

# NIOSH Mining Program Strategic Plan

2019–2023

(updated November 2019)

A roadmap for reducing and eliminating illnesses, injuries, and fatalities for the mining workforce



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

## Letter from the Associate Director for Mining

The Office of Mine Safety and Health Research (OMSHR) is an Office within the National Institute for Occupational Safety and Health (NIOSH) tasked with developing knowledge and technology advances for ensuring the well-being of mine workers. We perform this important work in close collaboration with many stakeholders including mine workers, industry, labor, trade associations, academia, government, and other public and private organizations as well as the occupational health and safety community at large. These relationships ensure that the NIOSH Mining Program focuses taxpayer dollars on solving the highest priority mine worker health and safety challenges.

In order to inform our stakeholders and the public about our current and future plans, we have written an updated five-year Strategic Plan (2019–2023). As in the previous version of the Plan, we remain stakeholder-driven with a mining subsector approach that includes coal, crushed stone, sand and gravel, metal, and industrial minerals. This approach allows us to focus our program to better address the health and safety challenges that are unique to each subsector.

The current version of the Strategic Plan was updated in November 2019 to reflect changing stakeholder priorities and needs as well to be responsive to changes in the regulatory agenda. Compared to the version published in 2018, 18 new research projects were added to the Plan, with new avenues of research including building an evidence-based framework for miner health, compatibility of electromagnetic devices being used in underground mines, the suitability and efficiency of monitoring and control solutions to help lower respirable crystalline silica exposure, and using day-to-day health and safety leading indicator data to identify trends and predict health and safety outcomes. Although the plan has been updated, as with the original Strategic Plan, our research continues to be driven by both our mission—“To eliminate mining fatalities, injuries, and illnesses through relevant research and impactful solutions”—and our core values of *relevance, impact, innovation, integrity, collaboration, and excellence*. With this focus on our mission and our core values, we are dedicated to achieving our overall vision of safe mines and healthy workers.

Three overarching strategic goals guide the research program. The goals are to: (1) reduce mine workers’ risk of occupational illnesses, (2) reduce mine workers’ risk of traumatic injuries and fatalities, and (3) reduce the risk of mine disasters and improve post-disaster survivability of mine workers. The research program includes the intramural program, which is primarily conducted at the Spokane Mining Research Division and the Pittsburgh Mining Research Division, in concert with mining-related research performed by our colleagues in Morgantown, Cincinnati, and Denver, along with the extramural program, which includes our outside partners that are involved in mining health and safety research.

This Strategic Plan aligns with the latest version of the [NIOSH Strategic Plan](#) and demonstrates our commitment to collaborating with our peers within the Institute to ensure the highest quality research for the mining community. As we face greater challenges to achieve meaningful and timely results in an ever more complex world, we will continue to expand our program to enhance the use of multidisciplinary and cross-divisional teams.

Jessica E. Kogel, PhD, Associate Director for Mining

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## Introduction

The National Institute for Occupational Safety and Health (NIOSH) is an institute within the Centers for Disease Control and Prevention (CDC) under the Department of Health and Human Services (HHS), and is responsible for conducting research, providing new scientific knowledge, making recommendations, and delivering practical solutions to prevent worker injury and illness. The NIOSH Mining Program provides health and safety research and science-based interventions for the mining workforce. The mining program is under the direction of the Office of Mine Safety and Health Research (OMSHR) and includes both the Spokane Mining Research Division (SMRD) in Spokane, Washington, and the Pittsburgh Mining Research Division (PMRD) in Pittsburgh, Pennsylvania.

The NIOSH Mining Program conducts research to eliminate occupational diseases, injuries, and fatalities from the mining workplace. Our goal is to ensure that our research portfolio responds to the greatest needs of our stakeholders, that our work is of the highest quality, and that our limited resources will have the greatest impact. We provide solutions for miners working in the five major mining subsectors: metals, industrial minerals, crushed stone, coal, and sand and gravel (see Appendix). Our work extends to surface and underground operations, along with associated plants, mills, shops, and offices.

