efforts.

Chapter 3: Identifying Effective Training Strategies and Existing Gaps

This chapter details how NIOSH contracted with gOE/Aptima to conduct a comprehensive review of the literature to identify training and assessment strategies applicable to self-escape. Also described is NIOSH's administration of a self-escape competency survey to identify existing gaps in self-escape KSA's. This work took place after the preliminary task analysis (PTA), and concurrent with the hierarchical task analysis (HTA) described in Chapter 2. Each of these efforts was based on the National Academy of Sciences (NAS) report recommendation 7B, summarized as follows:

> **Recommendation 7B**. Based on the task analysis activities (detailed in Chapter 2), NIOSH should identify training activities best suited for preparing mineworkers to self-escape effectively and identify existing gaps within the mining industry.

Specifically, the PTA of critical self-escape competency requirements as described in Chapter 2 enabled gOE/Aptima researchers to further the training needs analysis (TNA). The PTA also allowed NIOSH to develop a survey to establish a baseline measure of the existing gaps in self-escape preparedness from the mineworkers' perspectives, which also allowed for the consideration of best practices for developing and implementing targeted training content and delivery.

Exploring the Literature to Develop Training and Assessment Strategies

Within the task analysis scope of work was the requirement for gOE/Aptima to identify training and assessment strategies for use in the design of an evidence-based competency framework for self-escape training. This requirement was expanded to include a comprehensive review of the literature to identify best practices in competency-based training in the underground mining community as well as in other high-risk industries. To that end, an exploratory review of current learning strategies, theories, and practices was conducted by gOE/Aptima [2016b] to develop strategies for training and assessing miners' competency in non-routine yet critical tasks such as those identified in the PTA. A brief summary of this effort and its results are provided here, and the full report, "Improving self-escape from underground coal mines training initiative: Training and assessment strategy recommendations," is available upon request from mining@cdc.gov.

Purpose

To develop guidance for self-escape training and assessment relevant to underground coal mining, gOE/Aptima researchers had two goals:

1. To review the existing literature to identify learning strategies, theories, and practices related to training and assessment in high-risk industries.
2. To develop assessment strategies, guidelines, and/or principles for training emergency self-escape within the mining industry.

Literature Review

Researchers from gOE/Aptima relied on their expertise in training research and development and task analysis and their experience working with several mining SMEs during the early phases of the formal task analysis to develop an understanding of the potential constraints and limitations inherent in training for low-probability/high-severity events in the mining industry. With this general understanding, researchers conducted a review of the literature to identify factors to be considered while developing self-escape training flows.

A number of topics that reflect well-established learning theory as well as emerging trends in approaching training and assessment in high-risk industries were identified and explored. The relevance and effectiveness of the following topics were examined to assess needs related to advancing self-escape training in the mining industry: (1) training needs analysis; (2) skill decay; (3) adult learners; (4) individual factors; (5) team training; (6) decision-making under stress; (7) leadership; (8) situational awareness; (9) continuous learning; (10) fidelity; and (11) organizational factors.

Recent and emerging trends in learning theory and training strategies were examined within the context of self-escape to identify best practices for training improvement. While considering the constraints and limitations of training and assessing nonroutine KSAs within the mining industry, gOE/Aptima researchers explored relevant training strategy topics and their implications for self-escape training. These findings have been updated by the authors to include recent NIOSH research and are briefly summarized in Table 6.

Table 6. Training strategy topics relevant to self-escape training

Training Strategy	Relevance to Self-escape Training
Training needs analysis	A thorough training needs analysis (TNA) to define training content is a critical first step in developing an effective training program [Ostroff and Ford 1989]. Not all mines may have the capacity to conduct systematic TNAs themselves, so industry-wide efforts to identify common competency requirements and gaps are required.
Skill decay	Skills can decay over time—up to 90% if they are not practiced [Arthur et al. 1998]. Some skills decay more quickly than others will, especially those that require a response to a quickly changing situation [Bennett et al. 2012] such as a mine emergency.
Adult learners	A number of age-related factors can affect the efficacy of training [Colquitt et al. 2000]. NIOSH [2002] researchers reviewed implications of adult learning for training miners and suggested that training for non-routine skills can be made more effective using principles of adult learning. As an example, these researchers found that experience-based, task-centered training was particularly effective for self-contained self-rescuer (SCSR) training and suggested that such principles likely apply to many aspects of self-escape training.

Training Strategy	Relevance to Self-escape Training
Individual factors	Individuals approach training with varying degrees of characteristics such as self-efficacy and motivation to learn, both of which have been shown to positively relate to training outcomes [Mathieu et al. 1992; Salas et al. 2012]. Research suggests that emergency response training can provide attainable challenges and reinforcements as well as be clearly relevant and engaging [Hoebbel et al. 2015].
Team training	Miners involved in self-escape share a common goal and often need to work with one another during the escape. However, the “escape team” is typically formed on an “ad hoc” basis, where members may or may not be familiar with each other. This may be problematic when teams are made up of individuals who lack a history of working together, such as “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” [NRC 2013, p. 50]. It has been suggested that interventions designed to build non-emergency group cohesion among crew members and boost the leadership capabilities of both likely and emergent escape group leaders may improve ad hoc self-escape group performance [Bauerle 2016]. It may be beneficial for to miners to engage in problem-solving, role-playing, and other team training activities both with their own crew and with other miners with whom they are less familiar.
Decision-making under stress	A large body of research speaks to the degrading effect stress has on decision-making. However, decision-making under stress can be explicitly taught in training [Cannon-Bowers and Salas 1998; David 1997]. Decision-making training can be specialized for both the type of decision and the person most likely to face the decision [Ross et al. 2004; Thunholm 2005], whether it be those underground, on the surface, in leadership positions, or rank-and-file miners [MSTTC 2006].
Self-escape leadership	Research by NIOSH [2000] found the quality of leadership varied greatly when miners were required to escape underground mine fires. Galvin [2008] stresses that all persons going underground need to have some form of leadership training in the event that the person formally designated as a leader (e.g., foreman, escape group leader) is unable to effectively act as a leader. For example, when faced with a dynamic and dangerous situation, a designated leader could “freeze” leaving the opportunity for another leader to emerge.

Training Strategy	Relevance to Self-escape Training
Situational awareness	In self-escape, situational awareness (SA) can be considered the ability to identify, process, and comprehend the critical elements of information surrounding the event. Individual and team training can address KSAs required to maintain SA, clarify expectations, remove barriers to SA, and help miners know what to do when SA is lost. Classroom training, active scenarios, and cross-training are beneficial related activities. Gaba and Howard [1995] suggest that some aspects of SA can be specifically taught including the use of checklists, allocation of attention, multi-tasking, and pattern recognition.
Continuous learning	Research in organizational settings has shown that less than 10% of competency acquisition occurs through formal training [Flynn et al. 2006; Tannenbaum 1997]. Hoebbel et al. [2018], Kingsley-Westerman and Peters [2011], and Radomsky et al. [2009] all stress the importance of informal training activities that can be held in a locker room, shop, at pre-shift, or even during shifts. "Spot checks" can be regularly conducted to informally quiz miners on the mine layout, situational awareness, lifeline symbols, etc.
Fidelity	Research demonstrates mixed results when it comes to the relationship between training fidelity (the accurate representation of the processes required for a given task) and training effectiveness [Maitlis and Sonenshein 2010; Norman et al. 2012]. Both low-fidelity and high-fidelity simulations have been shown to be effective in promoting learning, and safety trainers can employ the level of fidelity that best fits the needs of the situation.
Organizational factors	Research suggests that workers who perceive greater organizational support for safety ("safety climate") and who have greater levels of organizational commitment are likely to enter training with higher levels of self-efficacy [Tracey et al. 2001]. A meta-analysis by Christian et al. [2009] found that group-level perceptions of the supportiveness of the organizational safety climate were strongly predictive of safety performance, which was confirmed by Haas et al. [NIOSH 2020].

Recommendations Based on Identification of Training Strategies

Based on the literature and other document reviews, gOE/Aptima [2016b] developed a list of recommended strategies to improve self-escape training. These are presented in six categories below: (1) clarifying training needs; (2) communication about training; (3) timing of training; (4) training design and methods; (5) training assessment; and (6) specific self-escape suggestions.

Clarifying Training Needs

In order to better clarify the training needs, mine safety and health professionals should consider using the following approach:

- Conduct a TNA to identify or confirm training needs.
- Utilize the ISD methodology to develop training that enhances the acquisition of miners' knowledge and skills.
- Conduct research to better understand skill decay and identify empirically based refresher targets.

Communicating about Training

In order to better communicate about training, trainers should consider the following training strategies:

- To increase trainee self-efficacy and motivation to learn, describe what the training will involve and why it is important prior to beginning training.
- Develop and provide advance organizers (e.g., outlines, checklists) at the beginning of training that describe what the training will involve.
- Communicate the organization's commitment to and support for ensuring the safety of miners.

Timing of Training

In order to increase the effectiveness of training, trainers should consider the following timing:

- Conduct unannounced training and/or "opportunistic" drills that occur at varying times and include "surprises."
- Train miners when they are relatively unoccupied to enhance retention.
- Where possible, have routine events double as opportunities for cross-training events (e.g., allow non-maintenance workers to shut down the belt for normal maintenance, rotate the operation of man-trips).

Training Design and Methods

In order to increase the effectiveness of training, trainers should consider the following designs and methods:

- Train miners on the distinction between information that can be accessed (e.g., the mine map) versus information that needs to be known (e.g., the location of the mine map).
- Design curricula and activities ("training flows") that deliver content using a broad range of methods (e.g., lecture, videos, hands-on practice, role plays, and computer-based modules) that include key decision points and actionable feedback.
- Ensure that the training includes ample challenge, but structure it so that trainees leave with a sense of efficacy at the end of training.
- If time allows during training, ensure each trainee can properly demonstrate or explain a procedure or topic before moving to the next training area. If necessary, utilize task-specific experts within the class (e.g., emergency medical technicians (EMTs), mine rescue team members, etc.) to assist in assessing performance.

- Adopt strategies to train miners to work together as a team (e.g., shared leadership, shared understanding) in the event of an emergency, rather than relying on the existing hierarchy.
- Provide opportunities for miners to communicate about how they will work together during an emergency to establish or confirm their roles, responsibilities, objectives, and priorities.
- Use part-task trainers to help miners learn the cognitive aspects of a task (e.g., the sequencing of parts during assembly) so trainees can focus future training time on practicing physical skills to develop automaticity.
- Provide some leadership training to all miners and cross-train rank-and-file miners in backup behaviors (e.g., occasionally place non-leader individuals in a leadership position during drills).
- Structure training so that decisions need to be made quickly and under some sense of pressure (e.g., time compression) and discuss potential tradeoffs and limitations of making quick decisions.
- Use realistic training experiences to help miners accurately assess a situation and gain an understanding of how they might respond emotionally.
- Develop training that involves reduced situational awareness or that challenges miners to gain/regain situational awareness to enhance psychological fidelity.
- Employ the type and level of fidelity in training that best fits the needs of the situation; explore opportunities to utilize lower levels of fidelity (e.g., chalk lines, role playing, "What if?" scenarios) when appropriate.
- Determine which type of fidelity is most important for a given situation—physical or psychological—and build training to meet that need (e.g., use "hands-on" training for SCSRs and other equipment and incorporate realistic scenarios into decision-making exercises.)
- Include surprises, equipment problems, etc., during annual refresher training to see how trainees respond.

Training Assessment

In order to ensure effective training assessment, trainers should consider the following:

- Periodically assess miners' KSAs through verbal or written quizzes during pre-shift or "spot checks" throughout the workday.
- Develop mechanisms to evaluate training at the team level (e.g., during quarterly escapeway drills).
- Conduct team debriefs following training events to clarify and confirm understanding.

Self-escape Specific Suggestions

In order to improve specific aspects of self-escape training, trainers should consider the following training approaches:

- Communicate the organization's commitment to and support for ensuring miners' readiness to self-escape.
- Generate potential self-escape options based on given situational constraints to enable miners to focus on selecting the best option when under stress.

- Practice donning and switching/swapping SCSRs often enough so that the physical task becomes automatic, leaving the miner with the mental capacity to focus on other information and response decision points.
- Provide responsible persons (RPs) with “cue cards” of scenarios and prepare them to conduct “spot checks” throughout work-shifts by asking questions such as: “If X happened right now, what would we do?”

Identifying Existing Gaps in Perceived Self-escape Competency among Mineworkers

As previously described, significant efforts to improve mine emergency response have been made since the passing of the MINER Act in 2006. However, it is difficult to know with any certainty whether these efforts have been effective. Additionally, the level of workforce preparedness remains difficult to ascertain. By contrast, many of the structural and technological advancements (e.g., location of lifelines, placement of SCSR caches, and redundant two-way communication systems) are observable, measurable, and have likely contributed to the improved post-accident survivability of underground mineworkers.

Industry consensus that deficiencies in competence in critical tasks required for effective self-escape exist is based largely on anecdotal evidence and stakeholder conjecture. That is, absent the opportunity to directly measure mineworker self-escape competency, researchers and practitioners have been left to speculate about the effectiveness of efforts aimed at improvement. Therefore, to aid in the identification and prioritization of existing self-escape competency gaps and to contribute to the understanding of actual miner capabilities, NIOSH researchers developed a survey to establish a gross baseline measure of the existing gaps in self-escape preparedness from the perspective of the mineworkers themselves. This survey effort was based on NAS Recommendation 7B as well as the recommendation from gOE/Aptima to clarify training needs [2016a, 2016b].

Purpose

To effectively identify and prioritize gaps to advance self-escape training and assessment, NIOSH researchers had three goals:

1. To quantify the level of perceived competence in critical self-escape knowledge, skills, and abilities (KSAs) among a sample of underground coal miners.
2. To provide actionable, mine-specific feedback to participating mines.
3. To characterize mineworkers’ perceptions of their own competence in self-escape KSAs and their organization’s commitment to health and safety.

Survey Development

The NIOSH-developed survey included 48 items designed to characterize the study sample, to gain a broad sense of worker perceptions as they relate to current organizational and individual efforts toward enhancing self-escape preparedness, and to quantify perceived competence in critical self-escape competency areas. A copy of the survey is available in Appendix H.

Individual and Organizational Characteristics

Fifteen survey questions captured demographic data including age, time in mining, time in job, time in current mine, background related to leadership experience, and specialized emergency response training or experience. Additionally, three questions related to miners' perceptions of the value placed on safety and health training ("training priority"), the realism of the self-escape training offered by their mine ("training realism"), and the level of importance the mineworkers place on their own self-escape preparedness ("individual motivation"). On a six-point Likert scale, participants were asked to indicate their level of agreement (from "strongly disagree" to "strongly agree") with the following statements:

1. Health and safety training is a priority here.
2. My mine's escape training is usually realistic and "hands-on."
3. It is important to put in extra effort toward improving my mine's ability to respond to an emergency.

Self-escape Confidence

Given the aforementioned difficulties of directly assessing competence in the KSAs required for non-routine tasks in dangerous and dynamic situations, it was necessary for NIOSH researchers to develop an instrument that could readily identify and quantify broad gaps in self-escape competency among underground miners. Previous research suggests that when competence is difficult or impossible to measure, "self-efficacy," or self-reported confidence in one's ability to perform a task, can serve as a reliable predictor of performance, particularly in very specific task domains [Bandura 2006; Pajares 1996] such as mine self-escape. In keeping with social cognitive theory [Bandura 1986], researchers often assess self-efficacy by asking individuals to report their level of confidence in their capability to "succeed" in accomplishing a task [Pajares 1997]. Therefore, in this study, mineworkers' self-reported confidence in their ability to properly demonstrate or explain critical self-escape tasks was used to quantify levels of perceived competence.

Survey items were derived from multiple sources [e.g., NIOSH 2015a; NRC 2013; Peters and Kosmoski 2013] and from results from the PTA [gOE/Aptima 2016a]. After items were reviewed by NIOSH SMEs, a final list of 29 items was selected for inclusion. These 29 items cover broad competency areas that all underground coal miners, regardless of self-escape role, should be able to confidently demonstrate or explain. Based on participant feedback about its clarity and appropriateness, item #26 (mineworker confidence in ability to correctly explain the mine's atmospheric monitoring system) was eliminated from the final analysis.

Methods and Materials

To maximize participation and reduce burden, convenience sampling was used to recruit volunteer mine sites and individual miners. The NIOSH Human Research Protection Program (HRPP) determined that this research activity (NIOSH Protocol 16-PMRD-01XM) was exempt from IRB review under 45 CFR 46.101(b)(2), and the activity was approved by the OMB (Control No. 0920-1135). Upon receiving the necessary approvals, NIOSH researchers used existing contacts, mining conferences, and other stakeholder interactions to invite underground coal mine operations across the U.S. to participate in the survey.

Participants

Eight hundred and ninety-five miners from eight underground coal mines volunteered to participate in this study ($n = 895$). The respondents consisted of rank-and-file miners (hourly workers with no formal self-escape leadership training; $n = 589$), miners in self-escape leadership positions (including all workers trained for the role of responsible person (RP); $n = 284$), contractors ($n = 15$), and a small number of unclassified individuals ($n = 7$). All participant sites were underground bituminous operations located in the Appalachian Basin in the eastern U.S.

Informed Consent

NIOSH research staff visited each participating mine site to provide volunteer mineworkers with a paper-and-pencil survey and to describe the informed consent process and answer any questions. Mineworkers were informed that participation in the survey research was voluntary and confidential, that individual results would not be shared with employers or anyone outside the research project, and that their consent to participate could be withdrawn at any time with no penalty. Oral consent was obtained for those who volunteered to complete the surveys. Refusal to participate was not recorded but was believed to be minimal based on the number of workers assigned to each shift and the number of surveys collected.

Survey Administration

NIOSH researchers administered the surveys in above-ground facilities either during pre-shift meetings or during scheduled training activities. The paper-and-pencil survey took approximately 10 minutes to complete. NIOSH researchers visited each site for the administration and collection of data in an effort to maximize the anonymity of individual responses.

Analysis

The 28-item self-escape confidence scale demonstrated high internal consistency with a Cronbach's alpha of $\alpha = .96$, which suggests it is a reliable measure of the "construct" of self-escape confidence. Exploratory factor analysis did not reveal any underlying constructs within the scale.

Analyses of survey data included descriptive, parametric, and non-parametric statistical methods where necessary. NIOSH researchers explored participants' individual characteristics, organizational perceptions, and confidence in their own self-escape KSAs. All three areas were examined across the whole sample and as a comparison between rank-and-file mineworkers and self-escape leadership. Descriptive statistics and frequency distributions characterizing the study sample are presented first, followed by a presentation of participants perceived competence in critical self-escape KSAs.

Key Findings Based on Self-escape Competency Survey

The self-escape competency survey highlighted outcomes in three major areas. As a result of the survey, NIOSH researchers were able to measure and characterize differences in individual factors, organizational perceptions, and levels of self-escape confidence between rank-and-file mineworkers and mineworkers in self-escape leadership roles. These results allowed for the identification of potential gaps in existing self-escape training as well as discrepancies between rank-and-file mineworkers' and self-escape leadership's confidence in their own ability to self-escape. The key findings are presented by each major area in the sections that follow.

Individual Characteristics

In general, the demographic makeup of participants in the self-escape competency survey were similar to national estimates of the underground coal workforce. As last estimated in 2008, U.S. coal mining employees (surface and underground operations) were 96% male with an average of 16 years of mining experience and 17% had post-high-school education [NIOSH 2012]. Comparatively, among this survey sample of 895 mineworkers:

- 99% of all respondents were male.
- 59% of all respondents have been in the mining industry between 6 and 15 years.
- 32% of all respondents reported a post-high-school education.
- 66% of all respondents reported being "multi-generation" mineworkers (i.e., their parents or grandparents were miners).

Although it is uncertain to what extent a convenience sample is representative of the population, the similarity to the national descriptives of the underground coal mining workforce suggests that the trends identified within this data may be more widely applicable across the industry. However, as indicated above, it is important to note that this sample was more educated than the general coal mineworker population, with almost double the percentage of respondents reporting a post-high school education. Appendix I shows the frequency distributions of all background and experience responses for the total sample and each subset of data (rank-and-file miners versus self-escape leadership).

Significant differences in the distributions of age, primary workgroup, time in current job, time in the mining industry, education level, general work schedule, primary work location, and the percentage of the working day spent underground were found between self-escape leadership and rank-and-file miners. Compared to self-escape leadership, rank-and-file miners tended to be:

- Younger
- More likely to work in production
- Less experienced in their current job
- Less experienced in the mining industry
- Less likely to hold a degree beyond high school
- More likely to have a shiftwork schedule
- More likely to work at the face or outby
- More likely to spend 100% of their workday underground

With regard to specific training and experience, the data also indicated:

- A much larger percentage of self-escape leadership (63%) reported some specialized emergency response training or experience compared to 34% of rank-and-file mineworkers.
- One hundred and forty-seven (147) mineworkers reported currently holding the role of the responsible person (RP), 66% of whom were hourly workers and the rest were salaried.

- Seventy-seven (53%) of the RPs indicated the working face as their primary work location and only 10 (7%) reported working primarily on the surface (e.g., operations center, hoist).

It is important to note that a majority of the hourly workers reporting current RP status likely received RP training to serve in a back-up or support role in the event of an emergency and could be considered part of what has been informally termed as the “responsible person team” [NRC 2013, p. 108]. Although not mandated by law, data from all eight mines revealed a purposeful practice of cross-training hourly workers in the role of RP, which was confirmed by NIOSH researchers during subsequent mine-specific research briefings. Ongoing NIOSH research is further examining how this role is being operationalized within the industry with a focus on more clearly characterizing the various roles and responsibilities of the “RP Team” and its interactions with other components of the mine emergency management system. Frequency distributions for specialized experience responses across subsets can be found in Appendix I, Table I-2.

Organizational Perceptions

Overall, participants in the self-escape competency survey reported that health and safety training is a priority, realistic training is provided, and they felt motivated to prepare for an emergency. As indicated by the levels of agreement with the self-escape training and preparedness value statements listed in Table 7 below, most of the respondents reported that they “agree” or “strongly agree” with all of the statements. This result suggests that mine sites within this sample have developed a positive organizational culture supportive of mineworker safety and health. This is often seen in convenience sampling where organizational support for health and safety is apparent by virtue of the organization’s willingness to participate in the research. The self-selection of both mines and mineworkers often precludes wide variability in employee perceptions on measures such as these.

However, the data also identifies differences between rank-and-file mineworkers and self-escape leadership. Table 7 shows that a larger proportion of self-escape leadership personnel agreed or strongly agreed with all three self-escape training and preparedness value statements than did rank-and-file miners, with a significant difference in levels of agreement for the statement, “health and safety training is a priority here.” These trends are often seen in mine safety and health climate data [NIOSH 2020] and present interesting lines of inquiry for researchers and important considerations for health and safety practitioners. A full comparison of the distribution of responses between rank-and-file miners and self-escape leadership can be found in Appendix I Table I-3.

Table 7. Percent who 'agree' or 'strongly agree' with self-escape training and preparedness value statements

Value Statements	Rank-and-file (n=589)	Self-escape leadership (n=284)
Health and safety training is a priority here (training priority)	77*	86*
My mine's escape training is usually realistic and "hands-on" (training realism)	65	70
It is important to put in extra effort toward improving my mine's ability to respond to an emergency (individual motivation)	83	86

*Results significant at the p<0.05 level based on Pearson chi-square tests

Self-escape Confidence

NIOSH researchers characterized levels of mineworkers' self-escape confidence in a number of ways. This was done to broadly characterize gaps in self-escape KSAs and to examine meaningful differences between rank-and-file and self-escape leadership. Self-escape confidence was reported as per participants' average self-escape confidence, levels of high and full confidence by KSA, and differences between rank-and-file and self-escape leadership.

Overall, as depicted in the box and whisker plot (Figure 7), the distributions of the self-escape confidence responses were highly and negatively skewed for both rank-and-file miners and self-escape leadership, with ranges of 42.50%–100% ($\bar{x}$ = 90.37%, SD=0.94) and 47.14%–100% ($\bar{x}$=93.05%, SD=0.85), respectively. Although both groups, on average, reported high confidence in their ability to demonstrate or explain most self-escape KSAs, rank-and-file mineworkers reported lower average confidence than mineworkers in self-escape leadership positions, with statistically significant differences in 20 of the 28 items. The average percent confidence for all self-escape items is detailed for each subsample in Appendix I Table I-4.

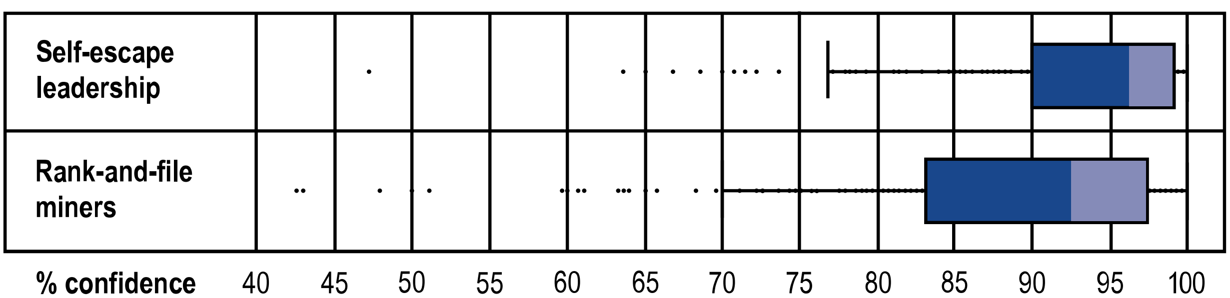

Figure 7. Box and whisker plot of average self-escape confidence for rank-and-file miners and self-escape leadership. The rectangle contains the 25th to 75th percentiles of dataset split at the median value (50th percentile). The whiskers mark the 5th and 95th percentiles, and the dots representing values beyond the lower bounds are considered outliers.

Due to the skewness of these data, NIOSH researchers also used distributions descriptive analysis to report the number and percentage of mineworkers who reported being “less than highly” (i.e., less than 80%) and “less than fully” (i.e., less than 100%) confident in their ability to properly demonstrate or explain each KSA. These cutoff points were established to identify areas in need of improvement based on the expected level of confidence for each item. For example, the expectation might be that all miners must be fully confident in their ability to explain where their primary and secondary escapeways are located, and at least highly confident in their ability to read mine map symbols. Alternatively, such expectations may not apply to all miners’ abilities to confidently explain their mine’s emergency response plan or the full chain of command for reporting a mine emergency.

Mine-specific survey feedback reports were also provided to participating organizations as descriptive distributions in order to allow mine operators and safety trainers to infer that, for example, “30% of our rank-and-file miners are not fully confident they can explain where our escapeways are,” or in other words, “60 of our 200 miners need help with this.” Framing the feedback within this context enabled organizations to target and prioritize areas on which to focus training activities, based on mine-specific results and expectations.

Table 8 depicts the 28 self-escape items along with the percentage of rank-and-file miners and miners in self-escape leadership positions who reported that they are not fully or highly confident in each of the self-escape tasks, respectively.

When comparing rank-and-file miners to those in self-escape leadership positions, the key findings are:

- Rank-and-file miners reported less than full or high confidence on 24 of 28 items compared to self-escape leadership who reported less than full of high confidence on 16 of 28 items.
- While both groups of mineworkers reported their highest confidence as their ability to demonstrate or explain when and how to properly don an SCSR, almost one in four rank-and-file miners (23.6%) and one in seven miners in self-escape leadership positions (14.8%) reported less than full confidence in their ability to demonstrate or explain how to properly don an SCSR.
- Roughly 43% of rank-and-file miners and 37% of miners in self-escape leadership positions reported less than full confidence in their ability to demonstrate or explain where their mine’s escapeways or SCSR caches are located.
- Both groups of mineworkers reported their highest confidence as their ability to demonstrate or explain when and how to properly don an SCSR.
- Both groups of mineworkers reported their lowest confidence as their ability to explain their mine’s emergency response plan (ERP) or the chain of command for reporting a mine emergency.

The total frequency distributions of responses to all 28 confidence questions can be found in Appendix I, Table I-5.

Table 8. Percentage of sample reporting less than full and less than high confidence in ability to properly demonstrate or explain the following to a new miner by subset

Self-escape Competency Items**	< Full R&F	< Full Lead	< High R&F	< High Lead
Your mine's emergency response plan	78.0*	67.3*	40.7*	30.2*
The chain of command for reporting a mine emergency	63.1*	55.5*	26.6*	18.9*
How to construct a proper barricade	59.2*	44.2*	24.0	20.1
Ventilation/smoke leakage	57.6*	40.1*	19.7*	12.4*
What alarms/alerts mean	56.6*	39.4*	21.7*	9.9*
How to read mine map symbols	56.5*	33.5*	21.0*	11.3*
How to reestablish ventilation	56.4*	43.3*	21.6*	15.8*
Your own role in your mine's ERP	54.7*	41.8*	21.7*	15.4*
Your mine's communication and tracking system	52.3*	37.3*	21.3*	12.2*
When to construct a barricade	52.2*	39.6*	19.8	17.0
How to operate your mine's refuge alternative (RA)	49.4*	33.6*	15.4*	7.8*
If or when to fight a fire	48.0*	38.0*	13.7	9.5
How to fight a fire	45.2*	35.5*	11.6	8.5
What lifeline symbols mean	44.4*	31.7*	14.0*	7.0*
Where your mine's SCSR caches are located	43.0*	26.3*	13.5*	6.0*
The location of your mine's escapeways	42.6*	26.7*	14.9*	7.5*
Where RA(s) is/are located	40.7*	27.0*	10.9*	6.8*
What to expect when using an SCSR	40.6*	27.2*	13.0*	5.7*
Where your mine's tetherlines are located	40.1*	30.7*	11.8	9.6
When to enter your mine's refuge alternative (RA)	38.5*	28.5*	11.6	8.1
Where to report in the event of a mine emergency	37.2	31.8	12.1	9.3
How to test roof conditions	36.4	30.6	8.5	7.7
Where your mine's escapeway maps are located	34.6	28.1	7.7	6.4
How to use a tetherline	31.7*	23.7*	9.5	6.8
How to use nonverbal communication	29.8	26.0	10.4	7.1
How to identify explosive atmosphere with a gas meter	28.6*	20.9*	8.2*	3.9*
When to don an SCSR	26.5*	16.9*	5.3	3.5
How to properly don an SCSR	23.1*	14.5*	4.8	2.8

* Indicates significant difference between R&F and Lead based on Pearson chi-square tests ($p<0.05$).
** Sorted from largest to smallest proportion of rank-and-file miners reporting less than full confidence for each item.
R&F = rank-and-file; Lead = self-escape leadership

Discussion of the Training and Assessment Strategies Identified to Address Gaps in Perceived Self-escape Competency among Mineworkers

The exploration of the literature associated with existing training and assessment in high-risk industries enabled gOE/Aptima researchers to identify strategies applicable to self-escape from underground coal mines. gOE/Aptima identified and explored topics that reflect well-established learning theory as well as emerging trends in approaching training and assessment. Of particular relevance are those strategies that focus on non-routine emergency response KSAs. Such KSAs are unique in that they are relevant to scenarios with low-probability, high-severity potential and may never be used. That is, many of the challenges associated with competency training in general (e.g., skill decay, knowledge retention) are exacerbated when skills are rarely, if ever, used. This can be particularly true in situations where performance of infrequently used KSAs is required during dynamic and potentially dangerous situations. Furthermore, the importance of non-routine KSAs may not be as obviously or directly aligned with operational objectives and organizational success and could inadvertently be dropped in priority.

The mining industry has, to some extent, begun to address these issues through mandates related to refresher training content, SCSR expectations training frequency, and the quarterly escapeway drill requirement (e.g., the MINER Act). In addition to the 30 CFR minimum requirements, some individual mines have also chosen to implement their own policies and procedures to increase the frequency and/or complexity of these training exercises even more, which could range from random and informal KSA spot checks throughout the workday to unannounced, hands-on, mine-wide drills to test the effectiveness of the mine's ERPs. As discussed in this chapter, identification of additional training targets (i.e., KSAs and/or personnel) for more frequent refreshers can be accomplished through observations, checklists, and debriefing sessions.

The self-escape competency survey furthers this idea by identifying trends in perceived strengths and weaknesses in emergency response preparedness. That is, out of all KSAs surveyed, mineworkers reported their highest confidence in their ability to demonstrate or explain when and how to properly don an SCSR. Although there is no baseline to validate the claim, the increase in SCSR training mandated by the MINER Act may have improved mineworkers' confidence in this skill. In terms of weaknesses, NIOSH researchers have identified "low-hanging fruit" that can be addressed immediately through routine training reinforcement throughout the workday [Hoebbel et al. 2018]. For example, all miners who work underground should be fully confident in declarative knowledge items such as the locations of their escapeways, SCSR caches, RAs, and escapeway maps. Since the survey revealed that a surprising percentage of mineworkers are not fully confident in this critical knowledge, it may be beneficial to briefly cover these items every shift, or periodically as the working sections move, or as part of the crew pre-shift meetings or via informal "quizzes" or "spot checks" during the workday as recommended by gOE/Aptima. A case study of how one participating mine site utilized its survey results to target tasks such as firefighting, SCSR donning, and map reading throughout the year is detailed in Ryan et al. [2018].

Furthermore, although the results from the self-escape competency survey indicate that most mineworkers report high confidence in their ability to demonstrate or explain the self-escape KSAs included on the survey, a surprising number of mineworkers reported being less than fully or highly confident they could do so. This suggests that there is room for improvement with all of the KSAs included in the survey. On top of that, the self-escape confidence question introduces no complicating conditions (e.g., stress, smoke, real-world emergency), so the responses should indicate how confident each participant is in his or her ability to properly demonstrate or explain these tasks to a new miner under *normal conditions*. The phrasing of the question, combined with other limitations of self-reported data (e.g. social desirability, concerns about confidentiality, and over-inflation of confidence), further suggest the results could be viewed as "best-case scenario" estimates of confidence. With that being said, it is also important to recognize that it is not realistic to expect all miners to be fully—or even highly—confident in all of the KSAs included on the survey (e.g., all the details of the emergency response plan or their ability to effectively make decisions under the stress of an unfolding emergency). Therefore, it is important to clarify training needs, support training through good communication, increase training effectiveness through strategic timing and design, and assess the results as suggested in the recommendations by gOE/Aptima. As a starting point, the results of the self-escape confidence survey also identify mining experience [Haas et al. 2019] and training realism [Hoebbel et al. 2022] as critical factors related to self-escape confidence for all mineworkers. Mine operators may consider exploring more hands-on and experiential training as possible ways to improve confidence in self-escape.

It is worth mentioning, however, that there are several limitations to the self-escape competency survey study described in this chapter that could limit the generalizability of the identified trends. First, the survey sample was drawn from a limited geographic region using convenience sampling. Furthermore, the cross-sectional design of the study does not enable causal relationships between individual factors, organizational factors, and perceived self-escape competence to be ascertained. Additionally, self-reporting can lead to overstating or understating levels of confidence due to social desirability, acquiescence, and/or concerns about the confidentiality of responses. Despite these limitations, the results of this study tend to confirm the widely held opinion among mining industry stakeholders that there is considerable room for improvement in the preparation of individual mineworkers to effectively escape a mine emergency.

As acknowledged earlier in this chapter, not all mines have the resources to conduct formal TNA activities, but they may benefit from insight gained from trends that were identified within the literature and through the NIOSH self-escape competency survey study. Overall, these results suggest that, despite the united efforts made by mining legislators, policy makers, researchers, operators, trainers, and other stakeholders to improve self-escape from underground coal mines, it is likely that several gaps in self-escape training and preparedness remain. The findings from this study have thus confirmed the need for the advancement of self-escape training and provided several considerations for the development and implementation of self-escape training, targeting a range of KSAs across multiple variables including levels of mining experience, organizational characteristics, and training realism.

Chapter 4: Preparing Miners for Decision-making Under Stress

This chapter details how NIOSH identified necessary tasks and subtasks and contracted with gOE/Aptima to perform a literature review and cognitive task analysis (CTA) based on the National Academy of Sciences (NAS) report recommendation 5, summarized as follows:

> **Recommendation 5**. NIOSH should use current decision science research to inform the development of self-escape training materials for effective decision-making for the predictable components of self-escape.

Based on the review of the literature and CTA and their relevance to self-escape, gOE/Aptima researchers focused their attention on naturalistic decision-making (NDM). This effort was designed to provide information to assist in optimally preparing mineworkers to perform critical self-escape tasks with a substantial cognitive component during dynamic and emergency situations.

Exploring the Literature to Develop Decision-making Strategies

As part of their research, the authors of the NAS report conducted their own review of decision science to consider the theoretical applicability of various approaches to decision-making during self-escape. Rather than a normative approach to decision-making, which presumes that the decision-maker possesses all of the information necessary to choose a favorable course of action, the authors focused on descriptive and naturalistic theories of decision-making to approach decision-making under the stress of a mine emergency. Citing Shafir and Tversky [2002] to frame the discussion, the focus was on the many factors (e.g., experiences, emotions, and biases) that can affect how decisions are made in dynamic, dangerous, and stressful situations. The NAS report concluded that, "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" [NRC 2013, p. 83]. To this end, NIOSH expanded the task analysis statement of work (SOW) and contracted with gOE/Aptima to include the development of training recommendations related specifically to decision-making under stress.

Purpose

Utilizing the Instructional Systems Development (ISD) framework described in Chapter 1 of this report, this effort was designed to provide information to assist in preparing mineworkers to optimally perform the critical self-escape tasks determined to have substantial cognitive components. To provide practical guidance to the mining industry, gOE/Aptima researchers had three goals:

1. To review current decision science literature to identify the most appropriate theoretical and practical approaches to improving self-escape from underground coal mines.
2. To define the cognitive processes associated with the critical cognitive self-escape tasks identified in the preliminary task analysis (PTA).
3. To develop recommendations on how to optimally prepare underground mineworkers to perform critical cognitive tasks with a particular focus on decision-making during dynamic and stressful emergencies.

Literature Review

The importance that the role of non-technical skills such as decision-making in emergency response has been emphasized by mining stakeholders for decades. One challenge associated with preparing miners to make decisions in dynamic and dangerous conditions is the seemingly infinite series of cognitions and decision points that could be associated with any given emergency scenario. Furthermore, emergency response management is multi-layered, and successful decision-making in an incident like a mine emergency is “dependent not only on endogenous, situation-specific training of individuals, but also on the interconnected exogenous factors associated with inter-team coordination and strategic response” [Alison et al. p. 261, as cited in Fuller 2014, p. 28]. In addition to these challenges, it is important to note that the state of Queensland, Australia has been conducting annual, full-scale “Level 1” exercises since 1998 and flawed decision-making during the exercises is regularly reported as a major concern indicating that further improvements to emergency response are necessary [Fuller et al. 2012, Queensland Government 2022]. In order to more effectively prepare individual workers to make effective decisions within the complex system of a mine emergency, the NAS [2013] suggests starting with the identification of the predictable components of self-escape that could be practiced in a variety of scenarios to varying degrees of complexity. Importantly, the decision-making processes in mine emergency response must be considered within a psycho-sociotechnical system while recognizing that group-level decision-making can be even more complex than individual decision-making due differing perceptions, communication styles, and levels of experience [Fuller 2014]. To inform the development of self-escape training materials for effective decision-making in response to a mine emergency, NIOSH contracted with gOE/Aptima to develop training recommendations based on a thorough review of existing literature.

Researchers from gOE/Aptima took an integrated human-systems approach to completing the decision-making literature review, considering the decision environment, work processes, and individual- and team-level cognitive factors (e.g., decision-making, memory, and attention) that may facilitate or impede successful self-escape under stress. Search topics included decision-making theory and practice, cognitive performance, psychological factors, real-world situations, working memory, emergency actions, and automatized behavior.

After a thorough search of business and academic databases related to current decision science, a selective review focused on literature from the publications of the highest quality (i.e., determined by impact ratings and reputation) was conducted. Researchers from gOE/Aptima reviewed peer-reviewed academic and technical literature published in scientific journals related specifically to training for decision-making under stress and integrated it with content from relevant NIOSH publications. Particular attention was paid to strategies that are currently in use in other industries and that could be feasibly applied to the mining sector. In addition, gOE/Aptima researchers also examined conference-delivered "grey literature"—materials and research produced by organizations outside of traditional commercial or academic publishing—and articles from periodicals. Some key findings of the literature review were extracted from the contractor report [gOE/Aptima 2017a] and are included below. The full report, "Improving Self-escape from Underground Coal Mines Training Initiative: Decision-making" is available upon request from mining@cdc.gov.

Naturalistic Decision-making

From the literature, researchers from gOE/Aptima concluded that naturalistic decision-making (NDM) approaches are best suited for self-escape. NDM approaches are concerned with how people make decisions in demanding, real-world contexts [Klein and Klinger 1991]. They also consider how the decision-making process may change based on people's experience, the biases they bring with them, and their work culture [NRC 2013]. Research has shown that traditional decision-making approaches do not apply in many real-life situations, and that decision-making cannot be meaningfully separated from the context in which it resides [Klein et al. 1993; Zsambok and Klein 1999]. NDM approaches, which rely on hypervigilant or intuitive processes, are more effective in operational settings, such as emergency response [Johnston et al. 1997; Payne et al. 1988]. According to NDM theories, decision-makers become more selective when searching for information; they evaluate data quickly, consider fewer alternatives, and select a solution from memory without extensive review or reevaluation. Although some researchers have argued that hypervigilance is impulsive and disorganized and a sign of degradation in performance [Janis 1982; Janis and Mann 1977], "others view hypervigilant decision-making as an adaptive response to naturalistic task demands" [Johnston et al. 1997, p. 615].

Effects of Stress on Individuals and Teams

The underground mining environment during an emergency is a complex, dynamic environment that poses physical, emotional, and cognitive threats to the mineworkers attempting to self-escape. These stresses can affect both individual- and team-level cognitive capabilities. Specifically, stress can negatively impact cognitive capabilities such as attention and memory [Driskell et al. 1999].

There is a rich body of research that suggests that stress tends to narrow attention, shifting focus from non-essential tasks to essential tasks [Gladstein and Reilly 1985; Staw et al. 1981]. However, during times of severe stress, team members may narrow their range of attention, shifting from a team focus to an individual focus [Gladstein and Reilly 1985]. According to Driskell et al. [1999], this shift can disrupt encoding, storage, and retrieval capabilities of individuals. As a result, people may start to look internally for solutions, rather than seeking help from those with expertise. This response not only changes team dynamics but could endanger the team if a poor decision is made.

Limitations with working memory can also be impacted by stress. Working memory is believed to be an executive function with limited capacity that is involved in the transient holding, processing, and handling of information immediately pertinent to the task at hand [Miyake and Shah 1999]. According to a model proposed by Baddeley [1986], individuals have a limited amount of working memory capacity available for various tasks. Therefore, each additional demand or stressor placed on working memory can compromise the quality of the decision-making. This is especially pertinent during mine disasters, where mineworkers have many competing tasks demands and must make high-risk decisions, such as deciding when to don and switch/swap SCSRs, when to use a refuge alternative, and when to continue with escape. Fortunately, behaviors that are well-learned tend to be more resilient to stress than other behaviors [Price et al. 2007]. Moreover, in stressful situations, individuals tend to revert to well-learned responses, particularly when knowledge, skills, or behaviors are overlearned (i.e., learned or practiced beyond the point of mastery). Frequent and deliberate practice can lead to automaticity or proceduralization of tasks, which can also minimize the role of working memory capacity on task performance [Reber and Kotovsky 1997].

Teams also present unique opportunities in the domain of decision-making, especially under stress. Teams can leverage teamwork skills (e.g., trust, cohesion, and adaptability) and shared mental models to cope more effectively with complex environments [Orasanu and Salas 1993]. The process improvements produced by teams can result in enhanced quality, safety, efficiency, and adaptability [Banker et al. 1996; Burke et al. 2006a; Cohen and Ledford 1994; Foushee 1984]. Teams can also be trained to make better decisions [Orasanu and Fischer 1997], to perform better under stress [Driskell et al. 1999], and to make fewer errors [Wiener et al. 1993].

Cognitive Skills Underlying Naturalistic Decision-making

Much of the research suggests that NDM-based decision-making, as suggested by its name, is a cognitive skill that naturally develops as a result of experience and expertise and cannot be directly trained [Flin et al. 1996; Klein 1993]. However, in order to support decision-making, mitigate additional stressors, and build more effective teams, many researchers believe that certain knowledge, skills, and processes can be developed. Cannon-Bowers and Bell [1997] identified the attributes of an effective decision, in that expert decision makers are: (1) flexible, (2) quick, (3) resilient, (4) adaptive, (5) calculating, and (6) accurate. In addition, gOE/Aptima researchers explored relevant competencies that can be trained to “accelerate” natural decision-making processes. These findings have been updated by the authors to include recent NIOSH research and are briefly summarized in Table 9.

Table 9. Cognitive skills that support effective decision-making in stressful situations

Cognitive Skill	Relevance to Self-escape Training
Situational Awareness	Situation assessment (i.e., situational awareness) refers to the “ability to make rapid, accurate assessments of the decision situation” [Cannon-Bowers and Bell 1997, p. 106]. In terms of self-escape, it refers to miners’ ability to continually assess or maintain awareness of the relevant and crucial elements of the environment, including mine conditions and equipment, crew member status, mine features (e.g., escapeways), their own location in the mine, and the evolving nature, extent, and severity of the situation.

Cognitive Skill	Relevance to Self-escape Training
Hazard Recognition	Hazard recognition refers to the ability to detect visual cues in the workplace and recognize them as significant [Cannon-Bowers and Bell 1997]. In terms of self-escape, hazard recognition refers to a miner's ability to (a) perceive critical warning indicators in the mine environment, such as obstacles, water, smoke, and alarms, and then (b) correctly diagnose the cues as hazardous.
Pattern Recognition	Pattern recognition refers to the ability to perceive and identify an entire pattern of pertinent cues when evaluating a situation [Kaempf et al. 1993; Klein 1989]. Seasoned decision-makers often use pattern recognition skills to determine whether the situation at hand reflects normal operations or an anomaly. For self-escape from an underground mine, patterns may refer to the usual location of equipment or personnel during operations, how equipment typically operates, or the cycle of changes in a mine environment over time. These patterns can help miners recognize when something is amiss [Klein 1993].
Risk Perception	Risk perception refers to one's ability to accurately perceive, recognize, and assess the degree of risk associated with a situation [Deery 2000]. It involves assessments of both the external situation and one's internal capabilities. Research suggests that during stressful events people tend to underestimate the risk associated with a potential hazard and overestimate their ability to cope with the hazard. During self-escape, this can cause mineworkers to misjudge the risks associated with a situation, make poor decisions, or engage in high-risk behaviors [Hunter 2002]. Research also suggests that misperception of risk can impact both decision-making and accidents in many industries including mining [Brown and Groeger 1988; Hunter 2002].
Template Matching and Mental Simulation	Research suggests that subject matter experts are better at organizing knowledge in a meaningful way [Druckman and Bjork 1991]. It is believed that experts store knowledge *reference problems*, or templates [Noble 1993]. These templates can be more easily retrieved and employed in decision-making. When a situation is new to the decision maker (i.e., they have no reference problem for solving it), they use a process called mental simulation to visualize and select a potential solution [Klein 1989]. According to Klein [1989], mental simulation allows the decision maker to determine whether a potential solution is feasible. Related to self-escape, mineworkers can develop a well-organized body of knowledge or collection of reference problems to draw on in stressful situations, allowing them to make decisions more rapidly and accurately.

Cognitive Skill	Relevance to Self-escape Training
Metacognition	Metacognition refers to the awareness and understanding of one's own thought processes [Cannon-Bowers and Salas 1998]. It allows subject matter experts to flexibly modify their decision-making strategy when they encounter new or contradictory information, or when the situation changes or evolves, especially in stressful situations like self-escape [Cannon-Bowers and Bell 1997]. Because of metacognition, experts are also better at understanding their own level of knowledge, assessing the difficulty of the situations they encounter, and noticing when their line of thinking is wrong [NRC 2013]. It also helps decision makers determine how much time they have to make a decision, which reduces the likelihood of decision bias and other errors that could critically derail a self-escape attempt [Cohen et al. 1998].
Reasoning Skills	Reasoning skills refer to the ability to diagnose dynamic or ill-defined situations, generate a creative or novel solution to a problem, or apply an existing solution in a new way. Good reasoning skills can be useful in many situations, particularly when problems are ambiguous like self-escape [Orasanu and Connolly 1993]. However, a part of reasoning skills is understanding when critical thinking is and is not required. Namely, critical thinking should only be employed when the risk of delay is acceptable, the cost of error is high, and the situation is non-routine or problematic. Reasoning skills are critical for self-escape decision-making in that the problems are often non-routine, but time can be critical.
Domain-specific Problem-solving Skills	Subject matter experts tend to have more domain-specific knowledge than subject matter novices. Experts use domain knowledge to determine how and when to employ various decision-making strategies [Glaser 1984]. Because NDM is meaningfully tied to the context in which it occurs, focusing solely on enhancing general problem-solving skills will not improve decision-making performance in naturalistic settings [Cannon-Bowers and Bell 1997]. Mineworkers can improve their self-escape specific problem-solving skills by increasing their self-escape knowledge [NRC 2013], including (1) knowledge of the mine emergency response plan, (2) knowledge of wayfinding (i.e., how to use alternate directional equipment, such as track and belt lines to evacuate the mine), (3) rote knowledge of primary and alternate escapeways, (4) knowledge of the spatial layout of the mine (e.g., the ventilation system, SCSR caches, lifelines, communication systems, and refuge alternatives), and (5) how to use the environment to find resources needed for self-escape.

Cognitive Skill	Relevance to Self-escape Training
Ad hoc Groups and Collective Decision-making Under Stress	Also relevant and specific to self-escape is the "ad hoc" nature of escape groups. That is, the "escape team" is typically formed based on location and proximity to one another at the time of an emergency event. In a literature review specific to ad hoc group decision-making, Bauerle [2016] cited research that suggested that the lack of inter-group familiarity negatively affected mental model similarity and accuracy [Resick et al. 2010], the utilization of group member expertise [Nemiroff et al. 1976], the ability to resolve group conflict through compromise [Hall & Williams 1966], and the willingness to engage in interventions designed to improve group decision-making [Curseu & Schruijer 2012]. Specific to self-escape group decision-making, Bauerle [2016] conducted a mixed-methods study of transcripts from interviews conducted with survivors of actual mine emergencies [NIOSH 2000] in an effort to characterize and assess self-escape decision-making performance. Findings were consistent with previous research and suggested that greater team performance was exhibited by groups with "more centralized group structure with greater collectivism and certainty regarding decision-making processes" p. 130. The ultimate decision as to whether and how to self-escape could be made more challenging within groups of endangered miners who may lack of a clear hierarchy of authority as is found in other contexts such as firefighting and the armed forces.

Key Findings based on Decision-making Strategies Literature Review

The first major outcome of the decision-making literature review was the framing of safe escape in the context of naturalistic decision-making (NDM). Although as previously described, NDM-based decision-making skills develop naturally rather than through formal training, it is believed that the training of cognitive skills required for effective decision-making in natural environments can accelerate decision-making proficiency in real-world situations [Cannon-Bowers and Bell 1997]. As detailed in the literature review of the previous section, effective decision-making requires general and domain-specific problem-solving skills along with other cognitive strengths including situational awareness, hazard recognition, pattern recognition, risk perception, template matching, mental simulation, metacognition, and reasoning skills, all of which can be practiced.

The second major outcome of the exploration of decision-making was the identification of the cognitive processes related to self-escape. Based on the PTA results, the comprehensive review of current decision science, and researcher expertise, gOE/Aptima researchers identified nine cognitive processes that are particularly relevant to successful performance (Table 10) and could be strategically addressed during existing self-escape training exercises and drills. These cognitive processes go a step beyond decision-making and consider the cognitive task requirements of overall self-escape and are central to expertise.

Table 10. Cognitive processes relevant to self-escape

Cognitive Process	Definition
Sensemaking/situational assessment	Collecting, assembling, and corroborating existing and emerging information, and assessing how it informs potential explanations, decisions, and events to form and/or reform an understanding of the situation
Coordination	Managing activities across multiple individuals acting in roles that have common, overlapping, or interacting goals
Managing uncertainty/risk	Coping with unknowns by reflecting and iteratively comparing the characteristics of the current situation with previous real-world or simulated training experiences
Detecting problems	Noticing anomalies or events that may be taking an unexpected (positive or negative) direction and may signal a need or opportunity to reframe the situation and/or revise plans in progress
Shared cognition	Building shared team knowledge of what to do under different escape conditions and circumstances; understanding how team member actions affect one another
Managing attention	Simultaneous tracking, processing, prioritizing, attending to and storing essential pieces of information while ignoring other non-essential information
Automaticity	Executing a task or process without consciously thinking about the details and actions required, allowing it to become an automatic response pattern or habit
Declarative knowledge	Memorized information that can be recalled quickly
Decision-making	A continuous process conducted under time pressure that involves examining default decisions within ongoing plans of action, which results in the commitment to one or more options
Resilience[13]	"The process and outcome of successfully adapting to difficult or challenging life experiences, especially through mental, emotional, and behavioral flexibility and adjustment to external and internal demands" [American Psychological Association 2022].

[13] "Resilience" added to contractor table and recommendations that follow based on SME feedback and external reviews of draft documents

The final major outcome of the decision-making literature review was the compilation of training strategies to address the cognitive tasks of self-escape. Using the nine identified cognitive processes outlined in Table 10, gOE/Aptima researchers developed a training strategy matrix (TSM) to provide the framework for research and development approaches to training for decision-making under stress. Congruent with the NAS recommendation to develop "training flows," discussed in Chapter 5, gOE/Aptima researchers recommended using systematic training procedures to cover the content included in the TSM framework. Effective training flows use a variety of training methods and consist of several phases of instruction, which typically include some form of classroom instruction, hands-on practice, scenario walkthroughs, teamwork challenges, feedback, and demonstration of mastery [Cannon-Bowers and Salas 1998; NRC 2013]. Importantly, as cited in NIOSH [2015a], while a large body of research supports the incorporation of simulated environments within training flows to cultivate effective decision-making under stress [e.g., Beilock 2010; McKinney and Davis 2003], simulations do not have to be costly nor elaborate to be effective.

The TSM is organized according to the nine cognitive processes described above and includes strategies for the mastery of requisite knowledge, methods that can be used to demonstrate correct behaviors, recommended low-fidelity options that can be used to practice complex cognitive skills, and recommendations for providing feedback, considering higher-fidelity options, accelerating individual expertise, and enhancing team effectiveness. An abbreviated TSM—modified to provide specific examples of previously identified KSAs, relevant ISD considerations, and selective training media and methods—is provided in Appendix J.

Analyzing the Cognitive Components of Self-escape Performance

In addition to explicit and observable behavioral tasks (e.g., declarative knowledge, procedural skill), there are also critical, but less observable cognitive tasks (e.g., decision-making, maintaining situational awareness) that could be required for successful self-escape. To respond to NAS Recommendation 5, gOE/Aptima conducted a detailed analysis of the critical cognitive tasks associated with self-escape [gOE/Aptima 2017c]. In keeping with the model depicted in Figure 6, researchers used results to develop recommendations based on whether tasks could be eliminated, redesigned, or augmented through tools, technology, or other equipment, or whether cognitive capabilities could be enhanced through training. The methods utilized for this phase of the work and related training recommendations are also described in detail in Keeney et al. [2018] and are summarized in the following sections. The full contractor report, "Emergency self-escape phase 4 report: Cognitive task analysis and recommendations," is available upon request from mining@cdc.gov.

Purpose

To further inform the development of self-escape training, protocols, and materials for training for effective decision-making during a mine emergency, gOE/Aptima researchers had two goals:

1. Further deconstruct the critical cognitive tasks required to identify distinctive elements of cognitive functioning central to self-escape performance.
2. Produce a set of specific recommendations for training miners to improve cognitive performance during self-escape.

Methods and Materials

Considering the four NIOSH-defined self-escape roles (inby worker, outby worker, responsible person [RP], and escape group leader [EGL]) and emergency scenarios (fire, explosion, impoundment/gas or water inundation, and rock burst/roof fall), gOE/Aptima researchers visited the two mine sites that participated in earlier phases of the task analysis (see Chapter 2). Experienced underground coal miners were "nominated" for participation by mine management at each location, and 14 miners volunteered to participate in the CTA.

Participants

Fourteen participants were selected by mine management based on their high levels of experience in underground coal mining and knowledge of mine emergency response. At least one participant from each mine was a state-certified foreman. Participants also included the safety managers from each mine, other supervisors, a mine owner, a senior mine manager, a section boss, and a number of crew members, one of whom was also a mine rescue team member who was deployed to the Upper Big Branch disaster in 2010.

Informed Consent

Researchers from gOE/Aptima conducted the individual interviews in private, above-ground facilities provided by mine management. The project purpose, interview process, and the informed consent document of the NIOSH Institutional Review Board (IRB Protocol; #14-OMSHR-10XP) approved protocol were explained, and each participant was given the opportunity to ask questions to seek clarification. All participants provided their oral consent, and no one refused to participate in the research.

Interviews

At each location, mine managers provided access to the volunteer participants for a total of approximately eight hours (16 hours across the two mines), and each interview lasted approximately two hours. Two researchers were present for each interview—one facilitated the discussions while the other took handwritten notes.

Researchers reviewed each of the four emergency scenarios (Appendix C) with participants prior to the data collection. Using the semi-structured interview approved by the NIOSH Institutional Review Board (IRB) (Appendix K) to guide the discussion, one researcher asked participants to recount related personal experiences and to identify any key decision points they have faced. Whenever possible, the participants were asked to draw pictures and use mine emergency response features and apparatus (e.g., self-contained self-rescuers [SCSRs], mine maps, lifelines) to illustrate how and why decisions were made, the level of difficulty in making the decision, whether and how their expertise played a role in their decision, and if and how emergency response mine features and/or equipment helped or hindered their efforts. If participants had no experience with any of the four scenarios, they were asked about past training experiences they thought were particularly difficult, valuable, or could provide useful lessons for fellow miners.

During the interviews, the second researcher took handwritten notes to capture the timeline, significant events, decision points, and decisions made. Both researchers asked probing "What if?" questions where appropriate to add richness to the data. Each session was concluded with participants being asked to describe what they believed to be the biggest challenges to adequate self-escape training and why, as well as to offer any suggestions on how to improve training.

Analysis

Based on the general CTA process offered by Rosen et al. [2012] and methodology presented by Crandall et al. [2006], the raw interview content was divided into separate and distinct elements for further analysis. Meaning was extracted by coding, categorizing, synthesizing, and summarizing the elements to identify central themes. Initially, the notes from the first set of interviews from the first mine were transcribed and reviewed separately by the two gOE/Aptima researchers who then engaged in discussions to identify trends and gaps for further exploration in the second set of interviews conducted at the second mine. This process was repeated with the second set of interview data, followed by discussions between the researchers to resolve any differences in interpretation and classification of the data.

This initial content analysis was followed by an examination of the preliminary set of 75 critical tasks identified in the PTA to identify those that present high cognitive demands (e.g., active information processing) and to exclude tasks that were primarily physical in nature or likely to depend on automatized mental processing (e.g., routine, or automatic procedures, rote knowledge). Three analysts from gOE/Aptima developed two sets of task inclusion criteria based on established CTA methodology [Crandall et al. 2006; Rosen et al. 2012].

The first considerations were the frequency with which the task appeared in the interview content and whether or not the task required the following: (a) perception of and attendance to relevant environmental stimuli; (b) effortful use of strategies and the application of knowledge and reasoning to generate goals; (c) planning of behaviors to achieve these goals; or (d) the communication of goals and plans to other miners.

The second criterion was met if the task involved any one of six cognitive elements (i.e., mental models, situational awareness, information sharing, goal setting, emotional control, or workload management) and could feasibly be practiced and improved through mental simulations or mental rehearsals.

Three rounds of analysis with intervening discussions were conducted to refine a shared understanding of the criteria and to reach consensus on classification of tasks that were not clearly cognitive or non-cognitive. Based on the outcomes of these activities, gOE/Aptima researchers worked to develop results-based recommendations to enhance training and preparation for self-escape decision-making, problem solving, and other cognitive aspects of self-escape.

Key Findings based on Cognitive Components of Self-escape Performance Analysis

The first key outcome of the CTA was the development of six high-level categories of cognitive tasks related to self-escape. These categories formed the basis for later recommendations development and were as follows:

1. Decisions miners have to make during emergency and self-escape.
2. Pre-emergency escape planning and preparation.
3. Sharing situational awareness (SA) through communications practices.
4. Mental simulation for continuous planning.
5. Preparation to lead.
6. Training philosophy and methods.

The process of identifying which of the initial PTA critical tasks were cognitive versus non-cognitive in nature resulted in the classification of 45 (60%) of the initial 75 critical tasks as cognitive [Appendix E], meaning that the task of self-escape requires a great deal of effective cognitive function. Finally, based on the totality of results from all task analysis activities, researchers designed a concept map [Crandall et al. 2006; Moon et al. 2011] of one possible view of a series of cognitions associated with self-escape as presented in Keeney et al. [2018]. Following this framework, an infinite number of such conceptual diagrams utilizing these cognitions, decisions, and KSAs could be developed for training and debriefing purposes.

The second key outcome of the CTA was the generation of nine recommendations relating primarily to increasing self-escape performance capabilities through improved self-escape training. In general, the CTA was framed around whether the task could be eliminated, changed, or whether associated KSAs could be improved through training, tools, and/or technologies. Based on the results of this analysis, no recommendations were made by gOE/Aptima to eliminate or redesign any self-escape tasks. The recommendations based on the CTA [gOE/Aptima 2017c p. 19–44] are briefly summarized as follows:

Helping Mine Operators to Balance Production and Protection

Leadership training can be developed to enhance understanding of the tradeoffs associated with balancing production and protection requirements [Reason 1997, 2016]. It is beneficial to both worker safety and the corporate bottom line for mine operators to maintain awareness of the human and economic costs associated with worker injuries and fatalities.

Enhancing Training Philosophy and Methods

Augmentations to legally mandated training are worthy of consideration. This is not to suggest that the training-related burden be significantly increased, but that a shift in training philosophy can enable operators to adopt local solutions (e.g., the integration of mine-specific equipment, situations, and KSAs) to increase cognitive workload through enhanced training fidelity.

Providing Leadership Training

Due to the dynamic and stressful conditions faced by escaping miners, all miners could benefit from leadership training. For many reasons, designated leaders may become incapacitated during escape or otherwise unable to lead a self-escape group. Group dynamics are likely to change during emergencies, and all miners should be prepared to emerge as leaders should it become necessary.

Teaching Miners Mental Simulation Techniques

Mental simulation (MS) is the mind’s ability to imagine actions taken and the most likely results of those actions. MS allows an individual to envision future possibilities and rehearse strategies for dealing with them [Taylor and Schneider 1989]. By envisioning realistic situations, miners may discover new and different approaches to responding.

Teaching Miners How to Build Cognitive Maps

Although it is critical for miners to be able to read and interpret physical mine maps and navigate using tactile lifeline symbols, it is also important for them to rely on mental representations, known as cognitive maps [Anderson 1990], of the general layout of the mine, the locations of emergency response features and apparatus (e.g., escapeways, SCSR caches), places (e.g., power center, “dinner hole”), and other landmarks.

Teaching Miners the Value of Standardized Communication

In addition to guidelines for structured communication, radio discipline, and nonverbal communication developed by NIOSH [2011a,b,c], the adoption of standardized radio messaging practices can be encouraged, which can reduce the dependence on speech as the primary transmittal mode.

Teaching Miners to Avoid Functional Fixedness When Using Equipment

Functional fixedness refers to the default perception that tools and equipment have specific intended uses. “Out of the box” thinking could provide opportunities for optimal use of available equipment during emergencies. For example, miners could be reminded that refuge alternatives (RAs) can be utilized for situations other than as a “last resort.” Alternatively, the RA could be used for temporary rest, treatment of an injured miner, and as a source of breathable air.

Developing an Escape Hoist Simulation

Mine escape hoists are essentially improvised elevators that come in a variety of temporary and permanently installed configurations. This technology is intended for emergency use only, and miners are prohibited by law to otherwise use the escape hoist, which precludes the opportunity to conduct realistic hands-on training. Development of a simulation that replicates ride conditions and communication methods but would not present serious technological challenges could provide an ideal “out of the box” training solution.

Building Resilience among the Workforce

Based on a recent literature review on mental health in mine workers, Pizarro and Fuenzalida [2021] concluded that risky conditions, shift work, work-life balance, and high job stress were among many factors that can expose miners to occupational mental health risks and recommended specific programs to promote mental health and well-being among miners. Chronic stressors such as these as well as the potential for acute physical and psychological trauma resulting from life-threatening accidents and emergencies suggest that resilience training, in particular, could have beneficial effects for mineworkers. As cited in Seligman [2019], in working with the U.S. Department of the Army, which has since institutionalized the training, Harms et al. [2013] found that soldiers who participated in a program of resilience exercises based on the principles of Positive Psychology were significantly less likely to be diagnosed with posttraumatic stress disorder, anxiety, and depression than those without resilience training and that the rate of substance abuse among those who received the training was half that of those who did not. Although mine operators likely lack the resources to offer programs for protracted resilience training, both preventive and recuperative approaches to managing psychological trauma and the availability of counseling upon request were salient across high risk occupations (i.e. mining, policing, and emergency medicine) explored by Jonker et al. [2020]. Furthermore, this exploration revealed that mineworkers valued management support over family support while recovering from traumatic work-related events bolstering the suggestion that mine management be attuned to and supportive of the psychological needs of its workers.

Discussion of Self-escape Decision-making and Cognitive Components

Perhaps the most difficult tasks a mineworker could be called upon to accomplish during an emergency are those that require non-technical skills such as situational awareness, decision-making, and stress management. Not surprisingly, these are also the most challenging skills to train and reliably assess. In fact, NDM theories suggest that these skills cannot be directly taught [Flin et al. 1996]. However, as evidenced in the literature review, it is well-supported that competency-based training that helps trainees to work together and master the critical KSAs required for the predictable components of self-escape could help prepare mineworkers to preserve adequate physical and cognitive capacity to devote their attention to stressful and otherwise unexpected events. For example, training concrete critical KSAs, such as SCSR donning and switching/swapping to automaticity or "overlearning" communication techniques and technologies, can free up cognitive resources (i.e., working memory) and allow decision-makers to focus their attention on the situation at hand.

The literature also supports the idea that domain-specific knowledge, such as rote memorization and knowledge of the mine layout and locations of mine emergency response features can lessen mineworkers' cognitive workload. NDM dictates that decision-making cannot happen in the absence of context [Cannon-Bowers and Bell 1997]. An increase in contextual knowledge can help improve mineworkers' situational awareness, thereby reducing stress responses and increasing the capacity for detecting problems, managing uncertainty, and, ultimately, effective decision-making.

There is also evidence that training specifically designed to support cognitive skills can help accelerate NDM decision-making skills [Cannon-Bowers and Bell 1997]. Skills such as metacognition, template matching, and mental simulation can be practiced, as exemplified in the recommendations developed by gOE/Aptima based on the CTA. For example, avoiding functional fixedness relates back to metacognition and the awareness of how one is approaching a problem. Flexible and adaptable thinking is critical for effective decision-making. Despite the limitations in sample size and geographic region of the CTA participants, it is clear that the cognitive processes are critical throughout. Planning, decision-making, and communication as individuals and as a team are critical tasks of self-escape that cannot be overlooked in training development.

Beyond the specific CTA recommendations outlined in this chapter, the contractor-developed TSM [Appendix J] provides specific examples of previously identified KSAs, relevant ISD considerations, and selective training media and methods recommendations to guide mine safety and health professionals when considering the cognitive processes required for effective self-escape. As suggested in the TSM, the identified cognitive tasks [Appendix E] can be incorporated into scenario-based training for practice in working through a variety of decisions and combinations of both physical and cognitive critical tasks that may be required for effective self-escape.

Chapter 5: Developing Components for Self-escape Training Flows

This chapter describes NIOSH's efforts to provide learning objectives and training delivery and assessment mechanisms for developing self-escape training flows. These efforts are based on the National Academy of Sciences (NAS) report recommendation 7C, summarized as follows:

> **Recommendation 7C**. The Mine Safety and Health Administration (MSHA) and NIOSH should revise or develop training flows to bring individual miners and mine management to mastery in critical self-escape KSAOs.

Before the "final" design and implementation phases of ADDIE can be carried out by mine safety and health training professionals, appropriate training content, learning objectives, and training delivery mechanisms must be established. According to Gagne [1962 p. 88]:

> The basic principles of training design consist of: (a) identifying the component tasks of a final performance; (b) insuring that each of these component tasks is fully achieved; and (c) arranging the total learning situation in a sequence which will insure optimal mediational effects from one component to another.

The term "training flow" is sometimes used to describe a systematic training procedure that can enhance learning through a variety of methods by creating opportunities for practice, focus, immersion, and assessment. As noted by the NAS report [NRC 2013], training flows are also often used in industries outside of coal mining (e.g., the military, firefighting, and space exploration) to train and "prepare individuals and teams to escape a confined work environment under dire circumstances" [p. 114]. Much like the process put forth by Cannon-Bowers and Salas [1998], mentioned in Chapter 3, these training flows are typically sequenced to begin with classroom activities that present "the big picture" and "hands-on" procedures training. These are followed by the use of simulations with guided practice that progresses to independent practice and concludes with an assessment of mastery. Although these steps can be roughly adhered to through existing miner training, the opportunities for practice, focus, immersion, and assessment require flexibility to account for variations in availability of time and resources. Table 11 provides a scaled down hypothetical example of a self-escape training flow adapted from an example used for preparing astronauts for fire containment on missions aboard the International Space Station provided in the NAS report [NRC 2013 pp. 114–115]. A real-world case study of an underground coal mine's self-escape training components is provided in the related guidance document, "Self-escape Core Competency Profile: Guidance for Improving Underground Coal Miners' Self-escape Competency [NIOSH 2023].

It is important to note here that the entire flow, which begins with concrete identification of the learning objectives, plays a critical role in learning. The KSAs identified and prioritized throughout this report provide this basis. The following sections of this chapter discuss the finalization of the self-escape framework and materials that can be used to support it.

Table 11. Phases of a self-escape training flow example, adapted from NRC [2013, pp. 114–115]

Phase	Training Flow
1	Formal and informal instruction that presents the “big picture” of post-event survival and escape from an underground coal mine. Mandated training topics such as communication systems, refuge alternatives, roof or ground control, ventilation, mine gases, and response plans (30 CFR 48.8) are covered. Learning is reinforced through informal assessment activities such as “spot checks” throughout the work day (e.g., “What would you do if…?”) and brief reminders about the mine layout and locations of emergency features and apparatus during pre-shift meetings.
2	Traditional instructional activities are followed by classroom-based critical KSA familiarization activities that focus on hands-on training with first aid procedures and equipment and the use of devices and tools such as SCSRs (donning and transferring), communication technologies, lifelines, etc.
3	Instructor-led “walk-through” of plans and procedures using high- or low-tech simulated environments (e.g., virtual reality, on-site simulated mine sections, training facility rooms and hallways, etc.) to provide more familiarization with tools such as multi-gas detectors, fire extinguishers, mine maps, lifelines, SCSRs (with actual expired units if available), firefighting equipment, etc. during scheduled activities such as annual “fire school” and smoke training.
4	Safety trainers or supervisors provide details of imaginary unfolding emergency scenarios for mineworkers to physically or mentally simulate or demonstrate critical self-escape KSAs during quarterly response drills.
5	Repeated quarterly training with various scenarios requiring simulation or demonstration of both technical and non-technical self-escape KSAs, including decision-making and situational awareness. If feasible, annual (or more frequent) unexpected mine-wide drills and exercises are conducted.