## Purpose of the Strategic Plan

This Strategic Plan serves as a roadmap and forms the research foundation for the NIOSH Mining Program. It informs our research project planning, sets the priorities and goals for the upcoming years, and ensures that our work will be relevant and impactful. We initially developed the NIOSH Mining Program research strategy in 2004 to focus mining research and prevention activities on the areas of greatest need, as articulated by our stakeholders and supported by surveillance data.

Since the implementation of the original Plan, the face of mining health and safety has changed due to: (1) a series of disasters that resulted in passage of the Mine Improvement and New Emergency Response Act (MINER Act) of 2006, which drove new technological development; (2) a trend toward mining in more complex geological conditions; (3) a push toward deeper mines; (4) the continuing introduction of automation and new technologies; (5) the contraction of the U.S. coal industry and the recent growth of the aggregates industry; and (6) changes in the demographics of the mining workforce, with a trend toward younger, less experienced workers and more contractors. In light of these and other changes, this updated Plan sets new research priorities based on BNI (burden, need, and impact), stakeholder input, and the regulatory agenda including rulemaking by the Mine Safety and Health Administration (MSHA). The Plan is meant to clearly communicate, both internally and externally, what the NIOSH Mining Program is doing, why we are doing it, and how we will measure our success.

## Burden, Need, and Impact

The following definitions are adapted from the NIOSH Strategic Plan [NIOSH 2019].

**Burden** provides evidence of the health and safety and economic burden (or potential burden) of workplace risks and hazards. In considering these burden estimates, we also consider how well the burden evidence is assessed. Emerging issues, understudied populations, or hazards that would not have established burden due to their emerging nature, would have potential burden that can be described by many of the same parameters of established burden, such as potential for injury, illness, disability, and mortality.

**Need** helps define the knowledge gap that will be filled by the proposed research. It considers the comparative advantage NIOSH has over other research organizations and the unique resources NIOSH might have to respond to the research need. Need is where stakeholder needs are identified and addressed.

**Impact** is where we consider how well the research is conceived and likely to address the need. Impact or potential for impact helps us consider if the proposed research can create new knowledge, lead others to act on findings, promote practical intervention, adopt a new technology, develop evidence-based guidance, aid in standard setting or promote other outcomes. Consideration of impact is where we look to see if the proposed research will likely lead to a decrease in worker injury, illness, disability or death, or enhance worker well-being.

## Setting Research Priorities

Setting research priorities is one of our biggest and most important challenges. Our goal is to ensure that the priority setting process is broad-based, inclusive, unbiased, transparent, and data-driven. The process must also be responsive to changes in stakeholder needs and interests. We draw on a number of different sources for input into the process and they are described below.

### *Burden, Need, and Impact*

NIOSH uses Burden, Need, and Impact (BNI) to identify and define research priorities (see sidebar). BNI is an objective tool that ensures we do the most important work to protect the workforce and identify research priorities to guide the investment of limited resources in a clear and transparent manner.

The NIOSH Mining Program establishes burden and need through surveillance data, statistical analysis, stakeholder input, and risk analysis. Surveillance data show how workers are being fatally injured, injured, or impaired. Our stakeholders identify their needs, and we communicate with our stakeholders regularly to better understand those needs. We use risk analysis to assess low-probability, high-impact events such as mine explosions.

### *Stakeholder Engagement*

Our stakeholders are the end users of our research and therefore our research is largely driven by their needs. Our stakeholders are diverse (see sidebar on next page) and each stakeholder group has unique perspectives and interests when it comes to mine worker health and safety. NIOSH relies on several mechanisms for gathering stakeholder input.

One mechanism involves convening multi-stakeholder partnerships to bring diverse perspectives to the table around technically complex topics. This model for collaboration has proven to be highly effective. Currently there are five active partnerships [NIOSH 2018k] including the Breathing Air Supply Partnership (BAS), Diesel Health Effects

Partnership, Rock Dust Partnership, Proximity Detection Systems Partnership, and Refuge Alternatives Partnership. Two additional partnerships are currently under development that include topics related to automation and emerging technologies and respirable mine dust. These partnerships are comprised of representatives from equipment manufacturers, academia, mining companies, labor unions, trade associations, and government agencies.