Finalizing the Self-escape Competency Framework

To produce the “big picture,” effective training flow development must begin with valid training content. Answering the question “What is to be learned?” has long been acknowledged as the highest priority in training development [e.g., Gagne 1962; Hicks et al. 1996]. In fact, if training content is not valid, trainees might be “successful” in learning and transferring knowledge, skills, and abilities (KSAs) that are irrelevant, or worse, inappropriate for effective performance [Baldwin and Ford 1988].

However, what should be learned is often a difficult question. As previously stated, when task analyses are carefully designed and conducted, the content validity of the performance domain (e.g., self-escape) can be assumed. That is, if the SMEs involved in the task analyses include both workers and management who are true experts, then it is unlikely that the content validity can be reasonably challenged [Lawshe 1975]. “However, the parallel between curriculum content validity and job content validity is not a perfect one” [Lawshe 1975, p. 564]. The distinction is subtle, but it means that valid task analysis results may not precisely mirror optimal domain-specific training curricula. For example, a specific KSA may have been identified in the task analysis as required but is not practically important or common and does not need to be included in general training or should not be the major focus in the training curriculum. For this reason, a panel of mine emergency response curriculum experts was convened by NIOSH to finalize the content of the self-escape competency framework.

Purpose

Given the various types of emergencies, mine layouts, mining methods, mine structures, and other potential emerging hazards, underground coal miners could face a myriad of emergency scenarios from which self-escape may be necessary. Since no training program can reasonably be expected to cover the full range of KSAs that might be required for all miners to effectively self-escape, careful consideration and prioritization of final training curriculum and learning objectives is required. To advance the development of training objectives for use in improved self-escape training flows, NIOSH researchers had three goals:

1. To conduct consensus-building focus groups with mine safety and health subject matter experts (SMEs) to confirm task analysis criticality and to establish expected proficiency levels for rank-and-file underground coal miners for both inby and outby worker roles.
2. To develop a standardized, competency-based framework with valid and practicable training content and relevant training and assessment strategies.
3. To investigate past disasters and lessons learned to enhance the relevance of training content for self-escape trainees.

Developing Self-escape Competency Profiles

As summarized in Chapter 2, a formal task analysis was conducted which resulted in the identification of 214 critical and “trainable” KSAs for the “job” of self-escape, 192 of which are applicable to all miners, regardless of self-escape role. Task analysts from gOE/Aptima relied upon the PTA, HTA, CTA, mining SMEs, and their own task analysis expertise to judge the criticality of tasks and maintain content validity. Inherent in this process was continuous and iterative refinement of identified tasks through interviews with mine management, focus groups with veteran mineworkers, and several reviews by mining SMEs, including a panel of NIOSH researchers (see Chapters 2 and 4). This rigorous process produced the base content of the self-escape competency profiles.

To prepare the results of the formal task analysis for practical implementation, a reorganization was required. This reorganization was done to structure the material in a way that might enable practitioners to design modules for different phases of escape and/or consider when planning or assessing quarterly escapeway drills or other scenario-based training activities. To this end, NIOSH researchers reorganized the 21 critical competency areas and related KSAs into a sequential structure of seven major self-escape activities, presented loosely in the temporal order in which they might occur during a mine emergency. The related KSAs for each major activity became the performance criteria, where the draft competency profiles were created as hierarchical checklists in table format and included the major self-escape activities, competency areas, and critical KSAs (i.e., performance criteria). The complete draft competency profiles, which can be found in Appendix L, are based on the following major activities derived from the task analysis:

- Communicating
- Wayfinding
- Using Self-contained Self-rescuers
- Carrying, Using, and Maintaining Other Personal Tools and Equipment
- Assisting in Emergency Response
- Leading, Directing, and Managing
- Post-exit Activities

To further ensure the successful translation of these competency profiles into practical and feasible guidance for the industry, NIOSH researchers then sought the perspective of a number of mine safety and health professionals, including well-experienced mine safety trainers, to validate and build consensus around the final competency framework training content and appropriate performance criteria for rank-and-file miners. This final review is in line with the recommendations of the NAS committee, gOE/Aptima, and the earlier data collections. Specifically, the NAS committee recommended that upon completion of the identification of critical tasks, a group of mining stakeholders should meet to build consensus around competency standards and acceptable performance levels. In gOE/Aptima's recommendations for future work, they call for further examination of the critical KSAs across the four specified self-escape roles to establish expected levels of proficiency for each. For example, rank-and-file inby and outby workers might need a basic or moderate level of proficiency in a certain skill, while miners in self-escape leadership positions (e.g., mine management, responsible person) might need an advanced level. Lastly, the need to establish proficiency levels was also identified by the self-escape competency survey (see Chapter 3). These consensus-building activities are described in the following sections.

Methods and Materials

The NIOSH Human Research Protection Program (HRPP) determined that this research activity (NIOSH Protocol 18-PMRD-04XM) was exempt from IRB review under 45 CFR 46.101(b)(2). Office of Management and Budget (OMB) approval was not required as the total number of participants did not exceed nine.

Participants

A total of eight underground coal mine emergency response training SMEs participated in one of two focus groups.

Group A participants were drawn from those in attendance at the 2018 Joseph A. Holmes Safety Association Annual Meeting (JAHSAAM) in Denver, Colorado. Two underground coal mine emergency response training SMEs in attendance volunteered to participate. Both had command center experience and extensive experience in mine safety training and mine rescue. One of the two participants also had served in the role of the RP and had experience evacuating a mine during an emergency.

Group B participants were drawn from known industry contacts and identified by NIOSH researchers as underground coal mine emergency response SMEs. These SMEs were invited via email/telephone to participate in a focus group session at NIOSH's campus in Pittsburgh, PA. Group B consisted of a total of six participants, including representatives from MSHA, industry, and private consulting firms. These participants had a combined experience of approximately 200 years in underground coal mining, 75 years as members of mine rescue teams, and 75 years as mine safety trainers. All reported active participation in actual mine emergency events, either in the command center or under apparatus, on over 20 occasions combined.

Informed Consent

The project purpose and process were thoroughly explained to each focus group participant, and each was provided an informed consent document. All participants were informed that their participation was voluntary and were given the opportunity to ask questions and/or withdraw their consent at any time with no penalty. Participants provided their verbal consent, and no one refused to participate in the research.

Focus Groups

Two semi-structured focus groups with mine emergency response SMEs ("Group A" and "Group B") were convened by NIOSH researchers to review the draft self-escape competency checklist (hereafter referred to as the "draft checklist," Appendix L). The goal of these focus groups was to confirm the relevance and criticality of the draft checklist content for both inby and outby rank-and-file mineworkers and establish the expected proficiency levels (EPLs). Prior to the group activities, all participants were provided with an overview of the research project and the purpose of the group activities. The participants were then given the opportunity to review instructions, ask questions, and individually review each item in the draft checklist.

Focus Group A

During a scheduled presentation at the 2018 JAHSAAM in Denver, CO, NIOSH researchers provided attendees with the "Self-escape from Underground Coal Mines Training Initiative" [NIOSH 2018] project status update, which included a presentation of the self-escape competency framework development process. Those who expressed interest were recruited to participate in a focus group activity on the following day and were provided with the draft checklist (Appendix L) and instructions. Prior to the focus group, Group A participants were asked to review the checklist content and to independently either concur with the criticality of competencies and associated KSAs (e.g., "Yes, it is critical that an inby and/or outby rank-and-file miner know(s) this") or suggest the revision, addition, or deletion of items in writing.

After brief introductions, NIOSH researchers facilitated a group discussion beginning with general SME feedback on the overall framework content. Following general discussion, each self-escape KSA was considered, in turn, as to whether it was critical for inby workers, outby workers, both, or neither to master. If consensus was not reached during the allotted time or participants provided other comments or suggestions related to the content, researchers recorded handwritten notes and flagged the items for later consideration by the research team. Focus Group A lasted approximately 1.5 hours.

Focus Group B

The second focus group, Group B, took place at the Bruceton Research Center in Pittsburgh, PA. Again, prior to the focus group, Group B participants were asked to review the checklist content and to independently either concur with the criticality of competencies and associated KSAs or to suggest the revision, addition, or deletion of items in writing. Additionally, participants in focus Group B were asked to consider minimum EPLs for each critical task prior to the group exercise by rating them on the 6-point scale that was modified from the National Institutes of Health (NIH) Proficiency Scale [NIH 2009], as follows:

(0) Not Applicable ("not critical")
(1) Fundamental Awareness (basic knowledge)
(2) Novice (limited experience)
(3) Intermediate (practical application)
(4) Advanced (e.g., applied theory, deep understanding)
(5) Expert (recognized authority)

After brief introductions, NIOSH researchers facilitated a group discussion beginning with general SME feedback on the overall framework content. Following general discussion, each self-escape KSA was considered, in turn, as to its criticality and EPL. However, during the discussion, all SMEs and researchers agreed that a simplified EPL scale would be more useful for the exercise. Each critical task was subsequently rated on the following 3-point scale:

(0) "Not critical for rank-and-file miners to practice."
(1) "Good to know, but not necessarily critical" (supplemental competency).
(2) "Need to know" (core competency).

whereby zeroes (0s) would be removed from the rank-and-file competency profile development process, ones (1s) would be considered "supplemental" KSAs, and twos (2s) would be considered the "core" KSAs that all underground mineworkers should master.

Similar to focus Group A, if consensus was not reached during the allotted time or participants provided other comments or suggestions related to the content, researchers recorded handwritten notes and flagged the items for later consideration by the research team. Focus Group B activities lasted approximately five hours.

Key Findings on Self-escape Competency Framework

The first major outcome of the self-escape competency review was that all rank-and-file mineworkers, regardless of work location, require the same set of critical KSAs. Both focus groups agreed that distinguishing between inby (closer to the working face) or outby (closer to the mine entry/egress point) mineworkers was not necessary for a training and assessment framework based on the following observations:

1. Many mineworkers are cross trained for a variety of positions underground.
2. There could be any number of scenarios where underground workers could be situated in a location in which they do not typically work.
3. Annual trainings and drills are typically made up of entire crews regardless of job title or position.

As an example, one point of discussion was whether it was critical for outby workers to know where to meet in the event of a mine emergency. It was agreed that all mineworkers should understand that one should never travel inby during an emergency for the sole purpose of meeting up with others. All mineworkers could find themselves facing such a decision and must know that if self-escape is possible, they should proceed toward the mine egress rather than deeper into the mine. Similarly, workers who work primarily outby the designated meeting place may find themselves inby, in which case they must know where best to proceed in an emergency.

The second major outcome of the self-escape competency review was the reorganization of the KSAs in the self-escape competency framework into nine competency areas with core and supplemental performance criteria. SMEs recommended adopting this new organization rather than the 21 critical competency areas identified by gOE/Aptima researchers or the eight major activities identified by NIOSH researchers. This outcome was primarily generated by the discussion of Group B. As described above, the SMEs in Group B felt it was more useful to operationalize performance into "need to know" (core), "nice to know" (supplemental), and "not critical for rank-and-file miners to practice" (not critical). The core and supplemental KSAs were mapped to the appropriate competency areas and retained in the final competency framework for mine safety and health professionals to consider incorporating into training activities. Based on these research activities, nine core competency areas were identified for inclusion in this technical report's sister NIOSH guidance publication [NIOSH 2023] and are as follows:

- Everyday preparedness
- Situational awareness: mine layout
- Emergency diagnosis and response
- Wayfinding
- SCSRs: locating and donning/switching/swapping
- SCSRs: using and expectations
- Communication
- Refuge alternatives
- Firefighting

The ratings of each KSA along with focus group SME notes and suggestions are included in Appendix L.[14]

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[14] Minor modifications to the draft competency checklist were made and noted based on external SME reviews of this document and its companion IC, "Self-escape Core Competency Profile: Guidance for Improving Underground Coal Miners' Self-escape Competency".

Designing and Developing the Virtual Reality Mine (VR Mine) as a Mechanism for Training, Research, Development, Delivery, and Evaluation

As described in Table 11, simulated scenarios that include the practice of critical tasks to meet learning objectives are a key component of effective training flows. Research has shown that effective training is engaging, authentic, and understandable [Burke et al. 2006b; Burke and Hutchins 2007; Wilkins 2011], playing a significant role in the absorption and retention of the material. Trainees not only benefit from exposure, but additional context and realism has also been shown to improve mineworkers' abilities to identify and understand hazards [Kowalski-Trakofler and Barrett 2003]. The added context also supports practice with NDM [Cannon-Bowers and Bell, 1997]. Characteristics of good training flows also include opportunities to demonstrate, practice, debrief, and assess [Salas and Cannon-Bowers 2001], and effective learning can result from the ability to visualize important concepts, the repetition of exposure, the inclusion of feedback, and the ability to determine if the skill has been mastered. Virtual reality (VR) is a mechanism that supports all of these characteristics.

In addition to its utility as a training tool, VR offers a safe place with high fidelity to simulate situations that would be too dangerous or costly to simulate in the real world. Among other things, VR can be used to communicate a message, provide hands-on experience, and measure performance. While it can be difficult and expensive to recreate complex manual tasks (e.g., an aviation flight simulator), a VR environment can easily incorporate visual and cognitive tasks related to mining (e.g., wayfinding, decision-making), making it a good addition to a training curriculum. As recent examples, VR has been used effectively in post-traumatic stress treatment [Loucks et al. 2019], emergency preparedness [Lovreglio et al. 2018], and safety training [Chittaro et al 2018].

In addition to the training content and learning objectives that were generated as a result of the work described in this report, NIOSH researchers have developed a simulated environment platform—VR Mine—that could be adapted to serve as a mechanism for self-escape training delivery and competency assessment as well as the empirical study of self-escape competencies. VR Mine can readily be deployed using large theater spaces, head mounted displays (HMDs), and desktop computers. VR Mine also allows for single and multiplayer configurations that are collocated or remote. Training content could be modified based on the target objective, participants, and availability of hardware.

The VR Mine platform design and features as they relate to self-escape training material development and delivery are summarized below.

Purpose

Extensive reviews of the training literature conducted as part of this study suggest that effective training curricula and activities (i.e., training flows) should deliver content using a broad range of methods (e.g., lecture, videos, hands-on practice, role plays, and computer-based modules) that include key decision points and actionable feedback. To provide options for some training flow content delivery, NIOSH researchers had two goals:

1. To create a VR platform to facilitate the rapid generation of custom VR software
2. To create example training scenarios for use in the mining industry

The overarching purpose of this development was to provide a modifiable virtual environment that can be adapted by mine safety and health professionals for specific training research and development needs, including self-escape.

Background

NIOSH researchers have developed immersive virtual environments and digital assets under several research projects over the course of the last two decades [Bellanca et al. 2019; Filigenzi et al. 2000; Navoyski et al. 2015; Orr et al. 1999, 2015, 2016, 2019]. This previous work provided researchers with a strong knowledge base for VR design and development. However, barriers to the stable and pervasive use of VR in the U.S. mining industry remain [see Bellanca et al. 2019; Orr et al. 2019], including limited industry collaboration [Stothard and Swadling 2010], rapid technology advancement [Stothard and Swadling 2010], a large time and resources commitment [Bauerle et al. 2016a; Navoyski et al. 2015; Stothard 2008], and limited asset reuse [Orr et al. 1999].

To combat these barriers, it is critical to understand that VR can be used in many different ways outside the traditional first-person training simulation, and simulation can be designed with greater flexibility to allow continued use. At its core, VR is a controlled environment that can be used to track events and data. Further, VR provides a way to bring prototypes to life, depict invisible concepts, make data more intuitive, and bring teams together. By providing an intuitive mechanism to integrate humans and layered information, VR has the potential to aid in solving complex problems in any domain of training, research, and development. Some of the major benefits include increased measurement, increased control, improved validity, enhanced engagement, improved accessibility, and increased collaboration [Bellanca et al. 2019; Kizil 2003; Vasquez et al. 2019].

VR Mine Development

NIOSH researchers developed "VR Mine"—a VR platform that allows the rapid generation of VR and virtual environment (VE) software applications—which can serve as a platform for self-escape training and assessment. In particular, the VE can be modified to represent a variety of mine layouts and conditions that can be used to provide opportunities for the practice of critical self-escape KSAs, such as establishing and maintaining situational awareness, wayfinding, and decision-making.

Technical Considerations

A high level of rigor is required in order to develop quality VR applications. During development, one must carefully consider the technical implications of (1) accuracy, (2) flexibility, and (3) control. Accurate conclusions can only be drawn when it is clear when, what, and how something was done. This is true for both training and research. Accuracy is necessary for quality feedback and assessment. Flexibility requires that an application be both modular and scalable, while supporting additional development. Flexibility is important to avoid the pit falls of previous VR development that resulted in fixed simulations that had limited use.

Control is important, specifically related to timing and responsiveness, to maintain a consistent and immersive simulation. Part of developing good training is controlling when and how trainees are exposed to certain scenarios depending on the individual and mine location. The modifiable nature of this technology allows for customization of specific training objectives.

Features

NIOSH researchers chose to develop VR Mine using the Unity[15] game engine—a stable, commercial off-the-shelf game engine with a large user base that offers life cycle support required for ongoing research and development activities. As a part of VR Mine, researchers developed features for the Unity editor as well as for use in the end applications. Some of the key features of VR Mine related to self-escape training and research include: (1) logging, (2) auto mine creation, (3) mine networks, (4) real-time ventilation, and (5) an experiment configuration interface. These features allow developers to rapidly create new scenarios that users can realistically experience and interact with. For example, the VR Mine is integrated with MFIRE—which is a dynamic, transient-state, mine ventilation network simulation program [Zhou et al. 2016]. MFIRE gives VR Mine the ability to simulate ventilation, smoke, and gas propagation through the mine in real time. These parameters can be measured and manipulated by users by opening man doors in the virtual mine, hanging curtains, and moving equipment. This level of realism and accuracy highlights the advantages of simulation to train and assess decision-making. In contrast to physical simulations, users can actually visualize and experience the consequences of their actions, giving them increased context and understanding that supports the development of expertise.

Asset Development

Because VR is a highly visual methodology, asset development typically plays a key role in application design and in achieving the high fidelity desired for engaging and immersive training. Assets in VR Mine ranged from coal materials to mobile equipment (e.g., scoop, mantrip). In order to produce a highly immersive environment for research purposes, NIOSH researchers chose to develop high-fidelity assets according to engineering specifications (Figures 8 and 9). However, level of effort and detail can and should be scaled by the purpose of the simulation.

[15] These materials are not sponsored by or affiliated with Unity Technologies or its affiliates. “Unity” is a trademark or registered trademark of Unity Technologies or its affiliates in the U.S. and elsewhere.

Figure 8. An example of an engineering accurate, three-dimensional battery hauler model developed for VR Mine.

Figure 9. Images depicting an example of the high level of visual fidelity incorporated into VR Mine. The left-hand image shows the modeled scoop bucket next to the reference photograph on the right.

Competency Visualizations

As described earlier, many critical KSAs of self-escape can be visualized using VR to more clearly describe the targeted skills required during the self-escape process. Below are several examples that could be implemented in VR Mine as dynamic tasks. These examples (in italics) come from this report's sister publication, the NIOSH IC "Self-escape Core Competency Profile: Guidance for Improving Underground Coal Miners' Self-escape Competency" [NIOSH 2023].

Wayfinding

There are several wayfinding or navigation tasks that were identified as critical to effective self-escape [NIOSH 2023]. One example is as follows:

> *Knows how to use other tactile wayfinding techniques (rib line, power cables, waterlines, belt, a cane or stick, if available) if a lifeline is not available*

VR Mine can be used to depict such situations and can even be tailored to the specific layout of a specific section or individual mine (see Figure 10).

Figure 10. Screen captures from VR Mine depicting mine infrastructure that can be used in the KSA of wayfinding.

Communication

Several critical aspects of communication also play a critical role in effective self-escape. The dynamic interactive nature of a VR simulation allows users and trainers to embed examples as well as evaluate performance. VR Mine has several built-in communication networks that facilitate these actions. Specifically, one example KSA is as follows [NIOSH 2023]:

> *Knows how and when to communicate critical information about the situation (severity, conditions of the mine, affected areas, air quality, smoke, visibility, conditions of equipment, and needs).*

Configuration of the wireless communication mesh node or mine phone systems will influence how successfully mineworkers can communicate in the event of an emergency. VR mine can replicate various communication networks (see Figure 11) as well as provide a variety of scenarios that would allow for practice of both *how* to communicate as well as determining what information is critical to communicate and to whom.

Figure 11. Screenshots of mesh node and mine phone digital assets in VR Mine. These assets can be used to play a pre-recorded message or send a communication during a training scenario. VR Mine provides context to the message content through the dynamic events of a staged scenario.

Situational Awareness

Knowing where one is and where they are located in relation to their surroundings is another common theme in self-escape competence. Mineworkers must not only be able to locate critical emergency items but must understand how to get there and when to travel there. One relevant KSA is as follows [NIOSH 2023]:

> *Recognizes one's personal position within the mine relative to the locations of all emergency features and resources including primary and secondary escapeways, exits, and fresh air.*

The example in Figure 12 shows where a power center and SCSR cache may be located on a section. The added context of the equipment, cabling, and personnel can help give the worker the knowledge and understanding of his or her position with respect to known objects in the mine. In this example, the colocation of the power center and SCSR cache allows mineworkers to more easily locate the SCSR cache by following power cables.

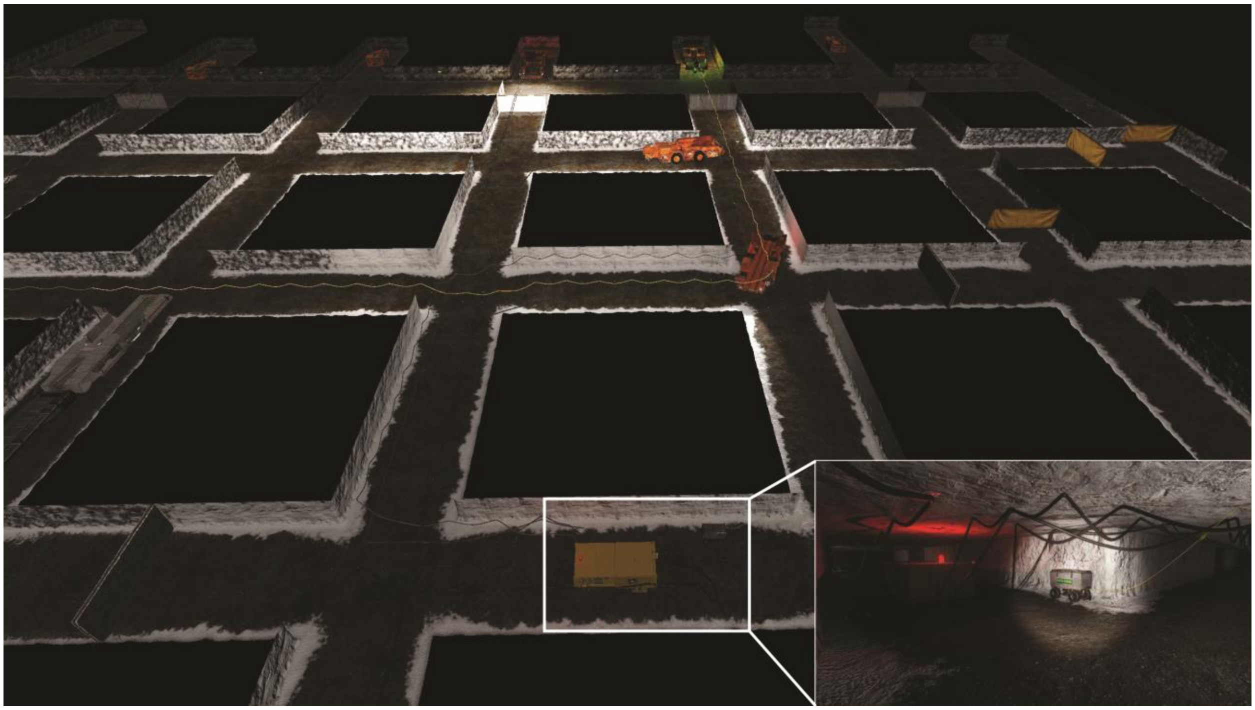


Figure 12. Screenshots of a power center and SCSR cache along with an overhead view of where these items are located on the section. The white rectangle in the overhead shot indicates the location of the callout image.

Ventilation

The integration of MFIRE within VR Mine enables dynamic interaction with the simulated mine's ventilation. Because aspects of ventilation have been identified as critical competencies for self-escape leadership roles in particular, this is another key example of how VR Mine can be used in training. Specific KSAs relevant to this scenario are as follows [NIOSH 2023]:

> *Understands the basics of mine ventilation and expected airflow/ventilation in the mine.*
>
> *Understands impact of fire, gases, and smoke on air quality.*

Figure 13 depicts a dynamic example where a ventilation control (i.e., brattice curtain) could be removed to release an inundation of methane coming from the face that would interact with a fire further outby. Users would then be able to simulate monitoring the gas levels using a handheld gas meter.

The purpose of this section was to introduce the reader to the functionality of the NIOSH-developed VR Mine and to provide examples of self-escape KSAs that can be practiced or reinforced in simulated environments. Interested readers are directed to Bellanca et al. [2019] for a more detailed description of the design and features of VR Mine and Orr et al. [2019] for details surrounding the technical development of VR Mine's digital assets (non-programmed elements such as 3D models, audio, and the user interface).

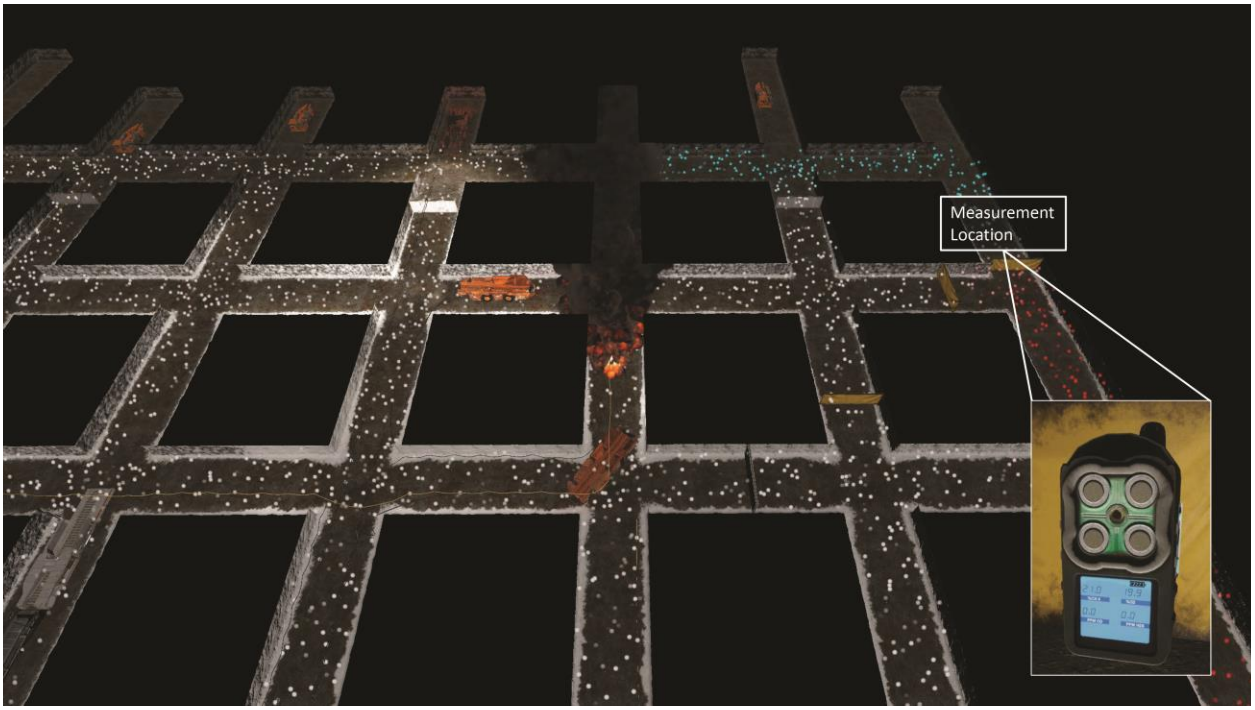


Figure 13. An overhead depiction of a section of a mine with methane liberation coming from the face of the third entry from the right and a fire two crosscuts outby as modeled by MFIRE. The small particle system represents the airflow velocity and methane concentration (i.e., blue = inert, red = explosive, white = none). The dots within the mine indicate level of contaminant by size and color (i.e., larger = higher concentration; red = high, white = none), which would typically be hidden from the user. The callout depicts a multigas detector that users would be able to control to monitor the changes in methane from the location of the star in the overhead view.

Discussion of the Utility of Incorporating the Self-escape Competency Framework and VR Mine into Self-escape Training Flows

Critical to effective competency-based training and assessment is a solid framework consisting of clear learning objectives, a variety of delivery mechanisms, and opportunities for meaningful assessment. Importantly, results of the NIOSH survey described in Chapter 3 suggest that training realism is directly associated with self-escape confidence for both rank-and-file miners and those in self-escape leadership positions [Hoebbel et al. 2022]. The development of the competency framework for rank-and-file miners enables mine safety and health professionals to utilize validated checklists for all critical tasks and subtasks in a variety of ways through both classroom instruction and scenario-based, hands-on learning. The development of VR Mine enables immense opportunities for the creation of applications for laboratory-based data collection, the development of VR training tools, and is expected to foster collaboration among mining safety and health researchers, trainers, and other stakeholders.

The self-escape competency framework and VR Mine developed under this NIOSH research project will add to the library of NIOSH-developed self-escape training resources (Appendix M) that are available to researchers and practitioners to continue to advance mine safety and health training and assessment.

As an extension of this work, NIOSH is also actively collaborating with MSHA to implement VR Mine at the MSHA academy in Beckley, WV. While the current focus of this iteration is mine rescue (i.e., VR Mine Rescue Training package), once implemented, it could also be repurposed for self-escape training. VR Mine Rescue Training is a salient example of how the VR Mine platform can be utilized to quickly develop targeted training. Furthermore, NIOSH is also working to package VR Mine Rescue Training as a stand-alone training package that can be used by individuals and organizations without programming knowledge. This software release would not only allow for the greater development and sharing of training materials, but enable adoption at smaller operations. As described above, the VR Mine platform and specifically the VR Mine Rescue Training package can be used with many different hardware and distribution configurations. The advance of less expensive HMDs also allows VR to be more easily accessed by small or remote operations (e.g., lower cost to entry, easily transportable). Additionally, the ability to join training remotely can facilitate additional collaboration and access to additional resources.

A low-tech real-world example of how early results of this study were used by one participating mine to develop a self-escape training flow utilizing new strategies and existing training opportunities is included in “Self-escape Core Competency Profile: Guidance for Improving Underground Coal Miners’ Self-escape Competency” [NIOSH 2023] and is summarized in the article, “Using Performance Management Strategies to Improve Mine Emergency Training and Preparedness” [Ryan et al. 2018].

Training strategies identified by gOE/Aptima [Appendix J] provide detailed guidance for mine safety and health professionals to consider in the development of new or revised training flows. Additionally, the identified cognitive tasks [Appendix E] can be incorporated into scenario-based training components for practice in working through a variety of decisions and combinations of critical physical and cognitive self-escape tasks.

Chapter 6: Other Activities and Future Plans

The research described in this technical report focuses on the four recommendations to advance self-escape training that NIOSH was equipped to address in the short term through project and contract research. In addition to these activities, other research pertaining to the NAS recommendations to accelerate the development of technologies associated with wayfinding (Recommendation 2) [Martell et al. 2019; Sammarco et al. 2020], breathable air supplies (Recommendation 3) [NIOSH 2019b], communication and tracking (Recommendation 3) [NIOSH 2019b], and to further the study of safety culture in the mining industry (Recommendations 6A and 6B) [NIOSH 2020] has taken place and is ongoing. The full text of these recommendations is provided in Appendix A. Other activities closely related to the work described herein are also underway, and the groundwork is laid for researchers and practitioners to focus attention on the remaining NAS Recommendations 1, 7D, and 7E, described in Appendix A. In keeping with the ADDIE framework, these recommendations focus on the further *development*, *implementation*, and *evaluation* of self-escape training flows.

The work presented in earlier chapters of this document focused on knowledge, skills, and abilities (KSAs) that are critical to effective self-escape for all underground coal miners, regardless of self-escape role. However, miners in self-escape leadership positions must also be competent in other areas of emergency response and could be responsible for leading escape efforts. In response to NAS Recommendation 7C, NIOSH researchers also began a deeper examination of the responsible person (RP) requirement and how this critical role is currently being operationalized within the mining industry. Materials were collected from subject matter experts (SMEs) from six underground coal mine companies in the U.S., with interviews conducted and observations made to determine how mines meet the Mine Safety and Health Administration (MSHA) requirement for annual RP training. Through this effort, NIOSH researchers noted great variability in how RP training is approached across participating mines and reported findings and recommendations in the article, "Ideas from the Field: Training Responsible Persons to Lead and Succeed" [Connor and Gallick 2018]. Additionally, it has been determined that designated RPs within the self-escape competency survey sample were significantly more confident in all critical self-escape KSAs than rank-and-file miners and significantly more confident on most critical self-escape KSAs than all other members of self-escape leadership positions (i.e. mine management) [Hoebbel and Sbaffoni 2021]. While this suggests that either RP training is working to some degree, or that operators are selecting more "qualified" or confident personnel to fill these positions, there is still significant room for improvement in the training and preparation of responsible persons.

To further the self-escape training needs analysis (TNA) described in this report, NIOSH researchers and other SMEs are currently working toward a deeper understanding of the role of the RP and other self-escape leadership positions, while exploring opportunities to maximize the benefit of existing training opportunities for more comprehensive evaluation of the mine emergency response system. Questions, 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?" [NRC 2013 p. 81], and others need to be more comprehensively addressed.

Related to this, and in response to NAS Recommendation 1, NIOSH field researchers also attended several mine emergency response training exercises to review current escapeway drill practices and to share observations with the personnel involved in each. The findings of the "first-order" assessment revealed great variability in how emergency response preparedness is approached across the U.S. [NIOSH 2015b]. Based on these observations, NIOSH researchers concluded that the feasibility and effectiveness of incorporating comprehensive self-escape scenarios into the mine-wide emergency preparedness processes should be further examined with consideration for differences in protocols, equipment, facilities, and conditions. NIOSH researchers are also exploring opportunities to maximize the benefit of existing self-escape training and drills, as well as the feasibility of more deeply integrating elements of emergency management into mine health and safety management systems. This integration might allow for the ongoing assessment of the mine emergency management system with an initial focus on self-escape preparedness and initial emergency response.

Stakeholder input meetings continue to be held to identify areas of need and opportunities for industry collaboration in the ongoing effort to improve self-escape. In addition to the need to develop and implement new training flows and study their effectiveness (NAS Recommendation 7D), further study of the non-technical aspects of emergency response such as decision-making and situational awareness has been identified as a priority. Importantly, findings from 20+ years of Queensland Level 1 mine emergency exercises support this conclusion [Fuller 2014, Fuller et al. 2012] among which the following observation was made:

> There is a further need to establish a clear organisational structure for the management of an emergency, including information gathering techniques, decision-making processes, and communication mechanisms. These are available within professional emergency services organisations and should be reviewed and considered for adaptation to the mining environment [Queensland Government 2003, p. 7].

The need to expand this work to address mine emergency management in all underground mining subsectors is also apparent.

Finally, the availability of critical components of effective self-escape training flows, such as the self-escape competency framework for rank-and-file miners and VR Mine (discussed in Chapter 5) will allow opportunities for MSHA, mine organizations, and universities to evaluate whether existing training programs and facilities could support self-escape simulation and scenario training and assessment (NAS Recommendation 7E) utilizing these tools.

To begin this effort, NIOSH is currently collaborating with MSHA to leverage VR Mine to develop a multiplayer VR mine rescue application—VR Mine Rescue Training—to be demonstrated and evaluated in upcoming mine rescue competitions in the U.S. The VR mine rescue application allows a mine rescue team to explore several emergency scenarios together while wearing HMDs. Mine rescue teams will be able to explore, put out a fire, map the area, rescue trapped mineworkers, and ventilate the section. These scenarios aim to provide mine rescue teams with experiential training and assessment that is specifically focused on decision-making and other cognitive skills that are also relevant to self-escape and other aspects of mine emergency response. Another strength of VR Mine is its flexibility—the simulated environment can be modified for a variety of mining subsectors, layouts, and other mine specific characteristics and regional differences. The integration of MFIRE allows ventilation decision making to be incorporated into a full problem scenario or the creation of stand-alone interactive ventilation exercises which can help to promote teamwork and decision-making among groups of mineworkers. Data is generated and recorded by the system which allows for detailed retrospection and debriefing of actions taken and decisions made. Multiple pilot demonstrations of this product have yielded positive feedback regarding the acceptability and usability of this product, which is expected to be utilized by trainers and MSHA's National Mine Health & Safety Academy after more formal evaluation activities, which will include a field deployment case study. The results of this case study could have important implications for making VR Mine more widely accessible to mine operators, who while recognizing the value of using simulated environments for emergency response training, have historically considered the availability and cost of providing simulated training as prohibitive [GAO 2007]. Additionally, once an operation has invested in the equipment to offer this training, which has significantly decreased in price, the availability may allow for the expansion of employees that are given mine rescue training as there is no additional cost outside of the employees time. This cross training also has the potential of increasing self-escape competencies.

In closing, ongoing health and safety issues and emerging priorities (e.g., silicosis, black lung disease, COVID-19) combined with the potential for complacency (as of this writing, the U.S. mining industry is experiencing its longest period without a disaster) require that all stakeholders keep the critical importance of emergency preparedness at the forefront of research and practice. Although much work remains, the outcomes of the efforts described within this report have laid the foundation for NIOSH and other interested stakeholders to further the development of workplace solutions to improve the post-disaster survivability of mineworkers.

References

30 CFR. Parts 1-199, Mineral Resources. Code of Federal Regulations. United States Department of Labor, Mine Safety and Health Administration. https://arlweb.msha.gov/regs/30cfr/.

45 CFR. Electronic Code of Federal Regulations. United States Government Publishing Office. https://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title45/45cfr164_main_02.tpl.

Adelman C [1993]. Kurt Lewin and the origins of action research. Ed Act Res *1*(1):7–24.

Albert A, Hallowell MR, Kleiner B, Chen A, Golparvar-Fard M. [2014]. Enhancing construction hazard recognition with high-fidelity augmented virtual reality. J Const Eng Man *140*(7):04014024.

Ali PA, Naylor PB [2013]. Intimate partner violence: A narrative review of the feminist, social and ecological explanations for its causation. Aggress and Viol Beh *18*(6):611–619.

Alison L, van den Heuvel C, Waring S, Power N, Long A, O'Hara T, Crego J [2013]. Immersive simulated learning environments for researching critical incidents: A knowledge synthesis of the literature and experiences of studying high-risk strategic decision making. J Cogn Eng Decis Mak. *7*(3):255–72.

Anderson JR [1990]. Cognitive psychology and its implications. WH Freeman/Times Books/Henry Holt & Co. 680 pp.

Arthur W Jr., Bennett W Jr., Stanush PL, McNelly TL [1998]. Factors that influence skill decay and retention: A quantitative review and analysis. Hum Perf *11*(1):57–101.

Baddeley AD [1986]. Working memory. Oxford, UK: Claredon.

Baldwin TT, Ford JK [1988]. Transfer of training: A review and directions for future research. Per Psych *41*(1):63–105.

Bandura A [1977]. Self-efficacy: Toward a unifying theory of behavioral change. Psych Res *84*(2):191.

Bandura A [1982]. Self-efficacy mechanism in human agency. Am Psych *37*(2):122.

Bandura A [1986]. The explanatory and predictive scope of self-efficacy theory. J Soc Clin Psych *4*(3):359–373.

Bandura A [2006]. Guide for constructing self-efficacy scales. Self-efficacy Bel Adol *5*(1):307–337.

Banker RD, Field JM, Schroeder RG, Sintia KK [1996]. Impact of work teams on manufacturing performance: A longitudinal field study. Acad Manage J *39*(4):867–890.

Bauerle TJ [2016]. Ad hoc groups engaged in emergency decision-making: A mixed-methods study to improve successful self-escape from underground coal fires. Doctoral Dissertation. Mansfield, Connecticut: Johns Hopkins University of Connecticut.

Bauerle T, Brnich MJ, Navoyski J [2016a]. Exploring virtual mental practice in maintenance task training. J Work Learn *28*(5):294–306.

Bauerle T Bellanca JL, Orr TJ, Helfrich W, Brnich M [2016b]. Improving simulation training debriefs: Mine emergency escape training case study. In: The Interservice/Industry Training, Simulation and Education Conference (I/ITSEC):16319.

Beilock S [2010]. Choke: What the secrets of the brain reveal about getting it right when you have to. New York, NY: Free Press. 384 pp.

Belbase A, Sanzenbacher GT, Gillis CM [2015]. Does age-related decline in ability correspond with retirement age? Center for Retirement Research at Boston College Working Paper 2015–24.

Belbase A, Sanzenbacher GT, Gillis CM [2017]. Beyond blue and white collar: Age-related decline, occupation, and retirement timing. J Ret *5*(2):26–41.

Bell BS, Kozlowski SWJ [2009]. Toward a theory of learner-centered training design: An integrative framework of active learning. In: SWJ Kozlowski, E Salas (Eds.), Learning, training, and development in organizations. New York: Routledge. 263 pp.

Bellanca JL, Orr TJ, Helfrich W, Macdonald B, Navoyski J, Demich B. [2019]. Developing a virtual reality environment for mining research. Mining, Metallurgy & Exploration *36*(4):597–606.

Bennett W Jr., Alliger GM, Rowe L, Colegrove C [2012]. Skill decay and the value of training. Paper presented at the NATO RTO System Analysis and Studies Panel (SAS).

Blume BD, Ford JK, Baldwin TT, Huang JL [2010]. Transfer of training: A meta-analytic review. J Man *36*(4):1065–1105.

Branson RK [1977]. Interservice procedures for instructional systems development: Task V final report.

Branson RK [1978]. The interservice procedures for instructional systems development. Ed Tech *18*(3):11–14.

Branson RK, Rayner GT, Cox JL, Furman JP, King F [1975]. Interservice procedures for instructional systems development. Executive summary and model. Florida State University Tallahassee Center for Educational Technology.

Brown ID, Groeger JA [1988]. Risk perception and decision taking during the transition between novice and experienced driver status. Ergonomics *31*(4):585–597.

Burke LA, Hutchins HM [2007]. Training transfer: An integrative literature review. Hum Res De. Rev *6:*263–296.

Burke MJ, Sarpy SA, Smith-Crowe K, Chan-Serafin S, Salvador RO, Islam G [2006a]. Relative effectiveness of worker safety and health training methods. Am J Pub Health Marketing *96*(3):480–487.

Burke CS, Stagl KC, Salas E, Pierce L, Kendall D [2006b]. Understanding team adaptation: A conceptual analysis and model. J of Appl Psychol *91*(6):1189–1207.

Cannon-Bowers JA, Bowers C [2011]. Team development and functioning. In: APA Handbook of Industrial and Organizational Psychology, Vol 1: Building and Developing the Organization. Zedeck S, ed. Washington, DC: American Psychological Association: 597–650.

Cannon-Bowers JA, Salas E [1998]. Making decisions under stress: Implications for individual and team training. Washington, DC: American Psychological Association.

Cannon-Bowers JA, Bell HH [1997]. Training decision makers for complex environments: Implications of the naturalistic decision-making perspective. In C. E. Zsambok & G. Klein (Eds.), Naturalistic decision-making. Mahwah NJ: Lawrence Erlbaum Associates: 99–110. https://apps.dtic.mil/sti/pdfs/ADA483721.pdf

Champaloux SW, Young DR [2015]. Childhood chronic health conditions and educational attainment: A social ecological approach. J Adol Health *56*(1):98–105.

Cheang KI [2009]. Effect of learner-centered teaching on motivation and learning strategies in a third-year pharmacotherapy course. Am J Pharm Educ *73*(3).

Chittaro L, Corbett CL, McLean GA, Zangrando N [2018]. Safety knowledge transfer through mobile virtual reality: A study of aviation life preserver donning. Saf Sci *102*:159–168.

Christian MS, Bradley JC, Wallace JC, Burke MJ [2009]. Workplace safety: A meta-analysis of the roles of person and situation factors. J Appl Psych *94*(5):1103–1127.

Cohen SG, Ledford GE [1994]. The effectiveness of self-managing teams: A quasi-experiment. Hum Relat *47*(1):13–43.

Cohen MS, Freeman JT, Thompson BT [1998]. Critical thinking skills in tactical decision-making: A model and training method. In: Decision-making under stress: Implications for training and simulation. Canon-Bowers J, Salas E, eds. Washington, DC: American Psychological Association.

Colquitt JA, LePine JA, Noe RA [2000]. Toward an integrative theory of training motivation: A meta-analytic path analysis of 20 years of research. J Appl Psych *85*(5):678–707.

Comfort LK [2007]. Crisis management in hindsight: Cognition, communication, coordination, and control. Pub Admin Rev *67*:189–197.

Commonwealth of Australia [2020]. Escape from hazardous situations unaided. RIIERR203D. Published by the Australian Government, Department of Education, Employment and Workplace Relations. Industry Skills Council. https://training.gov.au/Training/Details/RIIERR203E.

Connor BP, Gallick J [2018]. Ideas from the field: Training "responsible persons" to lead and succeed. Coal Age *123*(3):32–34.

Connor BP, Brnich MJ, Mallett LG, Orr TJ [2016]. Effective group training with computer-based virtual environments. Coal Age *121*(6):44–49.

Cook NM [1989]. The applicability of verbal mnemonics for different populations: A review. Appl Cog Psychol *3*(1):3–22.

Crandall B, Klein G, Klein GA, Hoffman RR [2006]. Working minds: A practitioner's guide to cognitive task analysis. MIT Press.

Curseu P, Schruijer S [2012]. Normative interventions, emergent cognition, and decision rationality in ad hoc and established groups. Manag Decis *50*(6):1062–1075.

David DG [1997]. Decision-making training for aircrew. In: Decision-making Under Stress. Flin R, Salas E, Strub M, Martin L, eds. Aldershot, UK: Ashgate. pp. 243–251.

Deery HA [2000]. Hazard and risk perception among young novice drivers. J Safety Res *30*(4):224–236.

DeGrosky MT, Parry CS [2011]. Beyond the AAR: The action review cycle (ARC). Proceedings of 11th International Wildland Fire Safety Summit, Missoula, MT.

Denissen JJ, Zarrett NR, Eccles JS [2007]. I like to do it, I'm able, and I know I am: Longitudinal couplings between domain-specific achievement, self-concept, and interest. Child Dev *78*(2):430–447.

DoD [2001]. Department of Defense Handbook: Instructional systems development/systems approach to training and education [Part 2 of 5]. MIL-HDBK-29612-2, Washington, DC. U.S. Department of Defense.

Driskell JE, Salas E, Johnston J [1999]. Does stress lead to a loss of team perspective? Group Dyn Theory Res Pract *3*(4):291–302.

Druckman D, Bjork RA [1991]. Modeling expertise. In: In the mind's eye: Enhancing human performance. Druckman D, Bjork RA, eds. Washington, DC: National Academy Press. 57 pp.

Drury CG [1983]. Task analysis methods in industry. Appl Ergo *14*(1):19–28.

Engle RW, Kane MJ, Tuholski SW [1999]. Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In: Models of Working Memory: Mechanisms of Active Maintenance and Executive Control. Miyake A, Shah P, eds. Cambridge, UK: Cambridge University Press.

FEMA [2019]. FEMA glossary. Washington DC: U.S. Department of Homeland Security. https://training.fema.gov/programs/emischool/el361toolkit/glossary.htm.

Filigenzi MT, Orr TJ, Ruff TM [2000]. Virtual reality for mine safety training. Appl Occ Env Hyg *15*(6):465–469.

Flin R, Slaven G, Stewart K. [1996]. Emergency decision-making in the offshore oil and gas industry. Hum Factors *38*(2):262–277. https://www.sciencedirect.com/science/article/pii/0925753596000112

Flynn D, Eddy ER, Tannenbaum SI [2006]. The impact of national culture on the continuous learning environment. Journal of East-West Business *12*(2-3):85–107.

Ford JK, Schmidt AMJ [2000]. Emergency response training: Strategies for enhancing real-world performance. J Haz Mat *75*(2-3):195–215.

Foushee HC [1984]. Dyads and triads at 35,000 feet: Factors affecting group process and aircrew performance. Am Psychol *39*(8):885–893.

Fuller R, Cliff D, Horberry T [2012]. Optimising the use of an incident management system in coal mining emergencies. In: Earth: Fire and Rain. Disaster and Emergency Management Conference, pp. 166–176.

Fuller RG [2014]. The impact of non-technical issues on decision-making by coal mining incident management teams. Thesis. Brisbane, Australia: The University of Queensland.

Gaba DM, Howard SK [1995]. Situation awareness in anesthesiology. Hum. Factors *37*(1) 20–31.

Gagne RM [1962]. Military training and principles of learning. Am Psych *17*(2):83. https://psycnet.apa.org/record/1963-02067-001**.**

Galvin JM [2008]. Review of best practices for escape and rescue from underground coal mines in Australia. Galvin and Associates Pty Ltd, St. Ives NSW, Australia: Unpublished contract report for Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

GAO [2007]. Better oversight and coordination by MSHA and other federal agencies could improve safety for underground coal miners. GAO-07-622. Washington, DC: U.S. Government Accountability Office.

Health and Safety Executive: United Kingdom [2015]. Mines Regulations 2014 (149). Can be retrieved from https://www.hse.gov.uk/pubns/books/l149.htm.

Gegenfurtner A [2011]. Motivation and transfer in professional training: A meta-analysis of the moderating effects of knowledge type, instruction, and assessment conditions. 3 vols, Vol. 6.

Gist ME [1987]. Self-efficacy: Implications for organizational behavior and human resource management. Acad Man Rev *12*(3):472–485.

Gladstein DL, Reilly NP [1985]. Group decision-making under threat: The tycoon game. Acad Manage J *28*(3):613–627.

Glanz K, Rimer BK, Lewis FM [2002]. Health behavior and health education: Theory, research, and practice. Third edition. Jossey-Bass: San Francisco, CA.

Glaser R [1984]. Education and thinking: The role of knowledge. Am Psychol *39*(2): 93—104.

gOE/Aptima [2016a]. Emergency self-escape phase 2 report: Identify and categorize primary self-escape tasks. Unpublished contract report for the Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

gOE/Aptima [2016b]. Improving self-escape from underground coal mines training initiative: Training and assessment strategy recommendations. Unpublished contract report for the Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

gOE/Aptima [2017a]. Improving self-escape from underground coal mines training initiative: Decision-making. Unpublished contract report for the Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

gOE/Aptima [2017b]. Emergency self-escape phase 3 report: Hierarchical task analysis and recommendations. Unpublished contract report for the Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

gOE/Aptima [2017c]. Emergency self-escape phase 4 report: Cognitive task analysis and recommendations. Unpublished contract report for the Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

Haas EJ, Hoebbel CL, Rost KA [2014]. An analysis of trainers' perspectives within an ecological framework: Factors that influence mine safety training processes. Safety and Health at Work *5*(3):118–24.

Haas EJ, McGuire J, Hoebbel CL [2017]. Workplace perceptions of safety: What do your workers think about health and safety, why does it matter, and what can you do about it? Rock Prod May:26–27, 30, 32.

Haas EJ, Ryan M, Hoebbel CL [2018]. Job autonomy and safety climate: Examining associations in the mining industry. Pro Safety *63*(12):30–34.

Haas EJ, Eiter B, Hoebbel C, Ryan ME [2019]. The impact of job, site, and industry experience on worker health and safety. Safety, *5*(1):16.

Haas EJ [2020]. The role of supervisory support on workers' health and safety performance, Health Comm *35*(3):364–374

Hackos JT, Redish J [1998]. User and task analysis for interface design. Wiley Computer Publishing. 512 pp.

Hall J, Williams MS [1966]. A comparison of decision-making performances in established and ad hoc groups. J Pers Soc Psychol *3*(2):214–222.

Hambrick DZ, Engle RW [2002]. Effects of domain knowledge, working memory capacity, and age on cognitive performance: An investigation of the knowledge-is-power hypothesis. Cog Psych *44*(4):339–387.

Hanson D, Hanson J, Vardon P, McFarlane K, Lloyd J, Muller R, Durrheim D [2005]. The injury iceberg: An ecological approach to planning sustainable community safety interventions. Health Prom J Australia *16*(1):5–10.

Harms PD, Herian MN, Krasikova DV, Vanhove AJ, Lester PB [2013]. The comprehensive soldier and family fitness evaluation. Report #4: Evaluation of resilience training and mental and behavioral health outcomes. Lincoln, NE: P.D. Harms Publications. 43 pp. https://digitalcommons.unl.edu/pdharms/10/

Hicks C, Hennessy D, Barwell F [1996]. Development of a psychometrically valid training needs analysis instrument for use with primary health care teams. Health Serv Man Res *9*(4):262–272.

Hoebbel C, Bauerle T, Macdonald B, Mallett L [2015]. Assessing the effects of virtual emergency training on mine rescue team efficacy. Conference Proceeding, Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), Orlando, FL, November 30–December 4, 2015.

Hoebbel C, Brnich MJ, Ryan ME [2018] The ABCs of KSAs: Assessing the self-escape knowledge, skills and abilities of coal miners. Coal Age *123*(1):30–34.

Hoebbel C, Sbaffoni J [2021]. Revisiting the role of the responsible person. Presented at the Joseph A. Holmes Safety Association Annual Meeting, October 14, Clearwater, FL.

Hoebbel C, Diamond J, LaFollette A [2022]. Training realism and mineworker confidence in self-escape KSAs: a case study of CONSOL Energy's enhanced training program. Presented at the Training Resources Applied to Mining (TRAM) Seminar, October 11–13, Beaver, WV.

Hunter DR [2002]. Risk perception and risk tolerance in aircraft pilots. Federal Aviation Administration Report No. PB2003100818. Washington, DC: Federal Aviation Administration.

Hutton RJ, Klein G [1999]. Expert decision-making. Systems Engineering: The Journal of The International Council on Systems Engineering *2*(1):32–45.

Janis IL [1982]. Groupthink: Psychological studies of policy decisions and fiascoes. Boston, MA: Wadsworth Cengage.

Janis IL, Mann L [1977]. Decision-making: A psychological analysis of conflict, choice, and commitment. New York, NY: Free Press.

Jarvis P [2006]. Teaching in a changing world. In: The Theory and Practice of Teaching. London: Routledge. pp. 17–29.

Johnson C, Gonzalez AJ [2008]. Automated after action review: State-of-the-art review and trends. J Def Model Simul *5*(2):108–121.

Johnston JH, Driskell JE, Salas E. [1997]. Vigilant and hypervigilant decision-making. J Appl Psychol *82*(4):614–622.

Jonker BE, Graupner LI, Rossouw L [2020]. An intervention framework to facilitate psychological trauma management in high-risk occupations. Front Psychol *27*(11):1–16.

Kaempf GL, Wolf S, Miller TE [1993]. Decision-making in the AEGIS combat information center. Proc Hum Factors and Ergon Soc Annu Meet *37*(16):1107–1111.

Kazak AE [1989]. Families of chronically ill children. J Consult Clin Psych *57*(1):25–30.

Keeney MJ, Wiggins S, Reynolds KD, Berger JL, Hoebbel CL [2018]. Cognitive task analysis of miner preparedness to self-escape from mine emergencies. J Org Psych *18*(4):66–87.

Kingsley-Westerman C, Peters R [2011]. Improved recognition of lifeline tactile signals by miners. Coal Age *116*(9):40–43.

Kirlik A, Fisk AD, Walker N, Rothrock L [1998]. Feedback augmentation and part-task practice in training dynamic decision-making skills. In: Making Decisions Under Stress: Implications for Individual and Team Training. Cannon-Bowers JA, Salas E, eds. Washington, DC: American Psychological Association. pp. 91–114.

Kizil M [2003]. Virtual reality applications in the Australian minerals industry. In: Proceedings of the Application of Computers and Operations Research in the Minerals Industries. pp. 69–574.

Klein GA [1989]. Recognition-primed decisions. In: Advances in Man-Machine Systems Research. Rouse WB, ed. Greenwich, CT: JAI. 47 pp.

Klein GA [1993]. A recognition-primed decision (RPD) model of rapid decision-making. In: Decision-making in action: Models and methods. Klein G, Orasanu J, Calderwood R, Zsambok CE, eds. Norwood, NJ: Ablex. 138 pp.

Klein GA, Klinger D [1991]. Naturalistic decision-making human systems. IAC Gateway, *11*(3).

Klein GA, Orasanu J, Calderwood R, Zsambok CE [1993]. Decision-making in action: Models and methods. Norwood, NJ: Ablex.

Kontoghiorghes C [2004]. Reconceptualizing the learning transfer conceptual framework: Empirical validation of a new systemic model. Int J Train D *8*(3):210–221.

Kowalski-Trakofler KM, Barrett EA [2003]. The concept of degraded images applied to hazard recognition training in mining for reduction of lost-time injuries. J Safety Res *34*(5):515–525.

Kowalski-Trakofler KM, Vaught C, Brnich MJ [2008]. Expectations training for miners using self-contained self-rescuers in escapes from underground coal mines. J Occup Environ Hyg *5*(10):671–677.

Lawshe CH [1975]. A quantitative approach to content validity. Personnel Psychology *28*(4):563–575. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.460.9380&rep=rep1&type=pdf.

Levin M, Greenwood D [2001]. Pragmatic action research and the struggle to transform universities. Handbook of Action Research: Participative Inquiry Practice. Reason P, Bradbury H, eds. London: Sage Publications. pp. 103–113.

Lewin K [1946]. Action research and minority problems. J Soc Iss *2*(4):34–46.

Loucks L, Yasinski C, Norrholm SD, Maples-Keller J, Post L, Zwiebach L, Fiorillo D, Goodlin M, Jovanovic T, Rizzo AA, Rothbaum BO [2019]. You can do that?!: Feasibility of virtual reality exposure therapy in the treatment of PTSD due to military sexual trauma. J Anx Dis *61*:55–63.

Lovreglio R, Gonzalez V, Feng Z, Amor R, Spearpoint M, Thomas J, Trotter M, Sacks R [2018]. Prototyping virtual reality serious games for building earthquake preparedness: The Auckland city hospital case study. Adv Eng Infor *38*:670–682.

Maitlis S, Sonenshein S [2010]. Sensemaking in crisis and change: Inspiration and insights from Weick. J Man Stud *47*(3):551–580.

Margolis KA [2010]. Underground coal mining injury: A look at how age and experience relate to days lost from work following an injury. Safety Sci *48*(4):417–421.

Martell MJ, Sammarco JJ, Macdonald B, Rubinstein E [2019]. Detectability of a self-illuminating lifeline for self-escape in smoke conditions of an underground mine. Lighting Res Technol 0:1–15.

Mathieu JE, Martineau JW [1993]. Individual and situational influences on the development of self-efficacy: Implications for training effectiveness. Pers Psych *46*(1):125–147.

Mathieu JE, Tannenbaum SI, Salas E [1992]. Influences of individual and situational characteristics on measures of training effectiveness. Acad Man J *35*(4):828–847.

McAteer JD, Bethell TN, Monforton C, Pavlovich JW, Roberts D, Spence B [2006a].The Sago Mine Disaster: A preliminary report to Governor Joe Manchin III. https://usminedisasters.miningquiz.com/download/SagoMineDisasterJuly2006FINAL.pdf.

McAteer JD, Bethell TN, Monforton C, Pavlovich JW, Roberts D, Spence B [2006b]. The Fire at Aracoma Alma Mine #1: A preliminary report to Governor Joe Manchin III. http://www.davittmcateer.com/2015/09/the-fire-at-aracoma-alma-mine-1.html.

McAteer JD, Beall K, Beck JA, McGinley PC, Monforton C, Roberts DC, Spence B, Weise S [2011]. Upper Big Branch: The April 5, 2010 explosion: A failure of basic coal mine safety practices. Report to the Governor, the Governor's Independent Investigation Panel.

McCombs BL [2001]. What do we know about learners and learning? The learner-centered framework: Bringing the educational system into balance. Educational Horizons: 182–193.

McGuire J, Haas EJ, Bohm S [2018]. Only when employees feel supported will they step up and say or do something if they observe an unsafe situation or behavior. Rock Prod: 112–115.

McKinney EH, Davis KJ [2003]. Effects of deliberate practice on crisis decision performance. Human Fact *45*(3):436–444.

McLeroy KR, Bibeau D, Steckler A, Glanz K [1988]. An ecological perspective on health promotion programs. Health Ed Quar *115*(4):351–77.

Militello LG, Hutton RJB [1998]. Applied cognitive task analysis: A practitioner's toolkit for understanding cognitive task demands. Ergo *41*(11):1618–1641.

MINER Act [2006]. Mine Improvement and New Emergency Response Act of 2006. United States Public Laws, 109th Congress – Second Session, convening January 7, 2005. PL 109-236 (S 2803). https://arlweb.msha.gov/MinerAct/2006mineract.pdf.

Miyake A, Shah P [1999]. Models of working memory: Mechanisms of active maintenance and executive control. New York: Cambridge University Press.

Moon BM, Hoffman RR, Eskridge TC, Coffey JW [2011]. Skills in applied concept mapping. Applied Concept Mapping: Capturing, Analyzing, Organizing Knowledge. pp. 23–46.

MSHA [2007a]. Report of investigation: Fatal underground coal mine explosion, January 2, 2006, Sago Mine, Wolf Run Mining Company, Tallmansville, Upshur County, West Virginia. By Gates RA, Phillips RL, Urosek JE, Stephan CR, Stoltz RT, Sentosky DJ, Harris GW, O'Donnell JR, Dresch RA. Arlington, VA: U.S. Department of Labor, Mine Safety and Health Administration.

MSHA [2007b]. Internal review of MSHA's actions at the Sago Mine Wolf Run Mining Company, Sago, Upshur County, West Virginia. By Chao EL, Stickler RE. Arlington, VA: U.S. Department of Labor, Mine Safety and Health Administration.

MSTTC [2006]. Improving mine safety technology and training: Establishing U.S. global leadership. Mine Safety Technology and Training Commission. National Mining Association. http://www.indiaenvironmentportal.org.in/files/mining%20safety_report.pdf.

Navoyski J, Brnich MJ, Bauerle T [2015]. BG 4 benching training software for mine rescue teams. Coal Age, *120*(12):50–55.

NIH [2009]. Competencies Proficiency Scale. National Institutes of Health, Office of Management. https://hr.nih.gov/working-nih/competencies/competencies-proficiency-scale.

NIOSH [1999]. The emergency communication triangle. By Mallett LG, Vaught C, Brnich MJ: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS Publication No. 99-157.

NIOSH [2000]. Behavioral and organizational dimensions of underground mine fires. By Vaught C, Brnich MJ, Mallett LG, Cole HP, Wiehagen WJ, Conti RS, Kowalski KM, Litton CD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS Publication No. 2000-126. IC 9450.

NIOSH [2002]. Principles of adult learning: Application for mine trainers. By Kowalski KM, Vaught C. Pittsburgh PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS Publication No. 2008-133. IC 9463.

NIOSH [2008]. Age awareness training for miners. By Porter WL, Mallett LG, Schwerha DJ, Gallagher S, Torma-Krajewski J, Steiner LJ. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS Publication No. 2002-156. IC 9505.

NIOSH [2009]. Refuge chamber expectations training instructor guide and lesson plans. By Margolis KA, Kowalski-Trakofler KM, Kingsley Westerman CY. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS Publication No. 2010-00. IC 9516.

NIOSH [2010a]. One hundred years of federal mining safety and health research. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS Publication No. 2010-128. IC 9520.

NIOSH [2010b]. Strategies for escape and rescue from underground coal mines. By Alexander DW, Bealko SB, Brnich MJ, Kowalski-Trakofler KM, Peters RH. Pittsburgh PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS Publication No. 2010-134. RI 9522.

NIOSH [2011a]. Nonverbal communication for mine emergencies. By Kosmoski CL, Margolis KA, Kingsley Westerman CY, Mallett LG. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS Publication No. 2012-104. RI 9688.

NIOSH [2011b]. Radio 101: Operating two-way radios every day and in emergencies. By Kingsley Westerman CY, Brnich MJ, Kosmoski C. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS Publication No. 2012-103. RI 9686.

NIOSH [2011c]. When do you take refuge? Decision-making during mine emergency escape. By Kosmoski C, Margolis KA, McNelis KL, Brnich MJ, Mallett LG, Lenart P. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS Publication No. 2011-177C. RI 9682.

NIOSH [2012]. National Survey of the Mining Population: Part I: Employees. By McWilliams LJ, Lenart PJ, Lancaster J, Zeiner JR Jr. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS Publication No. 2012-152. RI 9527.

NIOSH [2015a]. Enhancing mine workers' self-escape by integrating competency assessment into training. By Haas EJ, Peters RH, Kosmoski CL. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS Publication No. 2015-188. RI 9699.

NIOSH [2015b]. Review of current practices of ERP training and drills. By Trackemas J. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Unpublished report.

NIOSH [2018]. Mining project: Self-escape from underground coal mines training initiative. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/mining/researchprogram/projects/project/selfescape.html.

NIOSH [2019a]. Coal mining disasters: 1839 to present. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. https://wwwn.cdc.gov/NIOSH-Mining/MMWC/MineDisasters/Table

NIOSH [2019b]. NIOSH Mining Program: Evidence package for 2008–2018. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/programs/review/pdfs/MiningProgramEvidencePackage-508compliant.pdf

NIOSH [2019c]. NIOSH Mining Program: Strategic Plan FYs 2019–2023: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/mining/UserFiles/researchprogram/strategicplan/StrategicPlan11-10-2019_508-1.pdf

NIOSH [2020]. Assessing the impact of safety climate constructs on worker performance in the mining industry. By Haas EJ, Hoebbel CL, Yorio PL. Pittsburgh PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2020-120, RI 9704.

NIOSH [2023]. Self-escape core competency profile: Guidance for improving underground coal miners' self-escape competency. By Ryan ME, Hoebbel CL, Brnich MJ. Pittsburgh PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2023-134, IC 9534.

Nemiroff PM, Pasmore WA, Ford DL [1976]. The effects of two normative structural interventions on established and ad hoc groups: Implications for improving decision making effectiveness. Decis Sci *7*(4):841–855.

Noble D [1993]. A model to support the development of situation assessment aids. In: Decision-making in action: Models and methods. Klein G, Orasanu J, Calderwood R, Zsambok CE, eds. Norwood, NJ: Ablex. 287 pp.

Noe RA [1986]. Trainees' attributes and attitudes: Neglected influences on training effectiveness. Acad Man Rev *11*(4):736–749.

Noe RA, Schmitt N [1986]. The influence of trainee attitudes on training effectiveness: Test of a model. Pers Psych *39*(3):497–523.

Norman G, Dore K, Grierson L [2012]. The minimal relationship between simulation fidelity and transfer of learning. Med Ed *46*(7):636–647.

National Research Council (NRC) [2010]. A database for a changing economy: Review of the occupational information network (O*NET). Panel to Review the Occupational Information Network (O*NET). National Research Council (NRC), Committee on National Statistics, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Research Council (NRC) [2013]. Improving self-escape from underground coal mines. Committee on Mine Safety: Essential Components of Self-escape. National Research Council, Board on Human-Systems Integration, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

O*NET Resource Center [2016]. U.S. Department of Labor, Employment & Training Administration. https://www.onetcenter.org/.

Orasanu J, Connolly T [1993]. The reinvention of decision-making. In: Decision-making in action: Models and methods. Klein G, Orasanu J, Calderwood R, Zsambok CE, eds. Norwood, NJ: Ablex. 3 pp.

Orasanu J, Fischer U [1997]. Finding decisions in natural environments: The view from the cockpit. In: Naturalistic decision-making. In: Zsambok C, Klein GA, eds. Hillsdale, NJ: Erlbaum. 343 pp.

Orasanu J, Salas E [1993]. Team decision-making in complex environments. In: Decision-making in action: Models and methods. Klein G, Orasanu J, Calderwood R, Zsambok CE, eds. Norwood, NJ: Ablex. 327 pp.

Orr TJ, Filigenzi MT, Ruff TM [1999]. Hazard recognition computer based simulation. In: Proceedings of the Thirtieth Annual Institute on Mining Health, Safety and Research 21–28.

Orr TJ, Macdonald BD, Iverson SR, Hammond WR [2015]. Development of a generic mine visualization tool using unity. In: Proceedings of the Thirty-Seventh International Symposium on the Application of Computers and Operations Research in the Mineral Industry.

Orr TJ, Bellanca JL, Navoyski J, Macdonald B, Helfrich W, Demich B [2019]. Development of visual elements for accurate simulation. In: International Conference on Applied Human Factors and Ergonomics. Springer, Cham. pp. 287–299.

Orr TJ [2016]. NIOSH Mine emergency escape simulation technology available for developers. NIOSH Science Blog. https://blogs.cdc.gov/niosh-science-blog/2016/05/12/mine-escape-simulation/.

Ostroff C, Ford JK [1989]. Assessing training needs: Critical levels of analysis. In: Frontiers of Industrial and Organizational Psychology. The Jossey-Bass Management Series and The Jossey-Bass Social and Behavioral Science Series. Training and Development in Organizations San Francisco, CA, US: Jossey-Bass. pp. 25–62.

Pajares F [1996]. Self-efficacy beliefs in academic settings. Rev Ed Res *66*(4):543–578.

Pajares F [1997]. Current directions in self-efficacy research. Adv Motiv Ach *10*(149):1–49.

Parker CP, Baltes BB, Young SA, Huff JW, Altmann RA, Lacost HA, Roberts JE [2003]. Relationships between psychological climate perceptions and work outcomes: A meta-analytic review. J Org Beh *24*(4):389–416.

Payne JW, Bettman JR, Johnson EJ [1988]. Adaptive strategy selection in decision-making. J Exp Psychol Learn *14*(3):534–552.

Peters R, Kosmoski C [2013]. Are your coal miners prepared to self-escape? Coal Age *118*(1):26–28.

Peters RH, Vaught C, Mallett L [2010]. A review of NIOSH and U.S. Bureau of Mines research to improve miners' health and safety training. In: Extracting the Science: A Century of Mining Research. Brüne J, ed. Littleton, Colorado: Society for Mining, Metallurgy and Exploration.

Pizarro JM, Fuenzalida FA [2021]. Mental health in mine workers: a literature review. Ind Health. *59*(6):343–70.

Price JL, Catrambone R, Engle R [2007]. When capacity matters: The role of working memory in problem solving. In: Learning to Solve Complex Scientific Problems. Jonassen, DH ed. New York: Lawrence Erlbaum. pp. 49–76.

Proctor RW, Dutta A [1995]. Skill acquisition and human performance. Sage Publications, Inc. 451 pp.

Queensland Government [2022]. Queensland level 1 mine emergency exercise reports. The State of Queensland, Department of Natural Resources, Mines and Energy, https://www.publications.qld.gov.au/dataset/queensland-level-1-mine-emergency-exercise-reports.

Queensland Government [2012]. Recognised standard 11: Training in coal mines. The State of Queensland: Queensland Government Department of Natural Resources and Mines, https://www.dnrme.qld.gov.au/__data/assets/pdf_file/0016/240370/recognised-standard-11.pdf.

Queensland Government [2003]. Report of the level 1 mine emergency exercise held at Crinum Coal Mine. The State of Queensland, Department of Natural Resources, Mines and Energy, https://www.publications.qld.gov.au/dataset/e2cbc3e5-52e0-46b9-a2e8-7a764f0055ca/resource/7c1a23bf-8c67-4e39-9592-75c85298e46f/download/2003-crinum-mine-emergency-exercise-report.pdf.

Quiñones MA [1995]. Pretraining context effects: Training assignment as feedback. J Appl Psych *80*(2):226–238.

Radomsky M, Flick J, DeSalvo J, Grayson L, Ramani R [2009]. Escape & evacuation: A miners' education and training tool box, Instructors' handbook. Developed by the Penn State University Miner Training Program; funded by the U.S. Department of Labor, Mine Safety and Health Administration, MSHA Grant # BS-17826-08-60-R-42. https://sites.psu.edu/minertraining/files/2016/11/Escape-Evaculation-Handbook-2mapgm3.pdf.