In addition to partnerships, the NIOSH Mining Program receives advice from the Mine Safety and Health Research Advisory Committee (MSHRAC), which is a Federal Advisory Committee comprised of representatives from our major stakeholder groups. MSHRAC provides advice on mine safety research and serves as a productive forum for information exchange. To ensure that the advice from the committee is objective and available to the public, MSHRAC utilizes the rules for engagement under the Federal Advisory Committee Act (FACA) [GSA 2017].

An additional effort to advance communication and collaboration across the mining health and safety community includes the NIOSH-facilitated National Occupational Research Agenda (NORA) Mining Sector Council. This broad, non-advisory Council comprises representatives across the occupational health and safety spectrum, including public- and private-sector researchers, professionals, consultants, practitioners, and manufacturers. The Council works to identify the most salient needs of this large and diverse global sector, facilitate the most important research, understand the most effective intervention strategies, and learn how to implement those strategies to achieve sustained improvements in workplace practice. NORA runs in ten-year cycles and is now in its third decade. During its second decade, the Mining Sector Council developed the National Mining Agenda for Occupational Safety and Health Research and Practice in the U.S. Mining Sector (the Agenda). The Agenda is made up of 8 objectives and 62 sub-objectives and captures the breadth of current occupational health and safety challenges facing the U.S. mining industry. During its third decade, the Council is focusing on prioritizing the objectives and sub-objectives of the Agenda. These objectives are for the good of the nation and all of its research and development entities, whether government, higher education, or industry-related. The Mining Program goals support each of the NORA Mining Sector Agenda objectives and articulate NIOSH's contribution. The NORA Mining Sector Agenda objectives support each of the strategic goals of the Mining Program.<sup>1</sup> In summary, the [NORA Mining Sector Agenda was developed and implemented through the NORA Mining Sector Council](#) and is guidance

## Mining Stakeholders

Our broad base of stakeholders includes academia; equipment manufacturers; government; mine operators; mining industry trade associations; organized labor; regulatory agencies (on the local, state, and federal levels); research laboratories; and suppliers. We collaborate and communicate with our stakeholders on a regular basis to better inform our research and assess its direct contributions to safety and health.

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<sup>1</sup> More information related to the NORA Mining Sector Council is available at: <https://www.cdc.gov/niosh/nora/councils/mining/default.html>.

for the nation as a whole, while the NIOSH Mining Program Strategic Plan is specific to NIOSH and its capabilities and resources.

### *Rulemaking*

The MSHA rulemaking process can also affect our research priorities. NIOSH and MSHA communicate on a regular basis to better serve our common goal of improving mine worker health and safety. One mechanism for communication between our agencies is through a Request for Information (RFI)—one recent example is MSHA’s Respirable Silica (Quartz) [MSHA 2019]. An RFI describes a problem or an issue for which MSHA requests data, comments, and other information from the public relevant to the problem presented. When relevant scientific research is available, the NIOSH Mining Program will submit a formal response to the RFI based on our scientific expertise. This comment period is a formal mechanism for the NIOSH Mining Program to participate in the rulemaking process.

Our responses to an RFI help MSHA to determine an appropriate course of action to address a particular health and safety problem or issue. MSHA may choose to enact or develop a rule based on this information. If a rule is pending, we may choose to redirect our research to bring the best science possible to the mining community before the rule is in place or during the rulemaking process. Through this process, we can proactively provide scientific evidence to MSHA for developing and implementing new rules that protect miner health and safety.