Reason J [1997]. Managing the risks of organizational accidents. Burlington: Ashgate. 252 pp.

Reason J [2016]. Managing the risks of organizational accidents. Vol. 1, London: Routledge. 272 pp.

Reber PJ, Kotovsky K [1997]. Implicit learning in problem solving: The role of working memory capacity. J Exper Psych: General *126*(2)178.

Resick CJ, Dickson MW, Mitchelson JK, Allison LK, Clark MA [2010]. Team composition, cognition, and effectiveness: Examining mental model similarity and accuracy. Group Dyn Theory Res Pract *14*(2):174.

Rich BL, Lepine JA, Crawford ER [2010]. Job engagement: Antecedents and effects on job performance. Acad Man J *53*(3):617–635.

Rosen MA, Salas E, Lazzara EH, Lyons R [2012]. Cognitive task analysis: Methods for capturing and leveraging expertise in the workplace. In: The Handbook of Work Analysis: Methods, Systems, Applications and Science of Work Measurement in Organizations. Wilson MA, Bennet W Jr., Gibson, SW, Alliger GM, eds. pp. 185–200.

Ross KG, Klein GA, Thunholm P, Schmitt JF, Baxter HC [2004]. The recognition-primed decision model. Mil Rev *LXXIV*(4):6–10.

Ryan ME, Diamond J, Brnich MJ, Hoebbel C [2018]. Using performance management strategies to improve mine emergency training and preparedness. Coal Age *123*(9):37–39.

Salas E, Cannon-Bowers JA [2001]. The science of training: A decade of progress. Ann Rev Psych *52*(1):471–499.

Salas E, Tannenbaum SI, Kraiger K, Smith-Jentsch KA [2012]. The science of training and development in organizations: What matters in practice. Psych Sci Pub Interest *13*(2):74–101.

Sallis JF, Owen N, Fisher E [2015]. Ecological models of health behavior. Health Behavior: Theory, Research, and Practice. Fifth edition. Glanz K, Rimer BA, Viswanath K, eds. Jossey-Bass Public Health Series. pp. 43–64.

Sammarco JJ, Demich B, Macdonald B, Rubinstein EN, Martell M [2020]. Recognition of illuminated colored markers that designate primary and secondary mine escapeways. Lighting Res Tech. Apr 19:1477153520916776.

Schmidt FL, Hunter JE, Outerbridge AN, Trattner MH [1986]. The economic impact of job selection methods on size, productivity, and payroll costs of the federal work force: An empirically based demonstration. Pers Psych *39*(1):1–29.

Schmidt RA, Lee TD [2011]. Motor control and learning: A behavioral emphasis. Fifth edition. Champaign, IL: Human Kinetics. 597 pp.

Seligman ME [2019]. Positive psychology: A personal history. Annu Rev Clin Psychol *15*(1):1–23.

Shafir E, Tversky A [2002]. Decision-making. In: Foundations of Cognitive Psychology, Chapter 26. pp. 601–620.

Siegrist M, Cvetkovich G [2000]. Perception of hazards: The role of social trust and knowledge. Risk Anal Inter Jour *20*(5):713–720.

South African Government. [1998]. Skills development act 97 of 1998 as amended. https://www.gov.za/documents/skills-development-act.

Squire LR, Schacter DL [2003]. Neuropsychology of memory. Third edition. New York: Guilford. 519 pp.

Stanton NA [2006]. Hierarchical task analysis: Developments, applications, and extensions. Appl Ergo *37*(1):55–79.

Staw BM, Sandelands LE, Dutton JE [1981]. Threat rigidity effects in organizational behavior: A multilevel analysis. Adm Sci Q *Dec 1*:501–524.

Stokols D, Perez Lejano R, Hipp J [2013]. Enhancing the resilience of human–environment systems: A social ecological perspective. Ecol Soc *18*(1):7.

Stothard P [2008]. Developing an enhanced VR simulation capability for the coal mining industry. UNSW School of Mining Engineering.

Stothard P, Swadling P [2010]. Assessment of maturity of mining industry simulation. Min Tech *119*(2): 102–109.

Surface EA [2013]. Training needs assessment: Aligning learning and capability with performance requirements and organizational objectives. In: The Handbook of Work Analysis. Routledge. pp. 437–462.

Swearer SM, Hymel S [2015]. Understanding the psychology of bullying: Moving toward a social-ecological diathesis–stress model. Am Psych *70*(4):344.

Tannenbaum SI [1997]. Enhancing continuous learning: Diagnostic findings from multiple companies. Human Res Man *36*(4):437–452.

Tannenbaum SI, Cerasoli CP [2013]. Do team and individual debriefs enhance performance? A meta-analysis. Hum Fact *55*(1):231–245.

Tannenbaum SI, Yukl G [1992]. Training and development in work organizations. Ann Rev Psych *43*(1):399–441.

Taylor SE, Schneider SK [1989]. Coping and the simulation of events. Soc Cog *7*(2):174–194.

Thunholm P [2005]. Planning under time pressure: An attempt toward a prescriptive model of military tactical decision-making. In: How Experts Make Decisions. Montgomery H, Lipshitz R, Brehmer B, eds. New Jersey: Lawrence Erlbaum. pp. 43–56.

Tracey JB, Hinkin TR, Tannenbaum S, Mathieu JE [2001]. The influence of individual characteristics and the work environment on varying levels of training outcomes. Human resource development quarterly *12*(1):5–23.

TRADOC [2017]. Army training and doctrine command, mission command training program. TRADOC Regulation 350-70. Fort Eustis, VA: U.S. Army TRADOC, July 10, 2017. https://adminpubs.tradoc.army.mil/regulations/TR350-70.docx.

Tziner A, Fisher M, Senior T, Weisberg J [2007]. Effects of trainee characteristics on training effectiveness. Int J Sel Assess *15*(2):167–174.

Vasquez G, Bendell R, Talone A, Nguyen B, Jentsch F [2019]. The use of immersive virtual reality for the test and evaluation of interactions with simulated agents. In: Advances in Human Factors in Simulation and Modeling. Cassenti D, ed. AHFE 2018. Advances in Intelligent Systems and Computing 780.

Vaught C, Brnich M, Wiehagen W, Cole H, and Kellner H [1993]. An overview of research on self-contained self-rescuer training. Pittsburgh, PA: US Department of the Interior, Bureau of Mines, Bulletin 695. https://www.cdc.gov/niosh/mining/userfiles/works/pdfs/bul695.pdf.

Waugh WL Jr., Streib G [2006]. Collaboration and leadership for effective emergency management. Pub Admin Rev *66*(1):131–140.

Wiener EL, Kanki BG, Helmreich RL, eds. [1993]. Cockpit resource management. San Diego, CA: Academic Press.

West Virginia Mine Safety Technology Task Force [2006]. Mine safety recommendations: Report to the Director of the Office of Miners' Health, Safety and Training: as required by West Virginia Code §56-4-4. https://minesafety.wv.gov/.

Wilkins, JR [2011]. Construction workers' perceptions of health and safety training programmes. Constr Manage Econ *29*(10):1017–1026.

Wu KK, Gray TA [2008]. Review of best practices for escape and rescue from underground coal mines in China. Tetra Tech NUS, Inc., Pittsburgh, Pennsylvania: CDC contract for the National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory.

Zhou L, Smith AC, Yuan L [2016]. New improvements to MFIRE to enhance fire modeling capabilities. Min Eng *68*(6):45–50.

Zimmerman BJ [2000]. Self-efficacy: An essential motive to learn. Cont Ed Psych *25*(1):82–91.

Zsambok C, Klein G. (eds.). [1999]. Naturalistic decision-making. Hillsdale, NJ: Erlbaum.

Appendix A: Full Text of NAS Recommendations to Improve Self-escape from Underground Coal Mines

The 12 recommendations listed in the table below are from the National Academy of Sciences (NAS) report, “Improving Self-escape from Underground Coal Mines,” [NRC 2013].

NAS 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 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.
2	NIOSH and MSHA 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.

NAS Recommendation	
3	NIOSH, MSHA, 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.
4	NIOSH and MSHA 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.
5	NIOSH 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.
6A	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.

NAS Recommendation	
6B	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 database 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.
7A	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.
7B	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.
7C	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.
7D	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.
7E	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.

Appendix B: Description of Mine Sites Participating in Formal Task Analysis

Two mines—one large and one small—were identified and subsequently approved by NIOSH to be included in the formal task analysis. Both mines are located in the Northern Appalachian Region and a brief description of each follows.

Large Mine

At the large mine, extracted coal is transported by belt to underground storage cars and is raised to the surface via two large, counterbalanced skip hoists. The mine currently employs 250–300 miners working three shifts. This mine has an average seam height of 84 inches. The coal is extracted using the longwall mining method. Two continuous miners develop the mine openings required for longwall operations. Personnel and supplies are transported via trolley powered, rail mounted vehicles. Management consists of a general manager, mine superintendent, mine foremen, shift and assistant shift managers, and front line supervisors. The safety department consists of a safety manager and five safety supervisors. Underground communications consist of radio handsets and mine (pager) phones that access the leaky feeder system; there is a personnel tracking system that continuously updates the location of everyone in the mine. The mine has carbon monoxide sensors along the entire belt. A dispatcher monitors the tracking system, alarms, manages communications and coordinates transportation. Lamp room personnel maintain and calibrate safety equipment. Mine phones are present in several offices on the surface besides the dispatcher's office. Requirements and the day-to-day job duties of surface personnel vary across states and mining operations. Miners receive annual safety training and practice mine-specific escape via drills quarterly.

Small Mine

The small mine is a single-section drift mine with approximately 45 miners working three shifts. The average seam height is 48 inches. A single continuous miner extracts the coal, which is transported out of the mine by a conveyer belt. Personnel transportation is via tire-mounted, battery-powered mantrips. Carbon monoxide sensors are present along the belt conveyor system. A dispatcher's office is located on the surface; among other responsibilities, the dispatcher operates systems for tracking, monitoring, and communicating with the underground crew. Relevant alarms can also be heard outside the office by means of outdoor speakers. There is a tracking system for identifying the location of miners underground. Because of tire-mounted mantrips rather than rail-mounted trolley vehicles ae used and due to the small number of employees per shift there is no need for a full-time dispatcher to coordinate underground traffic. Underground communications include mine phones and radios; the latter are based on a leaky feeder system. Mine management includes a mine superintendent, mine president, mine foreman, and shift/section supervisors. Safety is shared among management. Miners participate in maintaining their own safety equipment and they receive annual safety training and practice escape via drills quarterly.

Appendix C: Preliminary Task Analysis Focus Group Protocol and Four Disaster Scenarios and Worker Roles Included in Formal Task Analysis

Initial Task Analysis Focus Group Session: At each of the two mines, approximately six underground miners (for a total of 12) will participate in an initial task analysis focus group. An initial task analysis focus group could require up to 12 hours of participation per participant, which could be split across multiple days or sessions.

Following is the protocol for conducting the Initial Task Analysis Focus Group Session:

1. Obtain verbal participant consent and document their agreement to participate; provide them with the Informed Consent document.
2. Introduce facilitators.
3. Give session introduction.

We are examining mine self-escape. In this workshop, we will be asking you about the tasks that need to be accomplished to successfully self-escape in the face of several different disaster scenarios. The information you provide will be grouped together and referenced for similar and differing opinions. Our discussion will last no more than 12 hours total, across two or three sessions. ***Your responses to each question will be confidential, and we encourage you to not share information that other people provide during the discussion.*** *We are not recording any of your names, and in any public release of results, no data will be disclosed that could be used to identify specific individuals. Only NIOSH staff who are involved in collecting or preparing the information for analysis will have access to your answers.*

1. Ask participants to introduce themselves, using first names only.
2. Begin session.

During this session, we will focus on identifying the emergency escape tasks for the following four roles:

- Crewman (working face)
- Outby Worker
- Escape Group Leader
- Responsible Person

What are the equivalent positions in your mine?

We’ll use the following four scenarios as a starting point:

#1. Fire
A belt drive will be the source of the ignition for the fire. A hydraulic hose slowly fails on the hydraulic belt take-up letting pressure bleed off the belt system; over a period of time, hydraulic oil is sprayed over the take-up and drive pulleys resulting in small accumulations around the pulley areas. The belt slip switch had malfunctioned, allowing the drive pulleys to spin, generating enough heat to ignite the hydraulic oil and small coal accumulations around the area. The belt drive and fire are located on the main entries on one of the transfer belts to convey coal

out of the mine. This belt is ventilated with air traveling outby from the sections. The belt is monitored by a mine monitoring system which detects the fire and elevated carbon monoxide levels and goes into an alarm status. This belt system is located outby the operating sections.

Role	Location	What information do they have?
Crewman (working face)	Sections	Notified location of elevated carbon monoxide (CO)
Outby worker	Outby belt	Aware of belts shutdown
Escape group leader	Section	Notified to evacuate section due to elevated readings
Responsible person	Underground	Notified of possible fire location to investigate

#2. Explosion

During the idle period, belt repairmen had changed belt rollers on the mainline belt. The belt repairmen were carrying replacement rollers through a man door outby the belt line, which crossed above the overcast and had several bad rollers. This overcast, which was among several overcasts installed in conjunction with other ventilation controls, is where a continuous miner section breaks off from the main section. When the belt repairmen changed the worn rollers, they removed them from the beltline and carried them out through the man door. With their hands full during this process, the belt repairmen blocked the man door from closing. Once the belt repairmen loaded the rollers onto an empty flat car, they were notified that another belt repairman was having difficulty starting up one of the outby belts. The belt repairmen boarded their vehicle and traveled outby to assist getting the mine operational for the oncoming shift. They were able to get the belt running and started the subsequent belts inby. Once all of the belts were started, the belt repairmen traveled out of the mine, completing their shift. Through this process, the repairmen forgot they had left the man door along the main beltline open. Because the mine examiner had completed his exam of this area prior to the belt repair, the open door remained undetected. The mine is considered to be a “gassy” mine. The overcast area and inby area of the repaired beltline is not being properly ventilated because of the open door, allowing methane to accumulate in the high area of the overcast. After the shift starts producing coal for about three hours, an ignition occurs on the beltline above the overcast—possibly from a bad roller or poorly installed roller, producing sparks and igniting the methane. The force of the explosion destroys the intake overcast where the door was open and part of the return overcast banks, sending smoke into all entries of the continuous miner section that breaks off from the main section and to the continuous miner main super-section which is operating two sets of continuous miner equipment.

Role	Location	What information do they have?
Crewman (working face)	Sections	Blast and smoke on section
Outby worker	Travelway inby explosion	Blast and smoke
Escape group leader	Section	Blast and smoke on section
Responsible person	Outside	Notified of explosion and main fan spike

#3. Impoundment Failure/Liquid/Gas Inundation

During the normal mining cycle sequence, the right-side miner started to take a 37-foot cut in the outside right entry. While mining, the miner operator noticed water coming from the face area while taking the third in cut sequence on the ventilation side of the cut, which was unusual as the mine is reasonably dry with little water issues. In addition to the water, the operator noticed the methane readings toward the end of the cut at the face were elevated. Suddenly, coal was ejected from the face followed by a heavy flow of water, followed by an inrush of methane gas. The mine is located in an area that saw gas well drilling in the early part of the 1900s. Most wells in the area were abandoned and/or re-plugged by the mine as needed as mining progressed. The mappings of these gas wells were mostly accurate; however, the mine had experienced problems with this mapping in the past. The water that rushed into the section from the face was minimal. Methane gas quickly filled the entry and continued to flow into the mine from what appeared to be the intersection of an unchartered gas well. The continuous miner operator quickly notified the mechanic on the section with a handheld radio to de-energize the section power at the load center.

Role	Location	What information do they have?
Crewman (working face)	Sections	Aware of intersection of gas well on section
Outby worker	Beltline outby section	None
Escape group leader	Section	Aware of intersection of gas well on section
Responsible person	On haulage traveling to section	None, outside trying to contact

#4. Rockburst/Coal Burst/Roof Fall

A section was mining, when suddenly, approximately 10 cross cuts outby, the roof failed due to a coal burst of a pillar. This coal burst created an excessive roof span resulting in a roof fall across the section, blocking all but one entry for egress from the mine. The crew on the section felt the air blast from the fall and experienced problems with visibility due to the dust from the coal burst and roof fall.

Role	Location	What information do they have?
Crewman (working face)	Sections	Limited visibility, lack of ventilation, felt air blast from fall on section
Outby worker	Travelway outby explosion	None
Escape group leader	Section	Limited visibility, lack of ventilation, felt air blast from fall on section
Responsible person	Underground on section *Another person designated*	Limited visibility, lack of ventilation, felt air blast from fall on section *Aware of loss of communication on section and belt stopped operating*

Process/Questions:

- Which of these disaster scenarios is the most complex? Can we order the rest of these in terms of complexity?
- What are the broad phases of self-escape during a disaster? We are looking for tasks that are performed when: "a disaster has occurred, and the decision has been made to self-escape" until self-escape has successfully occurred.
- Starting with the simplest scenario (information captured on flipcharts and one computer):
    - What happens first?
        - Who is involved?
        - What cues are they attending to?
        - What task(s) are they performing? What are the key decision points?
        - How are decisions made?
        - What equipment are they using?
        - Who are they communicating with?
        - [If not covered in above] What is the crewman doing? Outby worker? Responsible person? Escape group leader?

- What information needs to be monitored/conveyed/received? What happens next? (Cycle through these questions until evacuated)
    - Who is involved?
    - What cues are they attending to?
    - What task(s) are they performing?
    - What are the key decision points?
    - What equipment are they using?
    - Who are they communicating with?
    - What information needs to be monitored/conveyed/received?
    - [If not covered in above] What is the crewman doing? Outby worker? Responsible person? Escape group leader?
- Which of these tasks are most critical? Which are most critical for the crewman? Outby worker? Responsible person? Escape group leader?

- Next scenario, we would like to add any new tasks/events for this scenario that might be different from the prior scenario(s) [cycle through scenarios]:
    - What happens first? Is it similar?
        - Different people involved?
        - Different cues?
        - Different tasks?
        - Different decision points or processes?
        - Different equipment?
        - Different communications?
        - Different information monitored/conveyed/received?
        - [If not covered in above] What is the crewman doing? Outby worker? Responsible person? Escape group leader?
    - What happens next? (Cycle through these questions till evacuated)
        - Different people involved?
        - Different tasks?
        - Different cues?
        - Different decision points or processes?
        - Different equipment?
        - Different communications?
        - Different information monitored/conveyed/received?
        - [If not covered in above] What is the crewman doing? Outby worker? Responsible person? Escape group leader?
    - Which of these new tasks are most critical? Which are most critical for the crewman? Outby worker? Responsible person? Escape group leader?

Appendix D: Initial Interview: Mine Leadership and Safety Management

In the event of a mine disaster that requires evacuating the mine, we want to be sure all mine personnel leave the mine safely, so we are interviewing leadership and mine personnel to learn how we can improve the ability of miners to self-escape.

We'd like to learn as much as we can about how mine evacuation *should* take place, including some of the *best practices* mines are using to prepare miners and mitigate any potential risks.

We believe you have a great deal of knowledge about what should happen and how you would want your mine leadership and mine crews to respond.

Time permitting, I'd like to talk with you about a few of the following:

- **A.** What should happen during evacuation or **self-escape**
- **B.** The greatest **risk points** as you see them
- **C.** Training and **preparation** of mine management, safety managers, and miners
- **D.** Ideas and suggestions for **preventing and reducing** risks

We are not evaluating you or the mine in any way. Our sole intent is to learn about how self-escape should work so we can identify effective practices to share with others, along with ideas for improving the process.

When we summarize our results, we will not share anything that is attributable to you by name. At the end of the entire project, we will provide findings to the mine.

At any point, you can request that your comments not be recorded. Any questions before we begin?

A. Self-escape/Evacuation

1. Let's assume a decision has been made to **evacuate** the mine due to [*a fire, an explosion, impoundment failure/liquid or gas inundation, rockburst/coalburst/roof fall*]. Please help me understand what would happen once the decision has been made.
   - What happens at that point?
   - Then what happens? [Have them talk about what would happen in chronological order during the evacuation process using some of the probes below]

   Potential probes include:

   - What would **you** be doing at that point? What would you be thinking about? What are you concerned about and monitoring? What decisions need to be made? Where are you located to deal with this situation?
   - What would the **other leaders** be doing? What are they paying attention to and who are they talking with?
   - As the disaster unfolds, who has the **most complete picture** of what is happening?
   - What **information or updates** do you need from the managers and mine personnel?
   - What communications, if any, are occurring with corporate personnel (if applicable)?
   - What are other **mine personnel** doing at this time? For example, what are team leaders (section supervisors) doing? What is the safety/compliance officer doing? What are miners doing?
   - What equipment is being assembled topside, if any?
   - What happens if miners are injured?
   - What notifications have to be made to others (e.g., corporate, NIOSH, mine rescue team, local first-responders)?
   - How do we **track** where miners are at this point? What should we do if some miners aren't accounted for?
   - What are the greatest **risks or challenges** at this point? What could hinder miners from performing their roles successfully? What could go wrong?
   - If a challenge or problem emerged, what would be the **best way** to handle it?

2. We are also interested in evacuation at the **team level**. In an evacuation, are escape teams formed and how might they differ from their mining teams?
   - How do supervisors account for all miners in their charge?
   - If a smaller group of miners finds itself cut off from their team leader – what happens? Does someone **assume leadership**? Are there established protocols for that?
   - Are individuals **assigned to evacuation roles** as "backup" in case the first person can't perform that role? If not, how would that happen?
   - Do they **notify** anyone?
   - What roles are **critical** during an evacuation situation?

B. Greatest Risk Points

3. In general, where do you see the **greatest risk points** or challenges that could interfere with miners being able to safely self-escape? Do these differ among the four disaster scenarios?
    - What are ways to **prevent or mitigate** these challenges?
    - As necessary, probe about the following:
        - Miner readiness and preparation
        - Gaps between what miners are capable of doing and the demands of self-escape
        - Communications between the mine leadership and team leaders/crew members; between miners
        - Equipment challenges
        - Interactions with the topside/rescuers
        - Existing policies or procedures
        - Conditions (e.g., power outage, radio/comm failure, miner injuries, shift change)
4. What does your mine **do particularly well** to prepare for evacuations?
    - What would you recommend all mines do to be prepared for, and if necessary, to handle an evacuation successfully?

C. Training and Preparation

Mine Leadership/Safety Managers

5. What type of **training, preparation, and drills** do mine managers/safety managers participate in to prepare them for an evacuation?
    - When did you experience this? What was the purpose of the training/drill/material? How was it delivered?
    - What are some of the best training experiences, drills or other forms of preparation related to evacuation that you’ve experienced? What made them particularly useful?
    - How often and when do these training experiences/drills typically take place?
6. What is the role of the mine’s senior leaders/safety managers **during mine evacuation** drills?
    - What, if anything, do you or the leaders need to do to prepare for the drills?
    - Do you get any feedback about the drill? What, if anything, do you or the leaders do with the results from the drill?

Miners

7. What type of training do miners receive regarding evacuation?
   - Please describe each (how often does this training take place, what is done to prepare for the training, what happens during the training, what happens after the training)
     - Note: Consider whether/how the training provides information to trainees, demonstrates behavior, allows for practice, and provides feedback individually or through a debrief, etc.
   - Do miners train or drill with those on their shift?
   - What are the learning objectives of that training? [collect any documentation about the objectives, and training methods/materials]
   - How were the training requirements determined?
   - Any use of videos, readings, or computer-based training?
     - What is done after the training or drill to track, capture or share lessons learned?
   - What ideas do you have for improving training?
8. What **obstacles or challenges exist** that can interfere with evacuation training?

D. Ideas and Suggestions

9. What **changes,** if any, would you recommend that might help **improve** mine and miners' readiness to handle an evacuation?
   - Any changes to training, equipment, communications, worker roles, etc.?

THANK YOU VERY MUCH!

Appendix E: Major Self-escape Activities and Critical KSAs Identified through Preliminary Task Analysis

Activity	Critical KSA	Cognitive KSA?
Accounting for personnel	Ensure the location, movement, and safety of “Red Hats” when in charge of them.	Yes
	Take headcount at designated meeting place to determine miners present or missing; identify follow-on actions if crew members are missing (e.g., wait, try to find); if non-crew miners present, include in own group.	Yes
	During headcount, identify number/type of injuries.	Yes
Communicating nonverbally	Use nonverbal communications (e.g., hand, cap lamp signals) with others in the mine.	No
	Use nonverbal signals (e.g., tapping codes on radio/phone) from within the mine to communicate with others above ground.	No
	Use writing (e.g., paper & pencil, date boards) to communicate nonverbally with others in the mine.	No
	Communicate while using SCSRs (sounds, signals).	No
	Use “pulls” on tagline to communicate stop/go/advance/retreat, using standard mine rescue lifeline pull sequence.	No
Communicating verbally	Communicate with escape group leader (EGL), record who is in group, and communicate/confirm plans.	Yes
	Call RP upon alarm on section or other potential disaster event indicator, and ensure RP knows who is talking, where located, situation (nature, severity, how being handled).	Yes
	Receive and relay critical information to EGL, and crewman receive via pager/phone, radio.	No
	Communicate escape plan to crew.	No
	Communicate loudly and clearly; verbally repeat directions/information to confirm.	No

Activity	Critical KSA	Cognitive KSA?
Decision-making	Determine escape route (e.g., escape via primary escapeway and go to escape shaft) and communicate, working with dispatcher to relay as needed.	Yes
	Decide on self-escape methods (e.g., walking, riding), route (e.g., primary, secondary escapeway) and communicate conditions (e.g., multigas detector readings), working with dispatcher to relay as needed.	Yes
	If escapeway (e.g., primary) blocked, determine and move to alternate (e.g., secondary).	Yes
	Decide on whether/how to move injured miner(s) in conjunction with crew EMT(s).	Yes
	Decide to escape or receive order to escape.	Yes
	Decide whether to fight fire or abandon fire and escape.	Yes
	Decide to use refuge chamber.	Yes
Diagnosing	Help diagnose disaster (e.g., visual of problem, relay information (e.g., conditions, multigas detector readings).	Yes
	Diagnose: Type (e.g., fire, inundation, roof-fall, or rock burst, explosion), location, severity.	Yes
	Recognize dispatcher-initiated audio and/or visual alarms/alerts (e.g., horns, lights).	Yes
	Receive, interpret alarms/alerts/information from underground.	Yes
Directing and managing	Execute the Emergency Response Plan.	Yes
	Review Emergency Response Plan to ensure it is executed properly during an emergency situation.	Yes
	Handle panic in self.	Yes
	Handle panic in others.	Yes

Activity	Critical KSA	Cognitive KSA?
Establishing and maintaining situational awareness (SA)	Recognize disaster conditions/events (e.g., change in ventilation, smoke, blast, water).	Yes
	Assess and maintain awareness of physical conditions of mine/section (e.g., water, ventilation, construction activities).	Yes
	Assess and maintain awareness of conditions of mine communications equipment (e.g., phones, leaky feeder).	Yes
	Understand the workings and inherent/current limitations of the tracking system used to track movements of miners underground.	Yes
	To the extent possible, determine and maintain awareness of where others on crew are in the mine and relative to own position.	Yes
	Know the identity of the current shift's designated RP (and back-ups if so designated).	Yes
	Maintain awareness of escapeways, SCSR cache, and refuge locations.	Yes
	Note signage, escapeway reflectors.	Yes
	Determine and maintain awareness of where you are in the mine.	Yes
	Maintain "big picture" of unfolding disaster (nature/extent/severity of disaster conditions, location of escaping miners, next likely steps).	Yes
Firefighting	Fight fire (as per appropriate role as designated in mine-specific Firefighting Plan).	Yes
Leading	Exert calm, steady influence.	Yes
	Manage conflict and disagreements among crew members.	Yes
	Assume leadership role in situations where a group is without a leader (e.g., leader is separated from group, no leader from the start of situation).	Yes

Activity	Critical KSA	Cognitive KSA?
Moving	Move to fresh air.	No
	Guide self visually or tactically (follow ribs, equipment, cables).	Yes
	Climb over/around debris (e.g., due to explosion, roof fall).	No
	Travel by foot through mine where roof height is low (e.g., bending forward, duck walk, crawling).	No
	If no lifeline, use other tactile techniques (rib line, power feeder).	Yes
	Navigate through smoke-filled area of mine (e.g., go low, deal with limited visibility).	Yes
	Travel escapeway in darkened/changed conditions (e.g., rock dust blown off walls/ceiling/floor, walls/ceiling/floor covered in soot).	Yes
Operating communication technology	Operate mine phone for one-to-one communications and as mine-wide pager.	No
	Operate walkie-talkies (e.g., Leaky Feeder radios) on appropriate channels to communicate with others above and below ground.	No
	Operate trolley radio to communicate with others above ground and within the mine.	No
Post-exit	Assign person(s) to identify miners upon mine exit.	No
	Participate in debrief (i.e., report conditions in mine, information about others still in mine).	Yes
Supporting map usage	Ensure obsolete escapeway maps have been replaced with current escapeway maps to ensure accurate depiction of location of escapeways, airflows, refuge chambers, SCSR caches, and doors on escapeways.	No
Treating injured miner(s)	Administer first aid to injured miners.	Yes

Activity	Critical KSA	Cognitive KSA?
Using lifelines	Locate and follow lifeline (tactile wayfinding).	No
	Identify location of caches and refuge alternatives, follow escapeway.	Yes
Using mine maps	Retrieve and use escapeway map.	Yes
	Read and interpret the mine map to ensure familiarity with current working location and mine layout and to develop/maintain mine map reading skills that are important during self-escape scenarios.	Yes
Using multigas detector	Monitor/read air.	Yes
	Use gas monitor.	Yes
Using personal equipment	Conduct checks on lamp, radio, and gas monitor to ensure they are working.	No
	Ensure a serviceable self-contained self-rescuer (SCSR) is on own belt.	No
Using refuge alternatives	Deploy.	No
	Inflate.	No
	Set up scrubbers.	No
	Purge bad air.	No
	Enter (bring in one-hour SCSRs also).	No
	Communicate with RP/Dispatcher via phone, check outside air with gas detector, change/fix scrubber fan as needed.	No
Using SCSRs	Help others switch/swap SCSRs.	No
	Don short-term SCSR and move to nearest one-hour SCSR cache	No
	Move to cache and switch/swap own short-term SCSR (e.g., M-20s) for one-hour unit (e.g., OCENCOs); grab extra SCSR.	No

Activity	Critical KSA	Cognitive KSA?
Using taglines/tetherlines	Connect self to tagline/tetherline.	No
	Walk on tagline/tetherline.	No

Appendix F: HTA Critical KSAs by Self-escape Role

Critical KSA	Self-escape leadership	RF Miners
Understand what gases may be present in a mine environment and how they behave (e.g., substance that fills the area of containment; soluble gases can be released from water when water is disturbed).	X	X
Know desired min/max gas levels (methane, CO, oxygen).	X	X
Know how body and mind can react when exposed to low oxygen levels or high CO levels and the speed with which effects can occur.	X	X
Know procedures when air contains specific elevated levels of CO or low oxygen (e.g., when to don SCSR).	X	X
Know the explosive and inert levels of methane.	X	X
Know procedures when air contains specific elevated levels of methane (e.g., remove power to equipment).	X	X
Know where/how to find fresh air (e.g., go towards an intake air shaft).	X	X
Read and interpret CO systems/graphs/charts.	X	
Know effect of coal dust on methane explosibility and how a local methane explosion can transition into a mine-wide dust explosion.	X	X
Know that even a small, localized methane explosion can destroy ventilation control devices (stoppings, overcasts, etc.).	X	X
Understand that ventilation control devices destroyed by an explosion can cause fresh air to short circuit, which allows inby methane concentrations to increase and may result in a second explosion.	X	X
Know that a drop in barometric pressure causes sealed areas to outgas.	X	X
Understand the potential effects of elevated methane levels on oxygen.	X	X
Use hand-held gas meters to assess air quality.	X	X
Calibrate hand-held gas meters.	X	X
Understand why false (nuisance) alarms can occur (e.g., due to diesel exhaust CO).	X	X
Understand that both asphyxiation and poisoning can occur due to poor air quality.	X	X

Critical KSA	Self-escape leadership	RF Miners
From outside of the mine, understand significance of alarms and monitoring systems within the mine.	X	
Understand significance of sensor alarm activation patterns (e.g., multiple alarms, sequence of alarms).	X	X
Communicate critical information about the miners underground (location, headcount, names, physical condition, needs).	X	X
Communicate critical information about the situation (severity, conditions of mine, affected areas, air quality, smoke, visibility, conditions of equipment).	X	X
Communicate important information (e.g., what you see) to Responsible Person/Dispatcher.	X	X
Communicate plans and next steps (e.g., move to meeting point, move to escapeway).	X	X
Provide updates on situation to Responsible Person/Dispatcher (e.g., escape progress, change in plans).	X	X
Ensure all miners know what is in storage locations (e.g., glow sticks, map, hammer, tagline, or other items required by state/operation guidelines).	X	X
Prioritize information to identify critical elements to communicate with Responsible Person/Dispatcher.	X	X
Deliver or listen to roof support plan.	X	X
From a location outside of the mine, gather critical information from those working within the mine.	X	
Operate mine phones and radios.	X	X
Know what to do if signal is lost (e.g., move to another location to find signal).	X	X
Know direct line of site option with radio/walkie-talkie.	X	X
Know emergency radio channels.	X	X
Manage multiple/simultaneous communications.		X
Identify problems/issues with communications equipment.	X	X
Know backup and work-around communication options when there are problems with primary methods.	X	X
Know potential effects of disaster on communications equipment (e.g., impact of heat/explosion on nodes, antennas, and cables).	X	X
Communicate in writing.	X	X
Confirm information provided is received and understood.	X	X

Critical KSA	Self-escape leadership	RF Miners
Know check-in procedures when arriving at working section (e.g., if maintenance man arrives, check in with foreman so foreman knows he is there).	X	X
Know to ask yes/no questions to elicit information from individuals with limited verbal communication capabilities (e.g., a person using an SCSR).	X	X
Know nonverbal cap lamp communication standards.	X	X
Know nonverbal communication techniques using the tagline (e.g., standard mine rescue crew lifeline/link line pull sequences).	X	X
Know nonverbal tapping standards.		X
Repeat information received to confirm reception and understanding.	X	X
Speak clearly and loudly.	X	X
Use technology-based, nonverbal communication techniques where available (e.g., text pager).	X	X
Use various techniques to communicate with someone who has limited or no ability to communicate verbally (e.g., a person using an SCSR).	X	X
Help crew members understand other points of view or opinions.	X	X
Manage disagreements among others.	X	X
Coordinate with the mine foreman and other experts and authorities.	X	
Develop an understanding of the experience/inexperience of crew members.	X	X
Develop knowledge of all personnel working within or near one’s own section or area during shift.	X	X
Identify the Responsible Person for each shift.	X	X
Know crew members assigned locations.	X	
Know the strengths, capabilities, and experience of individual crew members.	X	
Know one’s own limitations and capabilities.		X
Know members of one’s own crew.	X	
Contribute information to exit debrief.		X
Know what questions to ask exiting miners.	X	

Critical KSA	Self-escape leadership	RF Miners
Understand the potential impact of different disasters/emergencies on mine, equipment, and power (e.g., effects of explosion on communications infrastructure, lifeline).	X	X
Detect/recognize changes in mine conditions or surroundings (e.g., ventilation change such as blast of air, airflow reversal).	X	X
Determine location of disaster.	X	X
Determine source of problem or emergency.	X	X
Recognize potential significance of the power going out.	X	X
Recognize your location relative to location of the disaster (e.g., if outby the fire).	X	X
Understand dangers associated with water (e.g., blocked airflow, hypothermia).	X	X
Understand significance of smoke.	X	X
Recognize signs of potential disaster in fan chart readings (e.g., spikes) and smoke from fans or exhaust shafts.	X	
Carry important personal equipment/tools/supplies.	X	X
Conduct checks on personal equipment/tools/supplies.	X	X
Drive and operate all vehicles in mine, including escape vehicles.	X	X
Know importance of carrying self-escape equipment/tools/supplies.	X	X
Operate cap lamps and blinking lights.	X	X
Execute Responsible Person checklist (know related procedures, information to gather).	X	
Gather, interpret, and synthesize information from multiple sources (e.g., sensors, people exiting mine, miners underground).	X	
Know the ERP.	X	
Know the Rescue Notification Plan.	X	
Maintain awareness of periodic changes to ERP.	X	
Understand how one’s role shifts over the course of the emergency and in execution of the ERP (e.g., when other authorities arrive).	X	
Understand one’s own and others’ roles in executing the ERP.		X
Document critical information and times.	X	
Know escape plans, protocols, and procedures.	X	X