## **Strategic Research Goals**

The Mining Program Strategic Plan focuses on two hierarchies of goals: strategic and intermediate goals. We keep our strategic goals purposely broad in scope, maintain them as generally long-standing, and achieve them through the outcomes of the Mining Program research portfolio. Intermediate goals are more specific goals that focus on the research or knowledge gaps that must be addressed in order to meet the strategic goals. Intermediate goals cascade from the strategic goals and each strategic goal has multiple intermediate goals that will change over time as specific intermediate goals are met.

The NIOSH Mining Program has established three overarching strategic goals for this plan:

## **NIOSH Mining Program**

### **Vision**

Safe Mines, Healthy Workers

### **Mission**

To eliminate mining fatalities, injuries, and illnesses through relevant research and impactful solutions.

### **Core Values**

**Relevance:** We pursue research that addresses and is responsive to the most critical needs of our stakeholders.

**Impact:** We develop timely, value-driven, and cost-effective solutions for our stakeholders.

**Innovation:** We foster an environment that encourages forward-thinking, creativity, and novel ideas.

**Integrity:** We work in a transparent, ethical, and accountable manner while practicing responsible stewardship of our resources.

**Collaboration:** We leverage diverse national and international partnerships and multidisciplinary teams to advance applied solutions.

**Excellence:** We passionately pursue rigorous, high-quality, and unbiased science in service of our mission.

**Strategic Goal 1:** Reduce mine workers' risk of occupational illnesses.

**Strategic Goal 2:** Reduce mine workers' risk of traumatic injuries and fatalities.

**Strategic Goal 3:** Reduce the risk of mine disasters and improve post-disaster survivability of mine workers.

As an overview of the Mining Program Strategic Plan, 2019–2023, Table 1 represents these three strategic goals, along with their associated intermediate goals (IGs) and related NIOSH goals, in the context of a five-year planning horizon.

**Table 1.** Mining Program Strategic Plan Overview, 2019–2023

<b>Strategic Goal 1</b> <b>Reduce mine workers’ risk of occupational illnesses</b>	<b>Strategic Goal 2</b> <b>Reduce mine workers’ risk of traumatic injuries and fatalities</b>	<b>Strategic Goal 3</b> <b>Reduce the risk of mine disasters and improve post-disaster survivability of mine workers</b>
<b>Intermediate Goal 1.1</b> Workplace solutions are adopted to reduce miner overexposure to hazardous airborne dust and diesel contaminants (supports <a href="#">NIOSH IG 1.8</a> , <a href="#">IG 5.8</a> , and <a href="#">IG 5.9</a> )	<b>Intermediate Goal 2.1</b> Workplace solutions are adopted to eliminate fatalities and injuries related to mobile and stationary mining equipment (supports <a href="#">NIOSH IG 6.6</a> )	<b>Intermediate Goal 3.1</b> Workplace solutions are adopted to reduce the risks associated with accumulations of combustible and explosible materials (supports <a href="#">NIOSH IG 6.8</a> )
<b>Intermediate Goal 1.2</b> Workplace solutions are adopted that reduce miner overexposure to noise (supports <a href="#">NIOSH IG 2.5</a> )	<b>Intermediate Goal 2.2</b> Workplace solutions are adopted to eliminate fatalities and injuries caused by global geologic instabilities at underground and surface mines (supports <a href="#">NIOSH IG 6.7</a> )	<b>Intermediate Goal 3.2</b> Workplace solutions are adopted to improve detection of and reduce the risk of hazardous conditions associated with fires and explosions and ground instabilities (supports <a href="#">NIOSH IG 6.7</a> and <a href="#">IG 6.8</a> )
<b>Intermediate Goal 1.3</b> Workplace solutions are adopted to reduce the effects of environmental factors on miners (supports <a href="#">NIOSH IG 6.9</a> )	<b>Intermediate Goal 2.3</b> Workplace solutions are adopted to eliminate fatalities and injuries caused by rock falls between supports or loss of containment from damaged ribs (supports <a href="#">NIOSH IG 6.7</a> )	<b>Intermediate Goal 3.3</b> Workplace solutions are adopted to prevent catastrophic failure of mine pillars, stopes, and critical structures (supports <a href="#">NIOSH IG 6.7</a> )
<b>Intermediate Goal 1.4</b> Workplace solutions are adopted that enable mines to remediate risk factors for musculoskeletal disorders (supports <a href="#">NIOSH IG 4.4</a> )	<b>Intermediate Goal 2.4</b> Workplace solutions are adopted that enable mines to remediate risk factors for slips, trips, and falls	<b>Intermediate Goal 3.4</b> Workplace solutions are adopted to improve miner self-escape, rescue, and post-disaster survival (supports <a href="#">NIOSH IG 6.8</a> )
<b>Intermediate Goal 1.5</b> Workplace solutions are adopted that reduce morbidity and mortality of chronic diseases in mining (supports <a href="#">NIOSH IG 1.8</a> )	<b>Intermediate Goal 2.5</b> Workplace solutions are adopted to identify, measure, and improve miners’ readiness for work (supports <a href="#">NIOSH IG 7.3</a> )	