Critical KSA	Self-escape leadership	RF Miners
Know location of escapeways (primary and secondary) relative to meeting point (e.g., power center).	X	X
Know potential alternative escape routes that crew members might take in emergency situations.	X	X
Know primary and secondary escapeways.	X	X
Recognize your location relative to location of primary and secondary escapeways.	X	X
Understand signage along the escapeway.	X	X
Know colors of reflective markers for primary and secondary escapeways.	X	X
Know location of all exits (e.g., shafts, drift opening).	X	X
Judge severity of fire (e.g., based on size and spread of fire, location of fire).	X	X
Know firefighting plans.	X	X
Know role in fighting a fire (e.g., as supervisor, using pager to communicate with outside the mine, gathering fire extinguishers).	X	X
Know where to move in the event of a fire, based on one's own current location relative to fire.	X	X
Recognize crew members who will/will not be involved in fighting the fire.	X	X
Understand impact of fire and smoke on air.	X	X
Understand whether you are in a location where it is possible to help fight the fire (e.g., if outby the fire, if in fresh air).	X	X
Use firefighting equipment (fire extinguishers).	X	X
Visually inspect fire (put eyes on it).	X	X
Communicate with others underground (e.g., shift foreman) to gather information about personnel working within the mine (e.g., confirm location and conditions).	X	X
Identify important unknown information (e.g., number and location of affected miners).	X	X
Know if a miner is out of communication when disaster occurs (e.g., someone in the bleeders).	X	X
Know what questions to ask to gather specific details about personnel involved with situation (e.g., air, potential smoke on section, names, location, and condition of personnel) and the conditions within the mine (e.g., air quality, escapeway conditions).	X	

Critical KSA	Self-escape leadership	RF Miners
Know/determine who is in the mine.	X	
Synthesize/integrate multiple sources of information.	X	X
Provide clear, decisive, and confident direction and guidance to others.	X	X
Provide EGL with guidance for escape.	X	X
Persuade others to own point of view if necessary.	X	X
Receive and follow Responsible Person/Dispatcher and Escape Group Leader guidance.	X	X
During headcount, determine whether non-crew members are present.	X	X
Know headcount procedures.	X	X
Listen to and interpret guidance provided by Responsible Person/Dispatcher.	X	X
Interpret elevation on a mine map when depicted.	X	X
Know mine elevation (e.g., where higher and lower elevation spots are located).	X	X
Know to move to high elevation points during a water inundation situation.	X	X
Know your own limitations and capabilities.	X	X
Understand Escape Group Leader role.	X	X
Understand the Responsible Person role.	X	X
Follow and interpret lifeline indicators to navigate through the mine.	X	X
Know how to handle injured miner when escape group requires lifeline.	X	X
Know how/where to find the lifeline.	X	X
Know meaning of lifeline indicators (e.g., ball indicates location of man door).	X	X
Know procedures for following a lifeline.	X	X
Use lifeline to navigate way out of mine.	X	X
Maintain awareness of own location.	X	X
Maintain awareness of location of others on crew (e.g., using radios, verbal and nonverbal communication techniques).	X	X
Oversee assigned "Red Hat(s)" and stay with them at all times.	X	
Understand mine maps.	X	X

Critical KSA	Self-escape leadership	RF Miners
Read and interpret mine and escapeway maps.	X	X
Know where maps are located.	X	X
Ensure all miners know where escapeway maps are located.	X	
Know when and how to update maps.	X	
Know where to store escapeway maps (refuge, cache locations).	X	X
Coordinate and communicate with EMT(s).	X	X
Implement basic first-aid skills.	X	X
Know backboard and first-aid supply locations.	X	X
Know basic first aid (e.g., steps, sequences).	X	X
Know how to operate first-aid equipment (e.g., backboard, oxygen).	X	X
Know procedures for transferring, immobilizing, and moving someone on a backboard.	X	X
Know tasks/skills in which EMTs are trained and capable.	X	X
Know which crew members are EMTs.	X	X
Recognize need to seek medical guidance or assistance for yourself.	X	X
Recognize need to seek medical guidance or assistance for someone else.	X	X
Recognize when medical treatment is needed.	X	X
Use backboard to lift and carry injured miner out of mine.	X	X
Recognize when movement of miner is too risky and how to stabilize/prepare him/her.	X	X
Know general mine characteristics (dry/wet, gassy/non-gassy).	X	X
Know storage locations of all emergency aid equipment (SCSRs caches, tethers/taglines, maps, first-aid kit, stretchers).	X	X
Know location of refuge alternatives.	X	X
Know location, direction of conveyor belts.	X	X
Know location of man doors.	X	X
Recognize changes to layout and conditions in the mine.	X	X
Listen and maintain awareness of communications from Responsible Person/Dispatcher/Escape Group Leader.	X	X
Know to trust your training (i.e., that you can rely on the plans, procedures, and equipment for self-escape).	X	X

Critical KSA	Self-escape leadership	RF Miners
Recognize signs of panic in others.	X	X
Recognize signs of panic in self.	X	X
Speak clearly and confidently when communicating with others in panic.	X	X
Know what can cause power to go out.	X	X
Know when, where, and how to shut off power.	X	X
Recognize when power is out.	X	X
Understand that SCSR caches are moved during a section power move and determine where they are placed after a move.	X	X
Recognize need to self-escape.	X	X
Decide whether to ride or walk.	X	X
Recognize when all options for escape have been exhausted (when no other alternatives) and refuge chamber is necessary.	X	X
Recognize when all options for escape have been exhausted (when no other alternatives) and barricade is necessary.	X	X
Know importance of waist strap for larger SCSRs (e.g., OCENCO) when crawling (i.e., so that SCSR is kept close to body for easier body movement).	X	X
Know limitations of verbal communications when using SCSR.	X	X
Perform steps for opening and donning an SCSR.	X	X
Know procedures and steps for switching/swapping an SCSR.	X	X
Know SCSR use procedures (e.g., do not take out to talk).	X	X
Know to pick up and carry as many SCSRs as feasible.	X	X
Know time when SCSR was donned. Depending on type of SCSR, monitor and interpret increased breathing resistance or check oxygen gauge (if available) to monitor levels.	X	X
Read and interpret SCSR gauge (if available) to monitor breathing air supply levels.	X	X
Recognize that others may need help (e.g., breaking seal on SCSR unit).	X	X
Climb over or under belt as necessary—at designated crossings, if possible.	X	X
Step/crawl through man doors.	X	X
Crawl through mine.	X	X
Walk in a bent-over posture when roof height is low	X	X

Critical KSA	Self-escape leadership	RF Miners
Determine the best way to navigate around debris (e.g., know alternate escapeways).	X	X
Know roof-fall event procedures (e.g., go around the roof fall, do not test roof, exit escapeway to into secondary, return to escapeway when outby the fall).	X	X
Know techniques for crossing over a belt.	X	X
Know how to navigate in smoke (e.g., to "go low").	X	X
Know to feel for and follow ribs to navigate through mine (tactile wayfinding).	X	X
Know to follow machine power cable to locate power center (tactile wayfinding).	X	X
Know to locate and follow the haulage track or belt structure as an alternate way out of the mine (tactile wayfinding).	X	X
Know when to use various self-escape methods or strategies (riding .versus walking).	X	X
Understand how rate of escape in disaster conditions can be reduced below normal walking speed (e.g., in dark, smoke, as a tethered group, due to limited SCSR air flow).	X	X
Deploy refuge chamber (i.e., following provided instructions).	X	X
Know procedures and steps for purging bad air.	X	X
Know procedures and steps for setting up scrubbers.	X	X
Recognize when bad air is completely purged.	X	X
Recognize when scrubbers are properly set up.	X	X
Follow instructions for maintaining and repairing equipment within refuge chamber.	X	X
Know back up filtering solutions (e.g., open and spread out charcoal).	X	X
Know how to check outside air.	X	X
Know procedures and steps for changing scrubbers.	X	X
Know sequence/steps for entering the refuge chamber.	X	X
Know strategies for conserving resources (food, water, power).	X	X
Know to bring SCSRs into refuge chamber.	X	X
Convince others to use tether/tagline.	X	X
Coordinate own movements with others on tether/tagline.	X	X
Know how to hook self and others to tether/tagline.	X	X

Critical KSA	Self-escape leadership	RF Miners
Know how to navigate when tethered to a tether/tagline (e.g., change direction as a group).	X	X
Know to be in the front of the tether/tagline or in back of group if no tether/tagline.	X	
Know to place hand on shoulder of person in front of self.	X	X
Know to remove tether/tagline prior to boarding a vehicle.	X	X
Know where taglines are stored (e.g., cache, mantrip).	X	X
Operate/monitor tracking system.	X	
Use tracking system to identify actual or last known location of miners.	X	
Know transportation vehicle characteristics (types, speeds, assigned numbers).	X	X
Operate vehicles.	X	X
Understand basics of mine ventilation (e.g., role of fans, doors, curtains).	X	X
Know the expected air flow/ventilation in the mine.	X	X
Understand significance of changes in ventilation (e.g., possible roof fall elsewhere in mine)	X	X
Adjust mine features (e.g., doors, curtains) to improve/reestablish ventilation and reduce impact of smoke	X	X

Appendix G: Task Demands Associated with Self-escape Abilities

Task Demand	Ability	Definition
Cognitive *Verbal*	Oral comprehension	The ability to listen to and understand information and ideas presented through spoken words and sentences.
	Written comprehension	The ability to read and understand information and ideas presented in writing.
	Oral expression	The ability to communicate information and ideas in speaking so others will understand.
	Written expression	The ability to communicate information and ideas in writing so others will understand.
Cognitive *Idea Generation and Reasoning*	Fluency of ideas	The ability to come up with a number of ideas about a topic (the number of ideas is important, not their quality, correctness, or creativity).
	Originality	The ability to come up with unusual or clever ideas about a given topic or situation, or to develop creative ways to solve a problem.
	Problem sensitivity	The ability to tell when something is wrong or is likely to go wrong. It does not involve solving the problem, only recognizing there is a problem.
	Deductive reasoning	The ability to apply general rules to specific problems to produce answers that make sense.
	Inductive reasoning	The ability to combine pieces of information to form general rules or conclusions (includes finding a relationship among seemingly unrelated events).
	Information ordering	The ability to arrange things or actions in a certain order or pattern according to a specific rule or set of rules (e.g., patterns of numbers, letters, words, pictures, mathematical operations).

Task Demand	**Ability**	**Definition**
	Category flexibility	The ability to generate or use different sets of rules for combining or grouping things in different ways.
Cognitive *Quantitative*	Mathematical reasoning	The ability to choose the right mathematical methods or formulas to solve a problem.
	Number facility	The ability to add, subtract, multiply, or divide quickly and correctly.
Cognitive *Memory*	Memorization	The ability to remember information such as words, numbers, pictures, and procedures.
Cognitive *Perceptual*	Speed of closure	The ability to quickly make sense of, combine, and organize information into meaningful patterns.
	Flexibility of closure	The ability to identify or detect a known pattern (a figure, object, word, or sound) that is hidden in other distracting material.
	Perceptual speed	The ability to quickly and accurately compare similarities and differences among sets of letters, numbers, objects, pictures, or patterns. The things to be compared may be presented at the same time or one after the other. This ability also includes comparing a presented object with a remembered object.
Cognitive *Spatial Abilities*	Spatial orientation	The ability to know your location in relation to the environment or to know where other objects are in relation to you.
	Visualization	The ability to imagine how something will look after it is moved around or when its parts are moved or rearranged.
Cognitive *Attentiveness*	Selective attention	The ability to concentrate on a task over a period of time without being distracted.

Task Demand	Ability	Definition
	Time sharing	The ability to shift back and forth between two or more activities or sources of information (such as speech, sounds, touch, or other sources).
Psychomotor *Fine Manipulative*	Arm-hand steadiness	The ability to keep your hand and arm steady while moving your arm or while holding your arm and hand in one position.
	Manual dexterity	The ability to quickly move your hand, your hand together with your arm, or your two hands to grasp, manipulate, or assemble objects.
	Finger dexterity	The ability to make precisely coordinated movements of the fingers of one or both hands to grasp, manipulate, or assemble very small objects.
Psychomotor *Control Movement*	Control precision	The ability to quickly and repeatedly adjust the controls of a machine or a vehicle to exact positions.
	Multilimb coordination	The ability to coordinate two or more limbs (for example, two arms, two legs, or one leg and one arm) while sitting, standing, or lying down. It does not involve performing the activities while the whole body is in motion.
	Rate control	The ability to time your movements or the movement of a piece of equipment in anticipation of changes in the speed and/or direction of a moving object or scene.
Psychomotor *Reaction Time and Speed*	Reaction time	The ability to quickly respond (with the hand, finger, or foot) to a signal (sound, light, picture) when it appears.
	Wrist-finger speed	The ability to make fast, simple, repeated movements of the fingers, hands, and wrists.
	Speed of limb movement	The ability to quickly move the arms and legs.

Task Demand	Ability	Definition
Physical *Physical Strengths*	Static strength	The ability to exert maximum muscle force to lift, push, pull, or carry objects.
	Trunk strength	The ability to use your abdominal and lower back muscles to support part of the body repeatedly or continuously over time without 'giving out' or fatiguing.
Physical *Endurance*	Stamina	The ability to exert yourself physically over long periods of time without getting winded or out of breath.
Physical *Flexibility, Balance, and Coordination*	Extent flexibility	The ability to bend, stretch, twist, or reach with your body, arms, and/or legs.
	Dynamic flexibility	The ability to quickly and repeatedly bend, stretch, twist, or reach out with your body, arms, and/or legs.
	Gross body coordination	The ability to coordinate the movement of your arms, legs, and torso together when the whole body is in motion.
	Gross body equilibrium	The ability to keep or regain your body balance or stay upright when in an unstable position.
Sensory *Visual*	Near vision	The ability to see details at close range (within a few feet of the observer).
	Far vision	The ability to see details at a distance.
	Visual color discrimination	The ability to match or detect differences between colors, including shades of color and brightness.

Task Demand	Ability	Definition
	Night vision	The ability to see under low light conditions.
	Peripheral vision	The ability to see objects or movement of objects to one's side when the eyes are looking ahead.
	Depth perception	The ability to judge which of several objects is closer or farther away from you, or to judge the distance between you and an object.
	Glare sensitivity	The ability to see objects in the presence of glare or bright lighting.
Sensory *Auditory and Speech*	Hearing sensitivity	The ability to detect or tell the differences between sounds that vary in pitch and loudness.
	Auditory attention	The ability to focus on a single source of sound in the presence of other distracting sounds.
	Sound localization	The ability to tell the direction from which a sound originated.
	Speech recognition	The ability to identify and understand the speech of another person.
	Speech clarity	The ability to speak clearly so others can understand you.

Appendix H: NIOSH Self-escape Confidence Survey

First, we'd like to get some general information about you and your experiences...

Age:
- 18-24
- 25-34
- 35-44
- 45-54
- 55-64
- 65+

Are you:
- Male
- Female

Are you:
- Salary
- Hourly
- Contractor

Primary workgroup:
- Production
- Maintenance
- Safety
- Engineering
- Other ________

Time in current job:
- Less than 1 year
- 1-5 years
- 6-10 years
- 11-15 years
- 16-20 years
- More than 20 years

Time in mining industry:
- Less than 1 year
- 1-5 years
- 6-10 years
- 11-15 years
- 16-20 years
- More than 20 years

Time in current mine:
- Less than 1 year
- 1-5 years
- 6-10 years
- 11-15 years
- 16-20 years
- More than 20 years

Education level:
- Less than high school
- High school
- Trade/Associate's degree
- Bachelor's degree
- Master's+ degree

General work schedule:
- Set schedule
- Rotates/shiftwork

Primary work location
- Working face
- Outby
- Surface
- Other ________

Family mining history:
- First generation mineworker
- Multi-generation mineworker (parents/grandparents are/were mineworkers)

In general, what percentage (%) of your working time is spent undergound?

0 1 2 3 4 5 6 7 8 9 10
0% 50% 100%

Do you curently hold any of the following positions? (Check all that apply)
- Responsible Person
- Dispatcher/Operation Center
- Shift supervisor
- Section supervisor
- Other sup/leadership role

If other, please explain

____

Do you have training or experience with any of the following? (Check all that apply)
- Volunteer fire-fighting
- Professional fire-fighting
- Military emergency response
- EMT/Paramedic
- Mine fire brigade
- Mine rescue team
- Evacuating due to a mine emergency
- Other emergency response training/experience

If other, please explain

____

Select the number from "1" to "6" which best describes your level of agreement with the following:

	Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree
Health and safety training is a priority here	1	2	3	4	5	6
My mine's escape training is usually realistic and "hands-on"	1	2	3	4	5	6
It is important to put in extra effort toward improving my mine's ability to respond to an emergency	1	2	3	4	5	6

On a scale from 0-10, how confident are you that you could correctly demonstrate or explain the following to a brand new miner?

		% confident (0% – 50% – 100%)
1.	Your mine's emergency response plan (ERP)	0 1 2 3 4 5 6 7 8 9 10
2.	The chain of command for reporting a mine emergency	0 1 2 3 4 5 6 7 8 9 10
4.	The location of your mine's primary and secondary escapeways	0 1 2 3 4 5 6 7 8 9 10
3.	Where your mine's escapeway maps are located	0 1 2 3 4 5 6 7 8 9 10
5.	Where to report in the event of a mine emergency	0 1 2 3 4 5 6 7 8 9 10
6.	How to read mine map symbols	0 1 2 3 4 5 6 7 8 9 10
7.	Lifeline symbols	0 1 2 3 4 5 6 7 8 9 10
8.	If or when to fight a fire	0 1 2 3 4 5 6 7 8 9 10
9.	How to fight a fire	0 1 2 3 4 5 6 7 8 9 10
10.	How to identify an explosive atmosphere with a gas meter	0 1 2 3 4 5 6 7 8 9 10
11.	Your own role in your mine's emergency response plan	0 1 2 3 4 5 6 7 8 9 10
12.	When to don an SCSR	0 1 2 3 4 5 6 7 8 9 10
13.	Where your mine's SCSR caches are located	0 1 2 3 4 5 6 7 8 9 10
14.	How to properly don an SCSR	0 1 2 3 4 5 6 7 8 9 10
15.	What to expect when wearing an SCSR (breathe, communicate)	0 1 2 3 4 5 6 7 8 9 10
16.	What alarms/alerts mean	0 1 2 3 4 5 6 7 8 9 10
17.	How to test roof conditions	0 1 2 3 4 5 6 7 8 9 10
18.	Ventilation/smoke leakage	0 1 2 3 4 5 6 7 8 9 10
19.	How to reestablish ventilation	0 1 2 3 4 5 6 7 8 9 10
20.	Where your mine's refuge alternative(s) (RA) is/are located	0 1 2 3 4 5 6 7 8 9 10
21.	When to enter your mine's refuge alternative (RA)	0 1 2 3 4 5 6 7 8 9 10
22.	How to operate your mine's refuge alternative (RA)	0 1 2 3 4 5 6 7 8 9 10
23.	When to construct a barricade	0 1 2 3 4 5 6 7 8 9 10
24.	How to construct a proper barricade	0 1 2 3 4 5 6 7 8 9 10
25.	Your mine's communication and tracking system (CT)	0 1 2 3 4 5 6 7 8 9 10
26.	Your mine's atmospheric monitoring system (AMS)	0 1 2 3 4 5 6 7 8 9 10
27.	How to use nonverbal communication (hand, cap lamp symbols)	0 1 2 3 4 5 6 7 8 9 10
28.	Where your mine's tetherlines are located	0 1 2 3 4 5 6 7 8 9 10
29.	How to use a tetherline	0 1 2 3 4 5 6 7 8 9 10
30.	What shift do you normally work?	1 2 3

For office use only
1 2 3 4 5 6 7 8 9 10

Appendix I: Detailed Self-escape Competency Survey Findings

Table I-1. Frequency distributions of background and experience responses for rank-and-file miners and self-escape leadership positions

Survey Item	Response	Total Sample (n=895[16]) Frequency (%)	Rank-and-file (n=589) Frequency (%)	Self-escape leadership (n=284) Frequency (%)
Age	18–24	42 (4.7%)	37 (6.3%)	5 (1.8%)
	25–34	301 (33.7%)	218 (37.1%)	80 (28.2%)
	35–44	273 (30.6%)	171 (29.1%)	94 (33.1%)
	45–54	131 (14.7%)	78 (13.3%)	48 (16.9%)
	55–64	137 (15.4%)	80 (13.6%)	53 (18.7%)
	65+	8 (0.9%)	3 (0.5%)	4 (1.4%)
	No response	3	2	0
Gender	Male	875 (99.4%)	584 (99.5%)	280 (99.3%)
	Female	5 (0.6%)	3 (0.5%)	2 (0.7%)
	No response	15	2	2
Pay Status	Hourly	695 (79.2%)	589 (100.0%)	106 (37.3%)
	Salaried	175 (20.0%)	0 (0.0%)	175 (62.6%)
	Contractor	7 (0.8%)	0	0
	No Response	18	0	3
Primary Workgroup	Production	544 (61.6%)	409 (69.7%)	135 (47.7%)
	Maintenance	199 (22.5%)	109 (18.6%)	82 (29.0%)
	Safety	14 (1.6%)	3 (0.5%)	8 (2.8%)
	Engineering	7 (0.8%)	2 (0.3%)	4 (1.4%)
	Other	119 (13.5%)	64 (10.9%)	54 (19.1%)
	No response	12	2	1

[16] Total N includes 22 cases that were not classified as either rank-and-file or self-escape leadership.

Survey Item	Response	Total Sample (n=895[16]) Frequency (%)	Rank-and-file (n=589) Frequency (%)	Self-escape leadership (n=284) Frequency (%)
Time in Current Job	< 1 year	96 (10.8%)	70 (11.9%)	34 (12.1%)
	1–5 years	306 (34.3%)	186 (31.7%)	82 (29.1%)
	6–10 years	302 (33.9%)	218 (37.2%)	92 (32.6%)
	11–15 years	112 (12.6%)	71 (12.1%)	45 (16.0%)
	16–20 years	40 (4.5%)	26 (4.4%)	20 (7.1%)
	> 20 years	35 (3.9%)	15 (2.6%)	9 (3.2%)
	No response	4	3	2
Time in Industry	< 1 year	12 (1.4%)	10 (1.7%)	2 (0.7%)
	1–5 years	146 (16.5%)	108 (18.5%)	37 (13.1%)
	6–10 years	349 (39.3%)	254 (43.4%)	85 (30.0%)
	11–15 years	170 (19.2%)	96 (16.4%)	70 (24.7%)
	16–20 years	77 (8.7%)	46 (7.9%)	30 (10.6%)
	> 20 years	133 (15.0%)	71 (12.1%)	59 (20.8%)
	No response	8	4	1
Time in Current Mine	< 1 year	108 (12.2%)	70 (11.9%)	34 (12.1%)
	1–5 years	272 (30.7%)	186 (31.7%)	82 (29.1%)
	6–10 years	315 (35.6%)	218 (37.2%)	92 (32.6%)
	11–15 years	118 (13.3%)	71 (12.1%)	45 (16.0%)
	16–20 years	47 (5.3%)	26 (4.4%)	20 (7.1%)
	> 20 years	25 (2.8%)	15 (2.6%)	9 (3.2%)
	No response	10	3	2
Education Level	< High school	12 (1.3%)	8 (1.4%)	3 (1.1%)
	High school	594 (66.6%)	426 (72.4%)	159 (56.0%)
	Trade/Associate's	194 (21.7%)	112 (19.0%)	75 (26.4%)

Survey Item	Response	Total Sample (n=895[16]) Frequency (%)	Rank-and-file (n=589) Frequency (%)	Self-escape leadership (n=284) Frequency (%)
	Bachelor's	80 (9.0%)	39 (6.6%)	38 (13.4%)
	Master's+	12 (1.3%)	3 (0.5%)	9 (3.2%)
	No response	3	1	0
General Schedule	Set schedule	188 (21.2%)	89 (15.2%)	96 (34.0%)
	Rotates/Shiftwork	697 (78.8%)	496 (84.8%)	186 (66.0%)
	No response	10	4	2
Primary Location	Working face	542 (61.4%)	394 (67.5%)	138 (49.1%)
	Outby	245 (27.7%)	154 (26.4%)	87 (31.0%)
	Surface	31 (3.5%)	12 (2.1%)	19 (6.8%)
	Other	51 (5.8%)	24 (4.1%)	37 (13.2%)
	No response	14	5	3
Family Mining History	First generation	297 (33.7%)	197 (33.8%)	92 (32.9%)
	Multi-generation	585 (66.3%)	386 (66.2%)	188 (67.1%)
	No response	13	6	4
Percentage of Working Time Underground	0%	17 (2.0%)	9 (1.6%)	8 (2.9%)
	10%	7 (0.8%)	0	7 (2.5%)
	20%	7 (0.8%)	3 (0.5%)	2 (0.7%)
	30%	3 (0.3%)	2 (0.4%)	1 (0.4%)
	40%	12 (1.4%)	4 (0.7%)	5 (1.8%)
	50%	33 (3.8%)	13 (2.3%)	17 (6.1%)
	60%	15 (1.7%)	9 (1.6%)	6 (2.2%)
	70%	28 (3.3%)	14 (2.5%)	12 (4.3%)
	80%	49 (5.7%)	24 (4.3%)	24 (8.7%)
	90%	93 (10.8%)	43 (7.6%)	49 (17.7%)

Survey Item	Response	**Total Sample** (n=895[16]) Frequency (%)	**Rank-and-file** (n=589) Frequency (%)	**Self-escape leadership** (n=284) Frequency (%)
	100%	595 (69.3%)	443 (78.5%)	146 (52.7%)
	No response	36	25	7
Mine Site	Mine 1	95 (10.6%)	58 (9.8%)	31 (10.9%)
	Mine 2	217 (24.2%)	154 (26.1%)	59 (20.8%)
	Mine 3	273 (30.5%)	187 (31.7%)	82 (28.9%)
	Mine 4	102 (11.4%)	55 (9.3%)	44 (15.5%)
	Mine 5	47 (5.3%)	32 (5.4%)	13 (4.6%)
	Mine 6	71 (7.9%)	45 (7.6%)	24 (8.5%)
	Mine 7	24 (2.7%)	14 (2.4%)	9 (3.2%)
	Mine 8	66 (7.4%)	44 (7.5%)	22 (7.7%)
	No response	0	0	0

Table I-2. Specialized experience frequency distributions across subsets

Experience	Response	Rank-and-file	Self-escape leadership
Self-escape leadership	Responsible Person	0[17]	147
	Dispatcher/Operation Center	0[18]	12
	Shift Supervisor	0	32
	Section Supervisor	0	79
	Other sup/leadership role	19[19]	66
Emergency Response	Volunteer fire-fighting	48	35
	Professional fire-fighting	3	4
	Military emergency response	22	20
	EMT/Paramedic	48	96
	Mine fire brigade	16	19
	Mine rescue team	35	38

[17] Ninety-seven hourly workers reported currently holding the role of responsible person (RP) and were classified as self-escape leadership.
[18] Six hourly workers reported currently holding positions in the communications/operations center (e.g., dispatcher, tracking) and were classified as self-escape leadership.
[19] Hourly workers who have some leadership responsibilities (e.g., fireboss, crew leader, assistant supervisor) but no formal self-escape leadership training or role were classified as rank-and-file.

Table I-3. Distribution of levels of agreement with individual and organizational and individual self-escape training and preparedness value statements

Question	Response	Self-escape leadership Frequency (%)	Rank-and-file Frequency (%)
Health and safety training is a priority here.	Strongly disagree	4 (1.4%)	5 (0.9%)
	Disagree	4 (1.4%)	10 (1.7%)
	Somewhat disagree	5 (1.8%)	26 (4.4%)
	Somewhat agree	24 (8.5%)	99 (16.9%)
	Agree	91 (32.4%)	213 (36.3%)
	Strongly agree	153 (54.4%)	233 (39.8%)
	No response	3	3
My mine's escape training is usually realistic and "hands-on."	Strongly disagree	5 (1.8%)	9 (1.6%)
	Disagree	13 (4.6%)	18 (3.1%)
	Somewhat disagree	13 (4.6%)	35 (6.0%)
	Somewhat agree	53 (18.9%)	146 (25.2%)
	Agree	106 (37.9%)	207 (35.7%)
	Strongly agree	90 (32.1%)	165 (28.4%)
	No response	4	9
It is important to put extra effort toward improving my mine's ability to respond to an emergency.	Strongly disagree	5 (1.8%)	4 (0.7%)
	Disagree	3 (1.1%)	12 (2.1%)
	Somewhat disagree	8 (2.8%)	7 (1.2%)
	Somewhat agree	24 (8.5%)	72 (12.4%)
	Agree	98 (34.9%)	205 (35.3%)
	Strongly agree	143 (50.9%)	280 (48.3%)
	No response	3	9

Table I-4. Average percent confidence in ability to properly demonstrate or explain the following to a brand-new miner: rank-and-file miners versus self-escape leadership

Self-escape Competency Items	Rank-and-file**	Self-escape
Your mine's emergency response plan (ERP)	75.7	78.4
The chain of command for reporting a mine emergency*	82.5	84.4
How to construct a proper barricade*	83.9	87.8
What alarms/alerts mean*	85.2	91.4
How to read mine map symbols*	85.3	92.1
How to reestablish ventilation*	85.4	89.1
Your own role in your mine's emergency response plan*	85.4	88.6
Your mine's communication and tracking system	85.9	91.2
Ventilation/smoke leakage*	86.1	90.4
When to construct a barricade*	86.2	89.8
How to operate your mine's refuge alternative (RA)*	88.1	93.0
If or when to fight a fire*	88.4	91.8
Where your mine's escapeway maps are located	88.9	94.1
Where your mine's escapeways are located*	88.9	94.1
Lifeline symbols*	89.3	93.6
How to fight a fire*	90.2	92.6
Where your mine's SCSR caches are located*	90.4	94.5
Where your mine's tetherlines are located	90.4	92.4
What to expect when using an SCSR*	90.6	94.7
When to enter your mine's refuge alternative (RA)	90.7	92.9
Where to report in the event of a mine emergency	91.1	92.2
Where your mine's RA(s) is/are located*	91.4	94.3
How to test roof conditions	92.5	93.6
How to use tetherlines	92.7	94.4
How to use nonverbal communication	93.1	94.1
How to identify an explosive atmosphere with a gas meter*	93.9	96.1
When to don an SCSR*	95.1	97.0
How to properly don an SCSR*	95.7	97.2

* Significant differences based on independent samples t tests ($p < .05$) and confirmed with Mann Whitney U tests ($p < .01$).
** Sorted from rank-and-file miners' lowest average confidence to highest average confidence.