On a yearly basis, this Plan will be reviewed and updated to ensure its relevance to the current issues facing the nation's mining workforce.

## Intermediate Goals

The NIOSH Mining Program recognizes that we cannot make improvements to occupational safety and health without the assistance of our stakeholders. Therefore, we also establish intermediate goals that specify desired actions on the part of external stakeholders—namely, to use NIOSH research findings and products that will directly contribute to health and safety. It often takes years and the combined effort of multiple research projects to achieve intermediate goals. Based on the standard research project cycle, an average time frame for achieving an intermediate goal is five years.

The intermediate goals defined in this Plan represent relevant problems that the NIOSH Mining Program is committed to solving, and they were selected because they are on the critical path to meeting our strategic goals. Furthermore, they are achievable given our staff, facilities, and funds.

## Activity Goals

Integrally tied to achieving intermediate goals are activity goals. These are activities that move the research through the [NIOSH research to practice \(r2p\) continuum](#). The NIOSH Mining Program organizes its research into four categories: (1) basic/etiologic, (2) intervention, (3) translation, and (4) surveillance. These four categories are defined below, as described by the [NIOSH Strategic Plan research goals webpage](#).

- *Basic/Etiologic Research*: Builds a foundation of scientific knowledge on which to base future interventions. Most laboratory research falls into this category, as well as exposure assessment.
- *Intervention Research*: Engages in the development, testing, or evaluation of a solution to an occupational safety and health problem or the improvement of an existing intervention. Intervention is a broad term that includes engineering controls, personal protective equipment, training, and fact sheets, and other written materials intended to inform and change behavior, among other occupational safety and health solutions.
- *Translation Research*: Discovers strategies to translate research findings and theoretical knowledge to practices or technologies in the workplace. This type of research seeks to understand why available, effective, evidence-based interventions are not being adopted.
- *Surveillance Research*: Develops new surveillance methods, tools, and analytical techniques.

Activity goals describe which of the four categories will be used to move goals along the r2p continuum and are presented in the context of their associated intermediate goals. Each activity goal names the research category, articulates how the problem or gap will be addressed, and identifies the targeted health or safety outcome.

## Extramural Research Program

In many cases, there are additional research problems that must be addressed outside of the NIOSH Mining Program intramural project portfolio in order to fully meet the strategic goal. Often these problems are addressed through our extramural program and, while our Strategic Plan does not specifically incorporate research being conducted outside of the NIOSH Mining Program, it does provide a strategic framework for extramural partnership.

The extramural research program that was established with the passage of the MINER Act of 2006 provides extramural funding through a contracts and grants program administered by OMSHR. According to the MINER Act [MINER Act 2006], OMSHR has the authority to:

- (A) award competitive grants to institutions and private entities to encourage the development and manufacture of mine safety equipment; and
- (B) award contracts to educational institutions or private laboratories for the performance of product testing or related work with respect to new mine technology and equipment.

While a small extramural contracts program existed prior to the MINER Act, that program became an integral part of the NIOSH Mining Program after the passage of the MINER Act. The extramural program stands separate from the intramural program but aligns with our strategic goals, with a strong focus toward the MINER Act intent. Similarly, the NIOSH Strategic Plan reflects the intent of the MINER Act by way of [service goals](#), which contribute to the NIOSH mission by providing a service to individuals and organizations outside of NIOSH, support internally to NIOSH staff, or a combination of the two.

The MINER Act Contracts and Grants Program consists of two parts: [extramural contracts](#) administered by the Mining Program and [grants](#) awarded by the [NIOSH Office of Extramural Programs](#) (OEP). Contracts are developed primarily through [Broad Agency Announcement](#) (BAA) solicitations aimed at fostering innovative solutions to key health and safety issues; support is also provided to the intramural program through detailed Request for Proposal (RFP) solicitations to supplement intramural research when resources (staff, facilities, expertise) are not available. Interagency Agreements (IAAs) are also used to take advantage of expertise and synergies with ongoing projects at other federal agencies and federally funded research and development centers (FFRDCs).

## Collaborations Across Non-mining Industry Sectors

This Strategic Plan recognizes that the mining industry shares many similarities with the oil and gas and construction industries. By leveraging NIOSH's broad-based resources to address worker health and safety challenges for all three high-risk industries, we can have a much greater impact on a larger segment of the U.S. workforce. According to the United States Census Bureau Current Population Survey [U.S. Census Bureau 2019], in 2018, there were 11.2 million workers in construction and 78,000 in oil and gas. According to MSHA data, including mine operator employees and contractor employees, 331,923 individuals were working in mines in the United States in 2018 [NIOSH 2018i]. In addition to a greater impact on worker health and safety, this

multisector strategy also significantly increases the market size for manufacturers by considering the marketing of health and safety interventions developed by NIOSH.

## **Overarching Research Approaches**

Certain activities span all strategic and intermediate goals and serve as an integral part of every research endeavor to ensure effective product design and implementation. These approaches may include organizational, physical, and/or psychological considerations when assessing risk and designing improvements for equipment, technologies, and processes—while placing the limitations and capabilities of the worker as the focal point for how products should be designed, tested, and implemented successfully.

We also consider early-on the relevant processes for product interpretation and dissemination. We require dissemination plans at the initiation of every project, as well as yearly updates, which are closely tied to the project’s intermediate goals. Because these overarching approaches constitute an integral part of all research efforts, they are not included as specific strategic goals. However, they are vital to the overall design, implementation, acceptance, and success of our research and product development and to all three Mining Program strategic goals. Specifically, these overarching approaches fall into five categories: *human factors, human-centered design, health communications, surveillance and statistics, and training solutions.*

### ***Human Factors***

Human factor considerations include health and safety management systems (HSMS), which are institution-wide approaches to managing and improving health and safety through organizational practices. The Mining Program recognizes the advantages of providing solutions and practices that can be integrated within an HSMS to provide direction to individual research projects and make their solutions HSMS-compatible. Moreover, the Program investigates the factors that contribute to HSMS effectiveness and communicates these factors in the form of recommendations to HSMS implementers in the mining industry.

### ***Human-centered Design***

Successful engineering solutions need to accommodate the capabilities and limitations of their human operators. To meet these criteria, the Program applies human-centered design approaches across all projects that develop and design human-machine-environment system interactions. This involves assessment of the entire system and how the human workers will interact with that system. We identify potential health and safety issues during the development process and resolve these issues during iterative design and testing phases.

### ***Health Communications***

The Mining Program includes a strong health communications function that ensures impact by communicating the program’s solutions to the stakeholders who are in the best position to improve mine worker health and safety. Purposeful communications of products and scientific results relevant to the mining workforce are necessary to reducing injuries and illnesses. The health communications staff initially engages with projects at the proposal and planning stages to ensure

that a detailed dissemination plan is in place, performs an audience analysis, then helps to execute that plan during the project's lifetime, with specific communication products targeting audiences who can take effective safety and health action. We execute and evaluate the dissemination plan through targeted communications, including publications, exhibits, videos, social media, software, and web content—choosing the best mix of communication tools to serve our stakeholders and their health and safety needs.