Table I-5. Frequency distribution of responses for all 28 self-escape confidence items

On a scale from 0% to 100%, how confident are you that you could properly demonstrate or explain the following to a brand-new miner?	Response (% confident)	Self-escape leadership Frequency (%)	Rank-and-file Frequency (%)
Your mine's emergency response plan	0	4 (1.4%)	5 (0.9%)
	10	2 (0.7%)	2 (0.3%)
	20	4 (1.4%)	7 (1.2%)
	30	7 (2.5%)	9 (1.5%)
	40	4 (1.4%)	15 (2.6%)
	50	39 (13.9%)	87 (14.9%)
	60	7 (2.5%)	30 (5.2%)
	70	18 (6.4%)	82 (14.1%)
	80	64 (22.8%)	120 (20.6%)
	90	40 (14.2%)	97 (16.7%)
	100	92 (32.7%)	128 (22.0%)
	No response	3	7
The chain of command for reporting a mine emergency	0	2 (0.7%)	3 (0.5%)
	10	2 (0.7%)	2 (0.3%)
	20	1 (0.4%)	5 (0.9%)
	30	4 (1.4%)	11 (1.9%)
	40	3 (1.1%)	6 (1.0%)
	50	19 (6.8%)	43 (7.4%)
	60	5 (1.8%)	21 (3.6%)
	70	17 (6.0%)	64 (11.0%)
	80	48 (17.1%)	116 (19.9%)
	90	55 (19.6%)	97 (16.6%)
	100	121 (44.5%)	215 (36.9%)
	No response	3	6
Where your mine's escapeways are located	0	0 (0.0%)	1 (0.2%)
	10	0 (0.0%)	1 (0.2%)
	20	2 (0.7%)	6 (1.0%)
	30	1 (0.4%)	4 (0.7%)
	40	1 (0.4%)	8 (1.4%)
	50	4 (1.4%)	27 (4.6%)

On a scale from 0% to 100%, how confident are you that you could properly demonstrate or explain the following to a brand-new miner?	Response (% confident)	Self-escape leadership Frequency (%)	Rank-and-file Frequency (%)
	60	5 (1.8%)	14 (2.4%)
	70	8 (2.8%)	26 (4.5%)
	80	18 (6.4%)	73 (12.5%)
	90	36 (12.8%)	89 (15.2%)
	100	206 (73.3%)	335 (57.4%)
	No response	3	5
Where your mine's escapeway maps are located	0	0 (0.0%)	0 (0.0%)
	10	1 (0.4%)	1 (0.2%)
	20	0 (0.0%)	0 (0.0%)
	30	3 (1.1%)	4 (0.7%)
	40	2 (0.7%)	5 (0.9%)
	50	5 (1.8%)	14 (2.4%)
	60	1 (0.4%)	7 (1.2%)
	70	6 (2.1%)	14 (2.4%)
	80	21 (7.5%)	48 (8.2%)
	90	40 (14.2%)	109 (18.7%)
	100	202 (71.9%)	381 (65.4%)
	No response	3	6
Where to report in the event of a mine emergency	0	1 (0.4%)	2 (0.3%)
	10	0 (0.0%)	2 (0.3%)
	20	1 (0.4%)	2 (0.3%)
	30	1 (0.4%)	4 (0.7%)
	40	3 (1.1%)	5 (0.9%)
	50	8 (2.9%)	16 (2.8%)
	60	4 (1.4%)	11 (1.9%)
	70	8 (2.9%)	28 (4.8%)
	80	32 (11.4%)	53 (9.1%)
	90	31 (11.1%)	93 (16.0%)
	100	191 (68.2%)	364 (62.8%)
	No response	0	3

On a scale from 0% to 100%, how confident are you that you could properly demonstrate or explain the following to a brand-new miner?	**Response (% confident)**	**Self-escape leadership Frequency (%)**	**Rank-and-file Frequency (%)**
How to read mine map symbols	0	0 (0.0%)	5 (0.9%)
	10	1 (0.4%)	1 (0.2%)
	20	2 (0.7%)	4 (0.7%)
	30	2 (0.7%)	5 (0.9%)
	40	1 (0.4%)	5 (0.9%)
	50	5 (1.8%)	29 (4.9%)
	60	8 (2.8%)	22 (3.8%)
	70	13 (4.6%)	52 (8.9%)
	80	20 (7.0%)	107 (18.3%)
	90	43 (15.1%)	101 (17.2%)
	100	189 (66.5%)	255 (43.5%)
	No response	0	3
Lifeline symbols	0	0 (0.0%)	4 (0.7%)
	10	0 (0.0%)	0 (0.0%)
	20	0 (0.0%)	3 (0.5%)
	30	1 (0.4%)	4 (0.7%)
	40	4 (1.4%)	8 (1.4%)
	50	3 (1.1%)	14 (2.4%)
	60	3 (1.1%)	16 (2.7%)
	70	9 (3.2%)	33 (5.6%)
	80	26 (9.2%)	76 (13.0%)
	90	44 (15.5%)	102 (17.4%)
	100	194 (68.3%)	325 (55.6%)
	No response	0	3
If or when to fight a fire	0	1 (0.4%)	1 (0.2%)
	10	0 (0.0%)	2 (0.3%)
	20	0 (0.0%)	1 (0.2%)
	30	1 (0.4%)	1 (0.2%)
	40	3 (1.1%)	4 (0.7%)
	50	6 (2.1%)	22 (3.8%)
	60	4 (1.4%)	15 (2.6%)

On a scale from 0% to 100%, how confident are you that you could properly demonstrate or explain the following to a brand-new miner?	Response (% confident)	Self-escape leadership Frequency (%)	Rank-and-file Frequency (%)
	70	12 (4.2%)	34 (5.8%)
	80	35 (12.3%)	82 (14.0%)
	90	46 (16.2%)	119 (20.3%)
	100	176 (62.0%)	304 (52.0%)
	No response	0	4
How to fight a fire	0	1 (0.4%)	2 (0.3%)
	10	0 (0.0%)	1 (0.2%)
	20	1 (0.4%)	3 (0.5%)
	30	1 (0.4%)	2 (0.3%)
	40	1 (0.4%)	2 (0.3%)
	50	4 (1.4%)	17 (2.9%)
	60	4 (1.4%)	5 (0.9%)
	70	12 (4.3%)	35 (6.0%)
	80	31 (11.0%)	86 (14.8%)
	90	45 (16.0%)	109 (18.8%)
	100	182 (64.5%)	318 (54.8%)
	No response	2	9
How to identify an explosive atmosphere with a gas meter	0	0 (0.0%)	0 (0.0%)
	10	0 (0.0%)	0 (0.0%)
	20	1 (0.4%)	0 (0.0%)
	30	0 (0.0%)	5 (0.9%)
	40	1 (0.4%)	0 (0.0%)
	50	2 (0.7%)	14 (2.4%)
	60	0 (0.0%)	9 (1.5%)
	70	7 (2.5%)	20 (3.4%)
	80	16 (5.7%)	39 (6.7%)
	90	32 (11.3%)	80 (13.7%)
	100	223 (79.1%)	417 (71.4%)
	No response	2	5
Your own role in your mine's ERP	0	3 (1.1%)	5 (0.9%)
	10	2 (0.7%)	0 (0.0%)

On a scale from 0% to 100%, how confident are you that you could properly demonstrate or explain the following to a brand-new miner?	Response (% confident)	Self-escape leadership Frequency (%)	Rank-and-file Frequency (%)
	20	0 (0.0%)	6 (1.0%)
	30	3 (1.1%)	1 (0.2%)
	40	1 (0.4%)	7 (1.2%)
	50	15 (5.4%)	37 (6.4%)
	60	4 (1.4%)	21 (3.6%)
	70	15 (5.4%)	49 (8.4%)
	80	33 (11.8%)	94 (16.2%)
	90	41 (14.6%)	98 (16.9%)
	100	163 (58.2%)	263 (45.3%)
	No response	4	8
When to don an SCSR	0	0 (0.0%)	0 (0.0%)
	10	0 (0.0%)	0 (0.0%)
	20	0 (0.0%)	1 (0.2%)
	30	0 (0.0%)	2 (0.3%)
	40	0 (0.0%)	0 (0.0%)
	50	2 (0.7%)	8 (1.4%)
	60	1 (0.4%)	8 (1.4%)
	70	7 (2.5%)	12 (2.0%)
	80	11 (3.9%)	36 (6.1%)
	90	27 (9.5%)	88 (15.0%)
	100	236 (83.1%)	431 (73.5%)
	No response	0	3
Where your mine’s SCSR caches are located	0	1 (0.4%)	1 (0.2%)
	10	0 (0.0%)	1 (0.2%)
	20	1 (0.4%)	0 (0.0%)
	30	0 (0.0%)	2 (0.3%)
	40	1 (0.4%)	5 (0.9%)
	50	4 (1.4%)	17 (2.9%)
	60	3 (1.1%)	11 (1.9%)
	70	7 (2.5%)	42 (7.2%)
	80	21 (7.5%)	70 (11.9%)

On a scale from 0% to 100%, how confident are you that you could properly demonstrate or explain the following to a brand-new miner?	Response (% confident)	Self-escape leadership Frequency (%)	Rank-and-file Frequency (%)
	90	36 (12.8%)	103 (17.6%)
	100	207 (73.7%)	334 (57.0%)
	No response	3	3
How to properly don an SCSR	0	1 (0.4%)	0 (0.0%)
	10	0 (0.0%)	1 (0.2%)
	20	0 (0.0%)	0 (0.0%)
	30	1 (0.4%)	2 (0.2%)
	40	0 (0.0%)	1 (0.2%)
	50	1 (0.4%)	7 (1.2%)
	60	1 (0.4%)	3 (0.5%)
	70	4 (1.4%)	15 (2.6%)
	80	8 (2.8%)	31 (5.3%)
	90	25 (8.8%)	76 (13.0%)
	100	242 (85.5%)	450 (76.9%)
	No response	1	4
What to expect when using an SCSR	0	1 (0.4%)	1 (0.2%)
	10	0 (0.0%)	1 (0.2%)
	20	0 (0.0%)	4 (0.7%)
	30	1 (0.4%)	1 (0.2%)
	40	0 (0.0%)	1 (0.2%)
	50	4 (1.4%)	20 (3.4%)
	60	3 (1.1%)	15 (2.6%)
	70	7 (2.5%)	33 (5.7%)
	80	20 (7.1%)	64 (11.0%)
	90	41 (14.5%)	97 (16.6%)
	100	206 (72.8%)	347 (59.4%)
	No response	1	5
What alarms/alerts mean	0	2 (0.7%)	4 (0.7%)
	10	1 (0.4%)	2 (0.3%)
	20	0 (0.0%)	3 (0.5%)
	30	1 (0.4%)	4 (0.7%)

On a scale from 0% to 100%, how confident are you that you could properly demonstrate or explain the following to a brand-new miner?	Response (% confident)	Self-escape leadership Frequency (%)	Rank-and-file Frequency (%)
	40	0 (0.0%)	4 (0.7%)
	50	7 (2.5%)	43 (7.4%)
	60	5 (1.8%)	17 (2.9%)
	70	12 (4.2%)	49 (8.4%)
	80	33 (11.6%)	93 (16.0%)
	90	51 (18.0%)	109 (18.8%)
	100	172 (60.6%)	252 (43.4%)
	No response	0	9
How to test roof conditions	0	1 (0.4%)	1 (0.2%)
	10	1 (0.4%)	1 (0.2%)
	20	0 (0.0%)	2 (0.3%)
	30	0 (0.0%)	2 (0.3%)
	40	1 (0.4%)	3 (0.5%)
	50	3 (1.1%)	10 (1.7%)
	60	4 (1.4%)	9 (1.5%)
	70	12 (4.2%)	22 (3.8%)
	80	24 (8.5%)	55 (9.4%)
	90	41 (14.4%)	108 (18.5%)
	100	197 (69.4%)	372 (63.6%)
	No response	0	4
Ventilation/smoke leakage	0	2 (0.7%)	3 (0.5%)
	10	1 (0.4%)	1 (0.2%)
	20	0 (0.0%)	2 (0.3%)
	30	0 (0.0%)	7 (1.2%)
	40	1 (0.4%)	0 (0.0%)
	50	13 (4.6%)	32 (5.5%)
	60	7 (2.5%)	21 (3.6%)
	70	11 (3.9%)	48 (8.3%)
	80	33 (11.7%)	96 (16.6%)
	90	45 (16.0%)	124 (21.4%)
	100	169 (59.9%)	246 (42.4%)

On a scale from 0% to 100%, how confident are you that you could properly demonstrate or explain the following to a brand-new miner?	Response (% confident)	Self-escape leadership Frequency (%)	Rank-and-file Frequency (%)
	No response	2	9
How to reestablish ventilation	0	1 (0.4%)	3 (0.5%)
	10	0 (0.0%)	2 (0.3%)
	20	0 (0.0%)	7 (1.2%)
	30	2 (0.7%)	4 (0.7%)
	40	3 (1.1%)	5 (0.9%)
	50	14 (4.9%)	29 (5.0%)
	60	9 (3.2%)	27 (4.7%)
	70	16 (5.6%)	48 (8.3%)
	80	35 (12.3%)	82 (14.2%)
	90	43 (15.1%)	119 (20.6%)
	100	161 (56.7%)	252 (43.6%)
	No response	0	11
Where your mine's RA(s) is/are located	0	1 (0.4%)	4 (0.7%)
	10	0 (0.0%)	1 (0.2%)
	20	0 (0.0%)	4 (0.7%)
	30	0 (0.0%)	3 (0.5%)
	40	0 (0.0%)	5 (0.9%)
	50	7 (2.5%)	18 (3.1%)
	60	3 (1.1%)	7 (1.2%)
	70	8 (2.8%)	21 (3.6%)
	80	21 (7.5%)	68 (11.7%)
	90	36 (12.8%)	105 (18.1%)
	100	205 (73.0%)	344 (59.3%)
	No response	3	9
When to enter your mine's refuge alternative (RA)	0	4 (1.4%)	4 (0.7%)
	10	0 (0.0%)	2 (0.3%)
	20	0 (0.0%)	2 (0.3%)
	30	1 (0.4%)	3 (0.5%)
	40	1 (0.4%)	2 (0.3%)
	50	5 (1.8%)	24 (4.1%)

On a scale from 0% to 100%, how confident are you that you could properly demonstrate or explain the following to a brand-new miner?	Response (% confident)	Self-escape leadership Frequency (%)	Rank-and-file Frequency (%)
	60	4 (1.4%)	9 (1.5%)
	70	8 (2.8%)	22 (3.8%)
	80	25 (8.8%)	59 (10.1%)
	90	33 (11.6%)	98 (16.8%)
	100	203 (71.5%)	359 (61.5%)
	No response	0	5
How to operate your mine's refuge alternative (RA)	0	0 (0.0%)	5 (0.9%)
	10	1 (0.4%)	2 (0.3%)
	20	1 (0.4%)	3 (0.5%)
	30	1 (0.4%)	1 (0.2%)
	40	2 (0.7%)	5 (0.9%)
	50	4 (1.4%)	25 (4.3%)
	60	5 (1.8%)	13 (2.2%)
	70	8 (2.8%)	36 (6.2%)
	80	24 (8.5%)	83 (14.2%)
	90	49 (17.3%)	116 (19.8%)
	100	188 (66.4%)	296 (50.6%)
	No response	1	4
When to construct a barricade	0	1 (0.4%)	3 (0.5%)
	10	0 (0.0%)	3 (0.5%)
	20	1 (0.4%)	4 (0.7%)
	30	2 (0.7%)	3 (0.5%)
	40	2 (0.7%)	10 (1.7%)
	50	12 (4.2%)	29 (5.0%)
	60	8 (2.8%)	24 (4.1%)
	70	22 (7.8%)	39 (6.7%)
	80	24 (8.5%)	87 (15.0%)
	90	40 (14.1%)	101 (17.4%)
	100	171 (60.4%)	277 (47.8%)
	No response	1	9
How to construct a barricade	0	2 (0.7%)	4 (0.7%)

On a scale from 0% to 100%, how confident are you that you could properly demonstrate or explain the following to a brand-new miner?	Response (% confident)	Self-escape leadership Frequency (%)	Rank-and-file Frequency (%)
	10	0 (0.0%)	3 (0.5%)
	20	2 (0.7%)	6 (1.0%)
	30	3 (1.1%)	8 (1.4%)
	40	1 (0.4%)	10 (1.7%)
	50	15 (5.3%)	28 (4.8%)
	60	11 (3.9%)	28 (4.8%)
	70	23 (8.1%)	52 (9.0%)
	80	25 (8.8%)	89 (15.4%)
	90	43 (15.2%)	114 (19.7%)
	100	158 (55.8%)	236 (40.8%)
	No response	1	11
Your mine’s communication and tracking system	0	1 (0.4%)	6 (1.0%)
	10	1 (0.4%)	2 (0.3%)
	20	1 (0.4%)	2 (0.3%)
	30	0 (0.0%)	8 (1.4%)
	40	3 (1.1%)	4 (0.7%)
	50	8 (2.9%)	26 (4.5%)
	60	3 (1.1%)	29 (5.0%)
	70	17 (6.1%)	46 (8.0%)
	80	27 (9.7%)	75 (13.0%)
	90	43 (15.4%)	104 (18.0%)
	100	175 (62.7%)	275 (47.7%)
	No response	5	12
How to use nonverbal communication	0	1 (0.4%)	0 (0.0%)
	10	1 (0.4%)	1 (0.2%)
	20	1 (0.4%)	0 (0.0%)
	30	1 (0.4%)	4 (0.7%)
	40	1 (0.4%)	1 (0.2%)
	50	3 (1.1%)	16 (2.7%)
	60	3 (1.1%)	13 (2.2%)
	70	9 (3.2%)	26 (4.5%)

On a scale from 0% to 100%, how confident are you that you could properly demonstrate or explain the following to a brand-new miner?	Response (% confident)	Self-escape leadership Frequency (%)	Rank-and-file Frequency (%)
	80	20 (7.1%)	39 (6.7%)
	90	33 (11.7%)	74 (12.7%)
	100	208 (74.0%)	410 (70.2%)
	No response	3	5
Where your mine's tetherlines are located	0	2 (0.7%)	2 (0.3%)
	10	0 (0.0%)	1 (0.2%)
	20	0 (0.0%)	4 (0.7%)
	30	1 (0.4%)	0 (0.0%)
	40	3 (1.1%)	6 (1.0%)
	50	9 (3.2%)	19 (3.3%)
	60	4 (1.4%)	15 (2.6%)
	70	8 (2.9%)	22 (3.8%)
	80	24 (8.6%)	77 (13.2%)
	90	35 (12.5%)	88 (15.1%)
	100	194 (69.3%)	349 (59.9%)
	No response	4	6
How to use tetherlines	0	2 (0.7%)	2 (0.3%)
	10	0 (0.0%)	2 (0.3%)
	20	0 (0.0%)	3 (0.5%)
	30	1 (0.4%)	1 (0.2%)
	40	0 (0.0%)	5 (0.9%)
	50	4 (1.4%)	9 (1.6%)
	60	6 (2.2%)	10 (1.7%)
	70	6 (2.2%)	23 (4.0%)
	80	19 (6.8%)	43 (7.4%)
	90	28 (10.0%)	85 (14.7%)
	100	213 (76.3%)	395 (68.3%)
	No response	5	11

Appendix J: Abbreviated Training Strategy Matrix Developed by gOE/Aptima for Preparing Mineworkers to Perform Critical Cognitive Tasks during Dynamic and Emergent Situations

Cognitive Requirement	ISD Considerations	Media/Method
Sensemaking/ Situation Assessment (SA) Collecting, corroborating, and assembling information and assessing how the information maps onto potential explanations, decisions, and events; includes integrating new information from the environment with existing knowledge to generate new potential hypotheses or revisit previously discarded hypotheses to form and reform a coherent picture of the situation.	• Provide miners with information and knowledge about key SA concepts: the significance of situational cues (e.g., hazard indicators), patterns of cues, and cue strategies relevant to emergency self-escape scenarios, actions required for maintaining SA, clues SA is lost, and obstacles to SA such as competing physical and cognitive requirements; provide an understanding of the environmental factors they should attend to, and why (e.g., mine conditions and equipment, crew member status, mine features, own location, and the evolving nature, extent, and severity of the disaster). • Demonstrate processes and behaviors used to gather and integrate information into an existing situation; could show techniques used to gather and track information from multiple sources and over time as well as how new information can be used to update the understanding of the situation. • Provide opportunities for miners to develop and practice hazard recognition and pattern recognition skills; provide practice gathering information from multiple sources and integrating new information into an existing picture; the practice scenarios can start out simple and build in complexity and fidelity. • Practice should develop team SA as well as individual SA; effective team SA is contingent on team members' ability to develop accurate expectations regarding team member roles and responsibilities; during training, develop shared mental models about roles and capabilities (and how these might be hindered during a self-escape situation) so crew members can anticipate and predict the needs of others. • Identify ways to provide feedback throughout and after the practice simulation or scenario.	• Use classroom lectures, computer-based training (CBT), or web-based training (WBT) to present important SA concepts; build in class discussions to emphasize key points and ensure understanding; consider using instructional scaffolding to first teach individual cues and then develop awareness of sequences or patterns of cues. • Show videos that demonstrate and model effective sense making/SA behaviors; during drills or other training scenarios, encourage experienced miners to explain how they integrate various sources of information to draw conclusions. • Use low-cost classroom simulations, during which trainees work through fictitious self-escape scenarios, which require integrating and making sense of a variety of information. • For more interactive and high-fidelity practice, use scenario-based training, drills, mock disasters or exercises (e.g., mine emergency evacuation drills) where miners work scripted realistic self-escape scenarios; these methods can be particularly useful for practicing losing and regaining SA. • Methods ideal for training of hazard recognition and pattern recognition skills include CBT and WBT, simulations, and embedded training. • Incorporate feedback (e.g., via debriefs/after action reviews during and after all active training activities).

Cognitive Requirement	ISD Considerations	Media/Method
Coordinating Managing activities and interdependencies across multiple individuals acting in roles that have common, overlapping, or interacting goals	• Provide information about coordination of tasks, procedures, and protocols so that people develop a shared understanding of what and how to coordinate; also, provide information about crew member roles and responsibilities in self-escape scenarios and in executing tasks so that crew members can better predict one another's needs, intentions, and actions • Provide demonstrations of good/bad coordination behaviors (e.g., verbal and nonverbal communication, backup behaviors) • Allow opportunities for trainees to practice executing coordination tasks and procedures, including communications and interactions using equipment (e.g., radios) • Give meaningful diagnostic feedback to develop declarative knowledge of roles, procedures, and communications equipment capabilities and limitations. Feedback should be timely and specific to the coordination behavior observed. • Use group activities with crew members in various roles and using appropriate technologies to simulate realistic exchange of information and coordination needs between individuals.	• Use classroom lectures and discussions to develop knowledge of important communications procedures and coordination techniques; CBT and WBT can also be used to deliver basic knowledge. • Use part-task trainers to train radio and phone procedures and skills to automaticity [Kirlik et al. 1998]. • Provide low-cost practice with classroom exercises or scenario-based training [Cannon-Bowers and Bowers 2011] incorporating realistic environmental constraints (e.g., static, lost communications, broken equipment); for greater fidelity, have students use real communications equipment. • Provide practice communicating in full self-escape gear (e.g., SCSRs); provide cap lamp signal training if needed. • Use exercises or drills that require coordinating the actions and information shared between multiple people; facilitate a debrief/AAR (After Action Report) after the drill so that trainees can identify what went well in terms of coordination and opportunities for improvement.

Cognitive Requirement	ISD Considerations	Media/Method
Managing Uncertainty/Risk Coping with unknowns and ambiguous situations by reflecting and iteratively comparing the characteristics of the current situation with previous experiences; often involves mentally simulating an intended course of action.	• Teach miners to understand risk as a combination of probability of event and severity of consequence. • For tasks where safety is particularly at risk, provide interactive training (e.g., simulation, hands-on); research indicates such training is more effective in these cases due to its greater ability to motivate learning and transfer. • Demonstrations (e.g., behavioral modeling) can be effective for situations rarely encountered on the job (this includes most of the self-escape tasks); for example, the need to handle panic in others is likely to be rare; modeling how to manage it can act to create proper expectations and behavioral repertoire. • Uncertainty in self-escape can relate to lack of needed information; trainees should be taught to ask questions or seek additional information; similar to "see something, say something," stress miners' responsibility to speak up, point out perceived risks, and ask clarifying questions. • Where possible, train all self-escape tasks to automaticity so that, for tasks involving uncertainty and risk, miners maintain cognitive capacity for controlled processing. • To help set expectations and build confidence, train miners to mentally simulate their roles in self-escape.	• Use discussions and lectures to teach the nature of risk. • "Empower" miners to speak up and ask questions during self-escape by explicitly telling them (in the classroom) that they have permission to do so and that it is their responsibility; they can be reminded of this by their foreman during drills. • Use simulation and drills for self-escape rehearsal; a variety of scenarios and trigger events should be used to build a flexible suite of miner responses. • Demonstrations and behavioral modeling can happen in the classroom or in the mine during a drill; miners should be allowed to practice demonstrated behaviors, with feedback. • A verbal classroom "walk-through" of an escape situation can help miners mentally simulate their roles in self-escape; for instance, they could be asked what they should be doing at each of several points during an evacuation, with feedback incorporated throughout. • Ensure that safety training (e.g., SCSR maintenance and use) is stressed and maintained and that miners are trained to automaticity with repeated practice, rehearsal, and feedback; this will allow miners to retain maximum working memory to manage uncertainty.

Cognitive Requirement	ISD Considerations	Media/Method
Detecting Problems Noticing anomalies, a reduced margin of error, or that events may be taking an unexpected (positive or negative) direction that requires explanation and/or monitoring may signal a need or opportunity to reframe how a situation is conceptualized and/or revise ongoing plans in progress; includes specific problem-detecting skills, hazard recognition, pattern recognition, template matching/mental simulation, and reasoning.	• In developing training, consider each of the first four steps in Kowalski-Trakofler and Barrett's [2003] proposed human processing and visual search skill model of hazard recognition: miner must (1) detect the presence of potentially relevant sensory cues in the environment, (2) selectively attend to a subset of those cues (on an automatic level), (3) correctly recognize the pattern or combination of cues that make it hazardous, (4) search for and confirm or disconfirm evidence that it is a hazard, and (5) consider and select an appropriate response; note that pattern and discrepancy recognition are central to this model. • Trainees should be taught root cause identification rather than simply identifying a surface issue (e.g., false alarms). • Train miners to understand and recognize various cues associated with potential problems; cues to the existence of problems may be subtle—cues are an interaction between the external world and the knowledge and expectancies of a trainee. • Both knowledge of general and site-specific potential problems should be addressed. • During training, include information on temporary states of miners that are related to problem detection (e.g., time pressure, fatigue, lack of vigilance); provide trainees with an awareness of the impact these states can have on their ability to recognize problems; give guidance on how these can be handled; that is, how trainees can develop the "meta-skill" of managing their temporary states. • Research indicates training on perception of risks and dangers is more effective if the trainees trust their organization and trainer [Siegrist and Cvetkovich 2000].	• High tech and high fidelity training tools, such as simulators/virtual training, provide excellent opportunities for teaching and practice; following Kowalski-Trakofler and Barrett [2003], provide trainees with degraded, subtle stimuli of problems (e.g., alarms, changed conditions); these can be "gamified" in that trainees could compete for problem detection, or exercises could be scored and timed, with feedback provided. • Include group exercises or discussions about the factors that result in distraction, time pressure, or lack of vigilance; more experienced miners may be able to provide tips and guidance; consider brainstorming the development of a list of factors and ideas for handling them. • Demonstrations that show positive or negative examples of problem detection; training could use live examples or videos of desired skills, procedures, and techniques. • Develop and teach mnemonics to provide structure to characteristics of potential problems; mnemonics have been shown to be useful in training detection of potential problems. Albert et al. [2014] provide a list of 10 sources of danger based on energy source (e.g., mechanical, gravity, pressure). • Use group settings to employ the What If? method of training, which uses a set of pre-prepared What if? questions on facility "deviations"; for example, the question: "What if you perceive substantial water today at the

Cognitive Requirement	ISD Considerations	Media/Method
		face where there was none yesterday?" can generate a discussion on whether a problem might exist. • Develop lessons learned from training efforts and disseminate them (e.g., newsletter, briefing). • Build trust between miners and the organization at the beginning of and throughout training; this could be done through allowing any issues to be raised and discussed; of course, building trust should be a long-term, sustained, general effort.

Cognitive Requirement	ISD Considerations	Media/Method
Shared Cognition Building shared team knowledge of what to do under different escape conditions and circumstances; understanding how team member actions affect one another.	• Because a group of miners will likely form an ad hoc team in a self-escape scenario, it would be helpful to develop shared cognitions among mineworkers. • Team Adaptation and Coordination Training (TACT) would be helpful, although not necessarily sufficient, to build shared mental models of self-escape; TACT has been shown to be effective even after a short training period. • Team Model Training (TMT) can be used to build interpositional knowledge, an aspect of shared cognition; TMT has been used to improve team communications. • Crew Resource Management (CRM) builds aspects of shared cognition such as adaptability, assertiveness, and decision-making. • Cross-training builds shared cognition such as interpositional awareness because trainees perform tasks that others typically do; cross-training would allow miners to more easily step into the role of escape group leader (EGL) if needed, for example. • Debriefing guided team self-correction can assist in building shared understanding in expert models of teamwork that are most effective in increasing performance. • Evaluating shared cognition among crew members can be beneficial since such shared cognition predicts performance. • Building shared group expectations for rare events via targeted expectations training can be helpful.	• A general consideration is that building shared mental models involves a group; while training as a group is not necessarily needed (see TMT below), it often will be useful (see CRM below). • TACT incorporates videos showing examples of good and bad behaviors; for relevant self-escape tasks, short videos could be created portraying useful and not-useful behaviors. • TMT has been carried out using computer-based training, such as providing incoming and outgoing communications; a simple self-escape simulation could be built providing communications between RP, EGL, and escape group members. • CRM can use role plays to teach CRM skills (and a shared awareness of these) such as assertiveness, cross-checking, and conflict management; quarterly self-escape drills could be designed with a role play component, such as helping others don SCSRs. • Cross-training is performance-based in that trainees actually perform the roles of others; self-escape drills or classroom role-playing could incorporate this by having other miners play the role of EGL (e.g., making decision to self-escape, conducting headcount). • Debriefing after a self-escape exercise or drill would be most effective in improving shared cognition if some kind of structured approach is used; for example, a debrief could be led by an experienced facilitator, or a computer-based debriefing system could be used. • NIOSH recommends expectations training for SCSR training; this concept could be expanded to other areas of self-escape where shared cognition is important (e.g., establish realistic group expectations of speed of escape travel by practicing group movement following a lifeline in the dark while on a tagline).

		• Some approaches to the assessment of shared cognition can be complex (e.g., card sorting, pairwise comparisons) and not appropriate to the real-world characteristics of mining; however, the presence or absence of shared cognition can be accessed via observation. Trained observers can answer questions such as: ○ Did team members have a common understanding of the task (e.g., deploying the rescue chamber), team roles, and available resources (e.g., deployment instructions)? ○ Did team members coordinate effectively? ○ Did team members recognize mistakes made by others? Were corrective actions agreed upon?

Cognitive Requirement	ISD Considerations	Media/Method
Managing Attention Simultaneous tracking, processing, considering, and storing information; includes prioritizing and attending to essential pieces of information, while ignoring non-essential information; particularly relevant in complex emergency situations, attention puts a heavy burden on working memory, particularly for tasks or actions requiring deliberation, critical thinking, diagnosis, problem solving, conflict resolution, and decision-making.	• To reduce the load placed on cognitive resources and potentially free a miner's working memory during a self-escape scenario, provide training that develops deep knowledge of important self-escape concepts, procedures, and plans; for example, develop knowledge of emergency plans, locations of emergency equipment and maps, and procedures for evacuation/escape, communications, terminology, and navigation [Radomsky et al. 2009]. • Explain to miners how attention can be impacted by fatigue and stress and how best to manage. • Practice tasks and procedures to the point where they can be performed with automaticity so that individuals are resilient to stress [Kirlik et al. 1998; Price et al. 2007]; this is particularly useful for tasks that deal with equipment (e.g., SCSRs) and self-escape procedures and plans. • Provide practice using protocols and checklists; practicing a complex task to the point where it is overlearned can result in better performance and greater resilience to stress [Squire and Schacter 2003]. • Provide exposure to practice with tasks that require simultaneous processing and storage of data, controlled attention, maintaining information despite distractions, attention to competing goals, attending to relevant information while ignoring irrelevant information, resolving conflicting actions to prevent error [Engle et al. 1999].	• Provide frequent and deliberate practice to develop automaticity of cognitive self-escape tasks [Reber and Kotovsky 1997; NRC 2013]; provide repeated or "mass" practice in realistic conditions; for example, practice donning activation and use of SCSRs during an emergency self-escape drill or exercise. Consider using simulations and VR technology to introduce environmental pressures such as noise, smoke, or heat. • Distribute repeated practice or rehearsals over time [Jarvis 2006] or intersperse skill practice with practice of other skills/tasks [Proctor and Dutta 1995; Schmidt and Lee 2011] to increase motivation and stress resilience. • Use part-task trainers to train tasks such as SCSR donning and activation to automaticity [Vaught et al. 1991]. • Provide miners with useful heuristics (e.g., ventilation direction/rate, effects of gases on physiology) to reduce the cognitive demands placed on evaluating multiple solutions and sources of information. • Consider training miners to use other techniques found to improve working memory capacity and efficiency, such as mnemonics [Cook 1989] and elaboration [Squire and Schacter 2003].

Cognitive Requirement	ISD Considerations	Media/Method
Automaticity Executing a task or process without consciously thinking about the details and actions required and with little dependence on controlled processing, allowing it to become an automatic response pattern or habit.	• Automaticity is often the result of overlearning (i.e., training even after acceptable performance has been reached), repetition, and practice; some self-escape tasks require automatized reaction to complete; examples include using radio and telephones to communicate and donning SCSRs • The goals of training to automaticity are at least twofold: (1) enabling performance that is resistant to degradation by stress, and (2) freeing working memory—the cognitive system with a limited capacity that temporarily holds information available for processing, which supports decision-making and behavior. • Training should develop declarative knowledge of ERPs, escapeways, equipment, etc., which reduces cognitive load during self-escape. • Expectations training as currently recommended by NIOSH reduces distractions due to unexpected responses of equipment (e.g., SCSRs) and so allows automatic performance to remain uninterrupted.	• Provide important declarative knowledge via presentations, lecture, and discussion. • Establish a training regimen of frequent and deliberate practice for tasks that can reasonably be automatized (e.g., donning SCSRs, cardiopulmonary resuscitation, reading and interpreting mine maps, fighting fire). • Practice can first be in a classroom, but later should take place under realistic conditions (e.g., during drills, in simulators). • Practice should be distributed over sessions rather than massed into a single session. • Intersperse practice on a given skill with other training. Multitask training has been shown to be effective. • Part-task training (e.g., on SCSRs only) can assist in training to automaticity; different tasks, once automatized, can then be compiled in a larger scenario. • Overtrain important skills. • Ensure SCSR expectations training is continued. • Assess skills to ensure automatization. • Refresh skills via later training to avoid skill decay.

Cognitive Requirement	ISD Considerations	Media/Method
Declarative Knowledge Memorized information that can be recalled quickly	• Repetition of information is crucial to building declarative knowledge; information and facts are learned best when presented in a distributed (at different points in time) rather than a massed (all at once) fashion, even when the total amount of time required is equal. • Knowledge acquisition, including in safety training, is superior in settings that are learner-centered, engaging, and with dialogue; the more miners are engaged in learning, the better they will learn; information context is also important—in the case of self-escape, context is easily provided. • Adaptive training has been shown to be effective; it provides information at a rate that matches an individual learner's learning rate. It does this by frequent assessments of knowledge gain and adjusting training as appropriate. • The testing of declarative knowledge is itself a teaching method, particularly when trainee results are provided.	• Lecture, often using pictures and/or physical displays (e.g., of equipment), is a common and still useful technique for communicating information to trainees; to the extent possible, encourage interactivity, dialog, and discussion during such training—the more engaged trainees are, the better for their learning. • Cycle back to the most important facts repeatedly, ideally in sessions distributed over time rather than only in a single session. • Develop content in an instructional scaffold—starting with the trainee's initial knowledge, build detail using examples, analogies, etc. • WBT or CBT may be offered to trainees either at the job site or at their homes; intelligent tutoring systems (ITS) are CBT systems that can provide adaptive learning; one limitation of ITS is that they provide only individual-level instruction. • Encourage questions during training sessions; answering questions can help avoid confusion and also reinforce learning points; one way to obtain interaction is to direct questions to various trainees at different times. • Use quizzes and tests; these need not be intimidating if done correctly; quizzes are a natural adjunct to lecture, and if using web-based training or CBT, built-in and automatically scored quizzes are a useful way to ensure that trainees are paying attention to content and to reinforce the learning content.

<table>
<tr><th>Cognitive Requirement</th><th>ISD Considerations</th><th>Media/Method</th></tr>
<tr><td>Decision-making

Committing to one or more options that may constrain the ability to reverse a course of action. A continuous process conducted under time pressure that involves re-examining embedded default decisions in ongoing plan trajectories for the predicted impact on meeting objectives, including whether to sacrifice decisions to which agents were previously committed based on considering tradeoffs; may involve a single decision maker or require consensus across distributed actors with different stances toward decisions.</td><td>Decision-making training strategies must consider important decision-making skills as well as constraints of the environment.
Naturalistic decision-making (NDM) research suggests that training the cognitive skills that underlie decision-making can accelerate decision-making proficiency [Cannon-Bowers and Bell 1997]; these skills include: situation assessment, hazard recognition, pattern recognition, risk perception, template matching and mental simulation, metacognition, reasoning skills, and both general and domain-specific problem solving skills.
As with the other cognitive requirements, follow an instruct/provide information, demonstrate, practice, feedback sequence approach when training decision-making tasks and skills.
Training for self-escape should:
Provide information necessary for mastering requisite knowledge
Demonstrate correct behaviors
Provide opportunities to practice
Incorporate feedback with practice
Accelerate individual expertise
Enhance team effectiveness
Free working memory
Keep skills fresh
Prevent cognitive bias
Normalize stress response
Develop coping mechanisms
NDM researchers suggest training should simulate decision-making under stress [Cannon-Bowers and Bell 1997]; however, research shows that psychological fidelity may be better than “physical” fidelity for training decision-making for crisis situations [Maitlis and Sonenshein 2010]; find opportunities to use lower-fidelity options when possible and appropriate.</td><td>When training decision-making, implement a simple-to-complex, low-to-high fidelity approach to training, gradually adjusting task difficulty, and employ a variety of training media and modes to target different learning styles.
Methods that can be used to develop decision-making knowledge and skills include classroom lectures, discussion, instructional scaffolding, CBT, WBT, distance learning, and part-task trainers.
To demonstrate decision-making behaviors, consider skill demonstrations, on the job coaching/mentoring, cognitive apprenticeships (for highly cognitive decision-making tasks), and verbal protocol analysis.
Some low-cost, high-impact methods for providing practice for decision-making skills include group problem-solving exercises, classroom simulations, scenario-based training, and case studies.
High-fidelity methods for training decision-making include embedded training; emergency drills, mock disasters, and exercises; virtual reality, part and full-task trainers; situation-based simulations; game-based learning (GBL); and stress exposure training (SET).
Strategies for enhancing decision-making practice with feedback include AARs (After Action Reports), reflective practice, and guided practice.</td></tr>
</table>

Appendix K: Semi-structured Interview Used for Cognitive Task Analysis

THE GROUP FOR ORGANIZATIONAL EFFECTIVENESS, INC. AND APTIMA, INC. COGNITIVE TASK ANALYSIS INTERVIEW PROTOCOL

NIOSH IRB Protocol

This analysis will focus on tasks, identified in the initial task analysis, that are both critical and have an important cognitive and/or decision-making component. The list below represents the complete list of probes that may be used during knowledge elicitation. A subset of these probes will be during each interview, depending on the goals of the interview, the nature of the experience of the interviewee, and the extent of information gathered in prior interviews and focus groups.

- Participant's role during emergency escape (company description).
- Participant's role during emergency escape (study categories).
    - Crewman (working face)
    - Outby worker
    - Escape group leader
    - Responsible person
- Review amount of time available for the interview.
- Review scenarios (Provide printed scenario handout.)
    - Scenario 1: Fire in belt drive (hydraulic oil and small coal accumulations).
    - Scenario 2: Explosion (open man door along the main beltline; methane accumulation).
    - Scenario 3: Impoundment failure/liquid/gas inundation: Strike into old gas well; methane gas and water).
    - Scenario 4: Rockburst/coal burst/roof fall (roof failed due to a coal burst of a pillar).
- Explain the information we are seeking (Provide this text in a printed question handout):
    - What stimuli in the mine environment differentiate an emergency situation from both (a) normal and (b) abnormal but not emergency conditions?
    - How would miners first recognize and conclude that an emergency scenario exists?
    - Given the emergency scenario, how does the miner decide to escape?
    - What information would miners immediately provide within and across groups of coworkers in the mine and the responsible person?
    - How do miners know when to ignore cues that might otherwise indicate an emergency?
    - How would miners make decisions about whether to attempt to correct an emergency situation as opposed to escaping from the mine?
    - How do miners determine the need to initially don self-contained self-rescuer (SCSR)?

- How do miners determine that pre-planned escape routes are feasible for use to escape the danger?
- What decisions do miners make to evacuate the danger area?
- What issues do miners anticipate during escape in using multiple types of equipment (such as how to communicate to other miners by speaking, telephone, or radio while using an SCSR)?
- How do miners plan to deal with injured coworkers during escape?
- How would miners determine an escape route is not usable, and what decisions do miners make to resolve the situation?
- What decisions do miners make concerning whether or how to use a refuge alternative?
- How do miners determine the presence of hazardous gases or lack of adequate breathable air?
- How would miners make decisions about whether a changing situation had made self-escape more or less difficult?
- How should miners receive updated information about the emergency, and what information would they expect and want?
- How do miners provide information about their own and others' conditions (both normal and emergency methods)?
- What decisions must miners make concerning egress from mining equipment or avoiding becoming entrapped by parts of equipment or controls?
- Do miners shut off equipment during an emergency, and depending on what equipment is or is not available, how does this impact escape?
- What decisions must miners make concerning obtaining stocks of food or water to survive extended entrapment?
- What decisions do miners make about emergency sources of light to enable escape?
- What decisions must miners make concerning abnormal temperature (heat or cold) conditions?
- If escape does not appear to be immediately possible, what decisions do miners make about barricading to create a refuge (such as how, when, what materials to use, whether to use what is in immediate area or retrieve materials from farther away)?
- What job aids or other sources of information are available for making decisions, signaling, or determining courses of action?
- What job aids may be critical to self-escape, but of reduced value due to loss of power, lack of visibility, or damage to mine systems (such as not being able to read printed instructions due to darkness)?
- What decisions and knowledge do miners use to find their way along escape routes, particularly in conditions of reduced visibility due to darkness or presence of dust or smoke?
- What understanding of the mine's physical layout do miners use to locate their way to safety (refuge or escape) during emergencies?
- What support do miners expect, need, or prefer from the responsible person?

    - What skills would miners apply within groups of miners to organize escape or survival efforts?
    - What information should miners share, to whom, and through what communications method?
    - How would miners determine whether to walk out of the mine or attempt to use the normal motorized transports?
    - Other than the emergency itself, what abnormal risks from equipment or the mine itself must miners be able to detect and act on to avoid injury (such as a damaged power cable that could cause electrocution)?
    - How do miners verify that they are making progress in escaping from the emergency (for example, have not gotten lost and doubled back)?
    - What sources of stress and uncertainty are miners likely to encounter during an emergency situation?
    - What might be potential sources or situations that could lead to cognitive overload during an emergency (simply too much information to process, unable to make decisions or select a course of action)?
    - What information would miners particularly seek to obtain to adjust and coordinate their escape actions?
    - What are the most likely and critical communication and coordination challenges?
    - What workarounds are anticipated when multiple pieces of equipment cannot operate or be used together or if equipment fails?
    - Please tell us a story about a particularly challenging self-escape experience, either in practice or real life.

- Select one of the scenarios to begin discussion.
- Review time budget for first scenario.
- Review the scenario's initial conditions.
- Make a first pass through the first scenario.
    - What does a miner need to know or be able to do?
    - What decisions does a miner have to make?
    - What information does a miner need to make decisions?
    - What tools or technology would a miner want to have available?
    - What strategies or techniques would miners use for making decisions?
    - What information would miners monitor or seek during the situation?
    - What will be demanding, if anything, in terms of thinking or making decisions?
    - What will be demanding, if anything, in terms of using self-escape technology?
- Recap from discussion about first scenario.
    - Interviewer recaps the major points heard based on notes. "Let me see if I understand the gist of what you said…So, you…" and misunderstandings are corrected.

- Review timeline for the first scenario, based on discussion. “What did you do first? What was challenging about this? What did you do after that?”
- Continue reviewing through all the events for the first scenario. Review notes about the scenario: The intent is to query the miner for details about:
    - What does a miner need to know or be able to do?
    - What decisions does a miner have to make?
    - What information does a miner need to make decisions?
    - What tools or technology would a miner want to have available?
    - What strategies or techniques would miners use for making decisions?
    - What information would miners monitor or seek during the situation?
    - What will be demanding, if anything, in terms of thinking or making decisions?
    - What will be demanding, if anything, in terms of using self-escape technology?
- Repeat for second scenario, focusing on what is different, missing from responses and actions to earlier scenarios.
- Repeat for third scenario, focusing on what is different, missing from responses, and actions to earlier scenarios.
- Repeat for final scenario, focusing on what is different, missing from responses, and actions to earlier scenarios.
- Training “what ifs.”
    - If you could have used any training or training asset to prepare you better for incidents such as the one you described, what would it be?
    - What exactly would you practice and why?

Thank You

Thank you very much for your time. This was very helpful.

Do you have any questions for us before we wrap up?

Appendix L: Draft Rank-and-file Competency Checklist with SME Consensus Results and Notes

This appendix includes the draft rank-and-file competency checklist that was developed by NIOSH based on the results of the formal task analysis by gOE/Aptima researchers. The framework is structured to include the NIOSH-revised major self-escape activities, associated gOE/Aptima-identified competency areas (or "task clusters"), and performance criteria (critical KSAs). Also included are the SME consensus ratings for the expected proficiency levels (EPLs) for rank-and-file miners by KSA, using the following scale:

0 – "Not critical for rank-and-file miners to practice"
1 – "Good to know, but not necessarily critical" (supplemental competency)
2 – "Need to know" (core competency)
X – "Remove item" (problematic)

These ratings were used to guide NOSH researchers in developing the final self-escape core competency profile framework for rank-and-file miners in the sister publication to this report, the NIOSH IC "Self-escape Core Competency Profile: Guidance for Improving Underground Coal Miners' Self-escape Competency" [NIOSH 2023].

Any changes to the performance criteria criticality or phrasing based on SME feedback are noted in the following table. Unless otherwise indicated, the changes were noted during the SME focus group consensus building exercise described in Chapter 5

Major Activity A: Communicating

Minimum levels of proficiency must be met for the KSAs required to communicate critical information about an emerging or developing situation to establish situational awareness and assist in the diagnosis and description of the event using verbal and nonverbal communication techniques and communication technology.

Competency Area A1: Establishing Situational Awareness

Performance Criteria (KSAs)	EPL	SME Notes
Pay attention to landmarks, signage, and direction and temperature of airflow on ride in to work location.	2	Added "temperature" and changed "section" to "work location." Airflow particularly important along beltlines.
Know whether transportation is staying or going; take one-hour unit if going.	2	Added by focus group SMEs.
Understand one's own role in emergency response plan and that of the RP and EGL.	1	Good to have a general idea, but not every responsibility of leadership roles.
Know the general layout of the mine.	2	-

Performance Criteria (KSAs)	EPL	SME Notes
Know how entries are numbered and the numbering of crosscuts on section.	2	Entries usually left to right. "…numbering of crosscuts on section" added based on external SME review of draft documents,
Know locations of mine phones and other communication technology.	2	-
Establish awareness of one's own location within the mine relative to the event(s).	2	-
Have a general escape plan in mind with crew every shift.	1	-
Recognize one's own position within the mine relative to the locations of all emergency features and apparatus, such as: ✓ Mine phones and other communication technologies ✓ Meeting place ✓ SCSR caches ✓ Lifelines ✓ Primary and secondary escapeways ✓ Refuge alternatives ✓ Barricading supplies ✓ Taglines/tetherlines ✓ Mine maps[20] ✓ Firefighting equipment ✓ Medical supplies	2	Added mine phones "and other communication technologies." Need to know mine map symbols. Legends should also be included on maps. Emphasis placed on importance of knowing the location of the secondary escapeway added based on external SME review of draft documents. Barricading supplies added based on external SME review.
Know the identity and approximate or likely location of the designated RP on each shift.	2	Removed "(and RP backup)" and added "approximate or likely." Miners should know whom to call to report an emergency.
Have knowledge of personnel on crew and assigned locations.	1	-
Know the identity and location of inexperienced miners (e.g., "red hats," "white hats"), if assigned.	1	Added "if assigned."
Ensure the safety of inexperienced miners, if assigned.	2	Added "if assigned."

[20] Mines are increasingly using handheld electronic devices which may contain preloaded maps. If applicable, all underground miners should have familiarity with this technology.

Performance Criteria (KSAs)	EPL	SME Notes
Understand the basics of mine ventilation and expected air flow/ventilation in the mine.	2	Changed from “good to know” to “need to know” based on external SME review
Understand significance of smoke presence (including from fans or in exhaust shafts).	2	-
Recognize the presence of unexpected water.	0	Fire boss and other leaders should be able to recognize signs of water inundation.
Know how to navigate through or around water (lift SCSRs above water, if necessary).	2	Added by focus group SMEs.
Understand the potential impact of different emergencies (e.g. fire, explosion, water or gas inundation) on mine structure, ventilation, equipment, and power.	1	-
Understand that even a small, localized methane explosion can destroy ventilation control devices.	2	-
Recognize the need to self-escape.	2	-
Decide to escape or wait to receive order to escape.	X	Never wait for order to escape during an emergency; add item below instead.
Decide to travel to meeting location or escape.	2	Added by focus group SMEs.
Stay current on changes to the mine related to the locations of entrances, shafts, and slopes.	2	Item added based on external SME review of the draft documents.

Competency Area A2: Assisting in Diagnosis

Performance Criteria (KSAs)	EPL	SME Notes
Know what mine gases may be present in the mine, how they interact, and potential consequences.	1	Need to know danger levels, how to read detectors, and when to don SCSRs.
Know what mine gases may be present in the mine, how they interact, and potential consequences.	2	External SME reviewer deemed this critical; above focus group SME notes retained.
Know relative risk propensity for specific mine (i.e., which are most likely to occur—gas or water inundation, fire, explosion.	2	For example, a “gassy mine” or other characteristics.
Know desired min/max gas levels (methane, CO, oxygen CH4, H2) and how to respond if out of acceptable limits.	2	Focus group and external review SMEs added “and how to respond if out of acceptable limits”.
Read and interpret CO systems (monitors, graphs, charts) to assess air quality.	0	-
Recognize the meaning and significance of audio and/or visual alarm sensor alerts.	2	-
Understand why false (nuisance) alarms can occur (e.g., diesel exhaust).	0	-
Recognize the occurrence of and potential significance of a power outage or other interruption to operation of fans.	2	Added “or other interruption to operation of fans.” Call to ask if fans are running.
Judge severity of fire (e.g., based on size, spread, and location).	2	-
Know what information is critical and how to communicate it to others within the mine or on the surface (See Competency A3, below).	2	-
Know to verify and never ignore alarms and alerts.	2	Added based on external SME review of draft documents.
Know the chain of command for reporting a mine emergency.	2	Item added based on external SME review of the draft documents. It was also noted this knowledge is particularly important for outby workers because it is not always clear to whom they should report—and the shift foreman and other “bosses” may not be in the direct vicinity of the workers.

Competency Area A3: Verbal and Nonverbal Communication

Performance Criteria (KSAs)	EPL	SME Notes
Know what information to gather and prioritize.	2	-
When possible, leaves handwritten notes or uses other communications to relay plans for escape.	2	Added based on SME external review of draft documents.
Does not remove SCSR mouthpiece to communicate unless in fresh air (e.g., from RA)	2	Added based on SME external review of draft documents.
Know to call out to confirm whether or not fans are running.	2	Added based on SME external review of draft documents.
Speak loudly and clearly.	2	-
Communicate plans and next steps.	2	-
Relay and receive updated information to and from others within the mine or on the surface, as able.	2	Important to know verbal and nonverbal communication techniques below.
Repeat information received to confirm reception and understanding.	2	-
Confirm information shared has been received and understood.	2	-
Know limitations of verbal communications while using SCSRs.	2	-
Know not to remove SCSR mouthpiece to speak.	2	-
Use nonverbal communications (e.g. hand, cap lamp signals, tapping codes, blinking lights, writing) with others in mine.	2	Add tapping codes to nonverbal communication description.
Use nonverbal signals (e.g. mine-specific standard tapping codes) from within the mine to communicate with others above ground.	2	Combined with nonverbal communication above.
Use chalk boards stored with first-aid equipment and caches, if available	1	Covered under "Carry or use cached writing instruments."
Carry paper and pen on person.	1	Covered under "Carry or use cached writing instruments."
Use "pulls" on taglines/tetherlines to communicate (stop, advance, retreat, help) using standard mine rescue lifeline pull sequence.	0	i.e., 1 pull=stop, 2 pulls=advance, 3 pulls=retreat, 4 pulls=help (SARH). SME focus group rates this 0. SME external reviews of the draft documents concur this is not applicable to self-escape.

Competency Area A4: Using Communication Technology

Performance Criteria (KSAs)	EPL	SME Notes
Operate all mine phones, radios, texting devices, and backup systems.	2	-
Know emergency radio channels.	0	-
Know backup and work-around communication options (e.g., direct line of sight option with handheld radios).	0	-
Understand potential effects of the emergency on communications equipment.	1	-

Major Activity B: Wayfinding

Minimum levels of proficiency must be met for the critical KSAs required to maintain situational awareness and effective verbal and nonverbal communication to navigate to a location of relative safety by knowing how and when to use mine emergency features and apparatus.

Competency Area B1: Maintaining Situational Awareness

Performance Criteria (KSAs)	EPL	SME Notes
Maintain awareness of own location within the mine relative to the event(s).	2	-
Maintain awareness of own position within the mine relative to all exits and fresh air.	2	-
Have general knowledge of relative mine elevation (e.g., where higher and lower elevation spots are located).	1	-
Know general locations of man doors (e.g., every 5th crosscut).	2	Know mine map symbols! Added "general" and made critical based on external SME review.
Understand how rate of escape in emergency conditions can be reduced below normal walking speed and know to pace yourself.	2	Added "and know to pace yourself."
Use handheld multigas detectors to continuously assess air quality as position changes.	2	-
Understand impact of gases, fire and smoke on air quality.	2	-
Know roof support plan.	1	0 for self-escape specifically, but "good to know" basic knowledge.

Performance Criteria (KSAs)	EPL	SME Notes
Have a basic knowledge of the roof control plan and how it might change due to fires, explosions, etc.	2	External SME reviewer of draft documents rephrased and rated this as critical.
Know if, when, and how to test roof conditions (if possible) and know where to set roof supports.	1	"Sound" the roof and know what the sound means. Added "know where to set roof supports."
Know mine's ventilation plan and how changing conditions can impact airflow and air quality.	1	Combined with other impacts of changing conditions; "basics of mine ventilation" already included.
Know that gas or water inundation can impact airflow and air quality.	2	Added based on external SME review of draft documents,
Know who carries an anemometer to measure velocity and direction of airflow (e.g., foreman, fire boss).	1	Added by NIOSH from other sources; confirmed as "good to know" by SMEs.
Stay current on changes to the mine related to the locations of entrances, shafts, and slopes.	2	Added based on external SME review of draft documents.

Competency Area B2: Maintaining Verbal and Nonverbal Communication

Performance Criteria (KSAs)	EPL	SME Notes
Communicate plans and next steps to others within escape group and others within the mine.	2	Call out progress, if able (do not remove SCSR mouthpiece).
Provide updates on situation, plan, progress, next steps, and needs to RP/EGL and/or surface personnel.	2	Use communication technologies and techniques, as able.
Receive, acknowledge, and act upon RP/EGL/dispatcher guidance, as appropriate.	2	Maintain communication.
Provide updates on own physical condition and that of others in the mine.	2	Report injuries.
Communicate changing environmental conditions of the mine to RP/EGL and/or surface personnel.	2	-
Know what questions to ask to gather specific details about changing conditions within the mine.	2	-
Convince others to use tetherline/tagline.	2	-
Carry or use cached writing instruments.	1	-

Competency Area B3: Navigating

Performance Criteria (KSAs)	EPL	SME Notes
Move as a group; do not split group whenever possible.	2	-
Move to high elevation points during water inundation.	1	Should be instinctive, but also good to have general idea of mine's higher and lower elevations (already included under Competency Area B1 above).
Know how to check man doors for heat or contamination	2	Added based on external SME review
"Go low" in smoke/explosion and debris/difficult walking conditions.	2	Especially to don/switch/swap SCSR.
Travel by foot through mine where roof height is low (e.g. duck walking, crawling).	0	Instinctive ability.
If no lifeline, use other tactile wayfinding techniques (e.g., rib line, power cables, belt, waterlines, cane or stick).	2	Added "belt, waterlines; cane or stick"
If no tagline, place hand on shoulder of person directly ahead.	2	-
Travel through man doors or regulators, returning doors to the position you found them.	2	-
Cross over or under belt at designated crossings.	2	-
Reduce speed or work rate if difficult to breath.	2	-
Locate and use: ✓ SCSRs (Competency C) ✓ Taglines (e.g., everyone on same side) ✓ Escapeways (markers and colors) ✓ Lifelines (tactile symbols) ✓ Firefighting equipment (Competency D1) ✓ Escapeway maps (symbols and how to read) ✓ Refuge alternative	2	-
Know most experienced should lead tethered group with the slowest person in the middle of the group.	2	-
Remove/reattach tagline when boarding or dismounting vehicles.	X	Remove item, add item below.
Whenever possible, remain attached to the tagline/tetherline when in smoke or dust.	2	Added by SMEs. Real world example of why not to detach, if at all possible.

Performance Criteria (KSAs)	EPL	SME Notes
Reestablish proper ventilation using check curtains and other available materials.	0	Should be left to those with complete knowledge of the situation.
Know when all options for escape have been exhausted and it is necessary to take refuge as a last resort.	2	-
Deploy, configure, and maintain RA following manufacturer's instructions and:	2	Remove "maintain RA" for rank-and-file miners.
✓ Know steps to enter RA.	2	-
✓ Know to take extra SCSRs into RA.	2	-
✓ Know backup filtering solutions.	0	-
✓ Know how to check air inside/outside of RA.	2	-
✓ Maintain communication with RP/Dispatcher, as possible.	2	-
✓ Conserve resources (e.g., air, food, water, light).	2	-
Barricade if RA is not accessible.	2	-

Major Activity C: Using Self-contained Self-rescuers (SCSRs)

Minimum levels of proficiency must be met for the critical KSAs required to effectively use SCSRs to maintain access to breathable air. All underground personnel must know when and how to don or switch/swap SCSRs as well as how to maintain the units. In order to increase the likelihood of proper use of SCSRs during an emergency situation, it is also critical that mineworkers know what to expect while using SCSRs.

Competency Area C1: Deciding When to Don or Switch/Swap SCSR

Performance Criteria (KSAs)	EPL	SME Notes
Know to don SCSR:	2	-
✓ At the first sign of smoke or evidence of fire or explosion	2	Added "evidence." External SME reviewer added "or explosion"
✓ When multigas detector alarms	2	-
✓ When instructed to do so	2	-
Know the duration of personal SCSR and where nearest one-hour units are available.	2	-
Know when to switch/swap SCSRs.	2	-

Performance Criteria (KSAs)	EPL	SME Notes
Know rated duration of all SCSRs in use at the mine.	2	-
Monitor increased breathing resistance or check oxygen gauge (if available).	0	Remove. Add item below instead.
Know breathing resistance will occur and it may feel as if the unit is not working properly even if it is.	2	Added by focus group SMEs.
Track time passage since SCSR was donned, if possible.	2	-

Competency Area C2: Knowing How to Don or Switch/Swap SCSR

Performance Criteria (KSAs)	EPL	SME Notes
Perform steps for opening, assembling, and donning all SCSR models in use by mine.	2	Added "all SCSR models in use by mine" based on SME external review of the draft documents.
Know to wear the goggles from SCSR unit to protect against absorption of carbon monoxide through the tear ducts.	2	Added based on SME external review of the draft documents.
Insert mouthpiece and don the noseclips to isolate the lungs first and then adjust straps to secure the unit close to the body.	2	-
Use the manual start-up procedure, if necessary, that is applicable to the model.	2	-
Adjust straps so there is no tension or kinking in the breathing tube.	2	-
Help others to don SCSRs.	2	-
Know short-term SCSR will last about 10 minutes and move to nearest one-hour SCSR.	2	-
Know locations of all SCSR caches.	2	-
Understand that SCSR caches are relocated during section equipment moves.	2	-
Help others to switch/swap SCSRs.	2	-
Pick up and carry as many SCSRs as feasible.	2	-
Move outby toward next accessible cache to switch/swap SCSRs.	2	-
Know when to switch/swap between SCSRs (based on gauge (if available) time, levels of exertion and breathing resistance).	2	More detail added by external SME review of draft documents.

Competency Area C3: Maintaining SCSRs

Performance Criteria (KSAs)	EPL	SME Notes
Ensure a serviceable[21] SCSR is on one's person or within 25 ft of current location at all times.	2	Added "serviceable" footnote and added "within 25 feet of current location based on external SME review of the draft documents.
Inspect unit before each shift, checking case, seals, clips, and moisture indicator.	2	
Check factory service date.	0	Dates vary based on whether SCSR is carried or stored.
Know not to use SCSR for anything it was not designed for (e.g., blunt force tool, seat).	2	Know NIOSH approval and do not use SCSR for non-approved tasks (e.g., blunt force tool, seat).[12]
Know when to retire SCSR from service.	2	Know when to remove the SCSR from service.[12]
Know SCSR use procedures (e.g., do not take mouthpiece out to talk).	2	Some miners are able to talk with mouthpiece fully inserted. Could be practiced during smoke training, etc. Sometimes called "grunt lingo" based on SME external review of the draft documents.
Nonverbally communicate status of own and others' SCSRs to other escape group members.	0	Remove as specific nonverbal KSA.

Competency Area C4: Knowing What to Expect While Using SCSRs

Performance Criteria (KSAs)	EPL	SME Notes
Know that mine-ready SCSRs will be more difficult to open than those used during training.	2	-
Know that breathing resistance will occur, and it may feel as if the unit is not working properly even when it is.	2	-
Know that unit can become hot to the touch and breathing resistance will increase toward the end of rated duration of the SCSR.	2	-

[21] "Serviceable" is defined by the manufacturer and may be different for different SCSR models.

Performance Criteria (KSAs)	EPL	SME Notes
Understand how rate of escape can be reduced below normal walking speed, due to limited airflow and to pace yourself.	2	-
Know that verbal communication will be difficult or impossible while using SCSRs.	2	-
Understand breathing resistance is greater toward the end of the units' duration/capacity.		-
Know to keep the lungs isolated by never removing the nose clips or mouthpiece, even if it is uncomfortable or difficult to communicate.	2	Added by external SME review of draft documents.
Know that oxygen depletion rates can vary.	2	Added by external SME review of draft documents.

Major Activity D: Carrying, Wearing, and Maintaining Other Personal Tools and Equipment

Minimum levels of proficiency must be met for the critical KSAs required to carry, wear, and properly use essential personal equipment and tools necessary for diagnosis, wayfinding, situational awareness, breathable air, communication and tracking.

Competency Area D1: Personal Equipment

Performance Criteria (KSAs)	EPL	SME Notes
If appropriate, carry or wear the following: ✓ Essential medications ✓ EMS sticker and card with known conditions ✓ Reading glasses ✓ Wristwatch ✓ Lunch and water ✓ Paper and pen* ✓ Extra permissible light* ✓ …and know how to use: Multigas detector ✓ Handheld radios ✓ Required personal protective equipment ✓ Proximity sensor targets*	2*	Added proximity sensor targets Added "EMS sticker with card and known conditions" by NIOSH from other sources; confirmed by SMEs. *All critical except "paper and pen" and "extra permissible light" are "good to have".
Conduct checks on all personal equipment to assure they are working.	2	-

Major Activity E: Assisting in Emergency Response

Minimum levels of proficiency in basic emergency response KSAs for rank-and-file miners without specialized firefighting or emergency medical training may be required to effectively assist with firefighting and/or treating injured miners.

Competency Area E1: Assisting with Firefighting

Performance Criteria (KSAs)	EPL	SME Notes
Know the location of firefighting equipment at all times.	2	-
Assist in monitoring the working condition of firefighting equipment and ensures all hoses, fittings, and nozzles are the same size and thread.	2	Added based on external SME review of draft documents.
Share responsibility with mine management to regularly test water supply (i.e. 50 gallons per minute and 50 pounds per square inch) throughout the mine.	1	Added based on external SME review of draft documents.
Visually inspect fire to judge its severity (e.g., based on size, spread, and location).	2	-
Know underground coal mine fires can double in size every 5 – 10 minutes.	2	Added by NIOSH, confirmed by SMEs.
Knows to seek advice from the EGL, RP, or other personnel if unsure whether to stay or fight the fire	2	Added based on external SME review of draft documents.
Know firefighting plan.	1	-
Know role in fighting a fire.	1	-
Do not attempt to fight fire while using SCSR.	1	-
Use fire extinguisher.	2	-
Assemble and use fire hoses (e.g., “right to fight”).	2	SMEs added “right to fight.”
Use fog spray at nozzle to push smoke.	2	Critical to know IF fighting fire.
Confirm water source before assembling fire hoses.	2	Critical to know IF fighting fire.
Keep hose between self and rib to reduce tripping hazard.	2	Critical to know IF fighting fire.
Understand impact of fire and smoke on air.	1	-
Know when to abandon firefighting efforts and begin/resume escape.	2	Critical to know IF fighting fire.

Performance Criteria (KSAs)	EPL	SME Notes
Know where to move based on current location relative to fire.	2	-
Know when, where, and how to shut off power.	2	-
Keep mine exit at your back when fighting fire, whenever possible.	2	Critical to know IF fighting fire. Added "whenever possible."
Use self-contained breathing apparatus (SCBA) with full facepiece, if properly trained and available.	2	"If available" is key. Very few mines currently have these stationed underground, but critical for those that do.

Competency Area E2: Assisting with Treating an Injured Miner

Performance Criteria (KSAs)	EPL	SME Notes
Recognize need to seek medical assistance for self or others.	2	-
Locate first-aid equipment (e.g., backboard, oxygen).	2	-
Use first-aid equipment.	2	-
Administer basic first aid.	2	-
Check airway, breathing, and circulation (ABCs) and administer CPR to injured miner, if needed.	2	-
Know which crew members are emergency medical technicians (EMTs) or paramedics.	2	-
Coordinate and communicate with EMT(s) or paramedics.	0	This is self-escape leadership responsibility.
Know procedures for immobilizing, transferring, and moving an injured miner.	1	-
Communicate critical information about own physical condition and that of fellow miners to others within the mine and on the surface.	2	-
Understand that both asphyxiation and poisoning can occur due to poor (noxious versus toxic) air quality.	2	-
Consider transferring injured miner to nearest refuge alternative for treatment or to wait for additional help to arrive.	2	Added as critical consideration by external SME review of the draft documents.

Major Activity F: Leading, Directing, and Managing

Although there are formal roles for leading, directing, and managing an emergency response, all personnel should know how to manage panic, show appropriate deference to those in leadership positions, and be as prepared as possible to assume a leadership role in situations where a group is without a clear leader.

Competency Area F1: Managing Panic

Performance Criteria (KSAs)	EPL	SME Notes
Trust your training and rely on procedures you've learned and the equipment you have.	2	-
Recognize signs of panic in self and others.	1	Breathe deeply, it works.
Speak clearly and confidently when communicating with others who are distressed.	2	-

Competency Area F2: Showing Appropriate Deference

Performance Criteria (KSAs)	EPL	SME Notes
Understand the roles of the EGL and RP and defer to them, if appropriate.	2	Remove "understand the roles."
Know the strengths, capabilities, and experience of fellow crew members (mine rescue team members, EMTs, etc.).	0	Necessary for self-escape leadership. Too much for rank-and-file; added item below.
Know which crewmembers, if any, have specialized emergency response training or experience (e.g., mine rescue, emergency medical, fire brigade).	1	Added by focus group SMEs.
Know own limitations and capabilities and those of others on the team.	2	-
Recognize the need for you or someone else to assume leadership role.	2	-

Competency Area F3: Assuming or Changing Self-escape Leadership

Performance Criteria (KSAs)	EPL	SME Notes
Take control of group, if appropriate.	1	Not required, but some supplemental leadership training for all miners could be useful.
Communicate clearly and confidently.	2	-
Participate in decision-making to defer to emerging leader.	2	-

Competency Area F4: Accounting for Personnel

Performance Criteria (KSAs)	EPL	SME Notes
Have knowledge of all personnel working within or near own section or area during shift.	1	-
Know the location and movement of inexperienced miners (e.g., “red hats”, “white hats”), if assigned.	2	-
Attempt to gather other individual miners as encountered and move as a group.	2	-
If separated from crew and unable to rejoin, attempt communication with EGL/Dispatcher/RP or other miners.	2	Combine with criticality of staying together as a group.
Participate in identification and headcount of miners present.	2	-

Major Activity G: Post-exit Activities

To effectively engage in emergency response management, it is critical to, upon reaching safety outside of the mine, remain calm, gather together, and contribute to critical incident debrief. It is critical for mine management to arrange a critical incident stress debrief and important for miners to follow up with physical and mental health professionals, as necessary. KSAs added by NIOSH researchers for discussions with SMEs are noted.

Competency Area G1: Debriefing

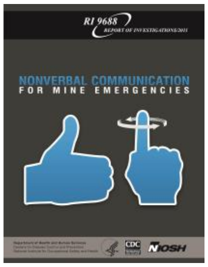
Performance Criteria (KSAs)	EPL	SME Notes
Communicate critical information about the miners still underground (location, headcount, names, physical condition, needs).	2	-
Communicate critical information about the situation (severity, conditions of mine, affected areas, route traveled, conditions of equipment, and needs).	2	-
Describes difficulties, barriers, deficiencies in information or other resources	2	Added by external SME review of draft documents

Competency Area G2: Engaging in Self-care*

Performance Criteria (KSAs)	EPL	SME Notes
Participate in group critical incident stress debrief.	N/A	-
Know that not everyone reacts to stress the same way.	N/A	-
Maintain a healthy diet and get adequate sleep and exercise.	N/A	-
Share experiences with trusted coworkers, family, and friends.	N/A	-
Recognize signs of traumatic stress in self and others.	N/A	-
Know when to seek additional help and support for self and others.	N/A	-

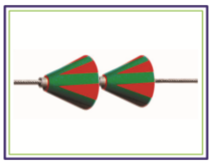
*Added by NIOSH researchers for discussion with SMEs. Deemed critical for leadership to encourage and/or facilitate, and for individual mineworkers to participate in post-escape self-care activities, as needed. Not a critical task for inclusion in rank-and-file miner self-escape training.

Appendix M: NIOSH Self-escape Training Resources



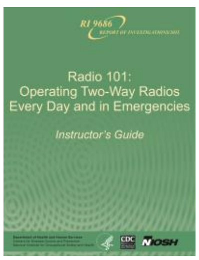
Nonverbal Communication for Mine Emergencies
A training program that teaches miners a series of nonverbal hand signals to use in the event of an emergency. These hand signals can be used by miners if they are unable to communicate verbally.

Published 11/2011
https://www.cdc.gov/niosh/mining/works/coversheet461.html



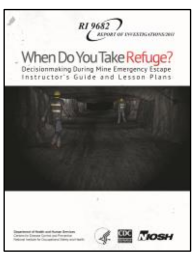
Lifeline Tactile Signal Flashcards
Flashcards for practicing lifeline tactile signals with miners.

Published 08/2011
https://www.cdc.gov/niosh/mining/works/coversheet1826.html



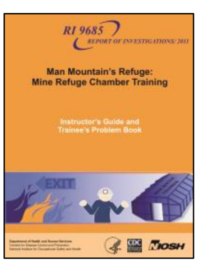
Radio 101: Operating Two-Way Radios Every Day and in Emergencies
A program to train miners in the use of two-way radio communication in mines.

Published 08/2011
https://www.cdc.gov/niosh/mining/works/coversheet522.html



When Do You Take Refuge? Decision Making During Mine Emergency Escape
Training that exposes trainees to the types of decisions that they may need to make during a mine emergency escape and stimulate group discussion about when and why to use a refuge alternative.

Published 08/2011
https://www.cdc.gov/niosh/mining/works/coversheet1556.html

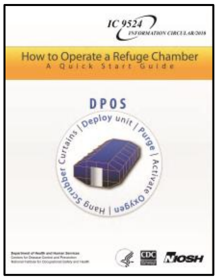


Man Mountain's Refuge: Refuge Chamber Training Instructor's Guide and Trainee's Problem Book
An instructor's guide for training mine employees on how and when to use a mine refuge chamber; aids the instructor in reinforcing the critical decisions that have to be made during a mining emergency.

Published 07/2011
https://www.cdc.gov/niosh/mining/works/coversheet1679.html

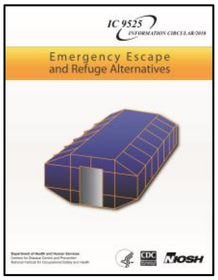
Underground Coal Mine Map Reading Training
Training that includes three components for teaching and testing mine map reading skills.

Published 11/2010
https://www.cdc.gov/niosh/mining/works/coversheet1825.html



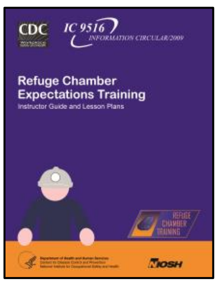
How to Operate a Refuge Chamber: A Quick Start Guide
A template for mine instructors to modify based on the refuge chambers used at their mine.

Published 10/2010
https://www.cdc.gov/niosh/mining/works/coversheet1695.html



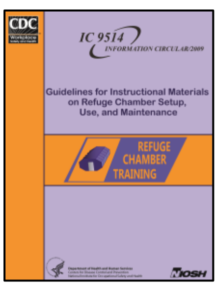
Emergency Escape and Refuge Alternatives
Guidelines to teach miners about emergency escape and using refuge alternatives.
Includes a PowerPoint presentation.

Published 10/2010
https://www.cdc.gov/niosh/mining/works/coversheet366.html



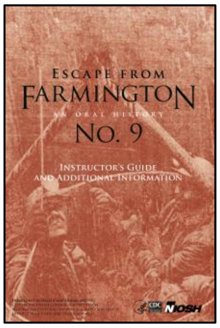
Refuge Chamber Expectations Training
Training to inform miners of what to expect psychologically and physically if it becomes necessary to use a refuge chamber in a mine emergency.

Published 10/2009
https://www.cdc.gov/niosh/mining/works/coversheet455.html



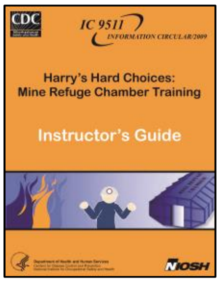
Guidelines for Instructional Materials on Refuge Chamber Setup, Use, and Maintenance
Suggestions for developing manuals and educational materials related to refuge chambers for miners.

Published 07/2009
https://www.cdc.gov/niosh/mining/works/coversheet498.html



Escape from Farmington No. 9: An Oral History
A video-based training module to educate both inexperienced and veteran miners on important issues related to self-rescue and escape procedures.

Published 05/2009
https://www.cdc.gov/niosh/mining/works/coversheet1628.html



Harry's Hard Choices: Mine Refuge Chamber Training
A paper-and-pencil simulation to teach miners about issues related to self-rescue and escape, including information gathering, knowing one's escapeways, use of SCSRs, the value of multigas detectors, and when to enter a refuge chamber.

Published 03/2009
https://www.cdc.gov/niosh/mining/works/coversheet1838.html

National Institute for Occupational Safety and Health
NIOSH

Promoting productive workplaces through safety and health research

DHHS (NIOSH) Publication No. 2023-134
DOI: https://doi.org/10.26616/NIOSHPUB2023134