### *Surveillance and Statistics*

The Mining Program's surveillance and statistics staff gather analyzable data files and summary statistics, economic analyses, production statistics, and MSHA data on accident, injuries, and illnesses specific to the mining industry. We perform surveillance analyses to identify the sectors, tasks, machinery and equipment, activities, contaminants, and other factors that are responsible for the greatest risk of injury and illness in order to target our research activities most efficiently. We undertake impact analyses based on injury and illness surveillance data from the mining and regulatory industry in order to determine the effectiveness of our activities in relation to each strategic and intermediate goal. As part of the dissemination plan, we also review products that involve statistics and apply proven statistical analysis techniques to ensure their quality and usability by stakeholders.

### *Training Solutions*

We integrate a training function across the Mining Program to identify solutions that lend themselves to training and are needed to achieve specific health and safety goals. Our training staff works across research projects to identify areas where miners will need training to accommodate new technologies and to implement new advances in health and safety knowledge, skills, and abilities. First, we perform a training analysis to identify whether there is a training component to a successful intervention; then, if a training component is needed, we develop and evaluate that intervention, which could range from instructional manuals to toolbox talks to simulations that can be performed in a safe environment. Training solutions are packaged alongside the Program's engineering solutions or can serve as standalone packages that demonstrate effective training approaches and techniques. Opportunities often exist to translate or transfer this knowledge to other industries such as construction and oil and gas extraction.

## **Ongoing Challenges and Emerging Issues**

Looking forward, the future of mining will involve working in deeper mines, mines that are less accessible, and ores that are lower grade. In addition, economic pressures will require companies to increase their efficiencies to remain competitive. Mining in the future will involve more and more challenging conditions. As mines go deeper, it becomes more difficult to ventilate them to remove contaminants and to cool the air, which may reach temperatures upwards of 110°F, especially considering the heat generated by equipment and increases in subsurface temperature with depth [Forrest et al. 2007]. In situ ground stresses increase with depth and can result in geologic instabilities and seismicity, which will likely require more sophisticated ground support to maintain safe work spaces. Future mining may also require more mine workers to commute longer distances or to remote locations. Lower-grade commodities will require new technologies that allow selective

mining to reduce waste rock and efficient processing of the ore. As the current mining workforce retires, the new workforce will be dominated by younger and less experienced workers as well as contractors and temporary workers. Finally, with new workers entering the workforce or transferring from other mines or other mining sectors, their inexperience at their new job may translate to increased injuries for these workers. Understanding the causes behind these injuries and how they can be addressed is critical.

Mines are adopting automation and other emerging technologies to remain competitive and increase efficiencies. Strategies such as monitoring and control systems, big data analytics, automation, and wearable and smart sensors are being deployed across the U.S. mining industry and particularly in coal and metal mines. The use of exoskeletons to aid with materials handling activities may have the potential to reduce both cumulative and traumatic musculoskeletal injuries that still are plaguing the industry. While automation technology may improve worker health and safety by removing workers from hazards, unintended hazards may also be introduced into the workplace. Inevitably, as we move towards automated equipment and processes, the interaction between manual and automated systems is another issue. Even fully automated systems require maintenance and will involve humans in those situations. Other areas of growing interest include increased injuries of powered haulage operators and those that work around powered haulage, the growing use of lithium-ion batteries and their possible effect of increasing the likelihood of fires and explosions, and the issue of electromagnetic interference between technologies that may affect the ability of devices to detect and warn mine workers. In order to address these emerging issues, we pay careful attention to the trending needs of the mine worker, as represented in detail throughout this Strategic Plan.

## **Strategic Goals and Intermediate Goals**

### **Strategic Goal 1: Reduce mine workers' risk of occupational illnesses**

The mining environment may expose miners to mineral, chemical, and physical hazards. Mineral hazards include exposure to airborne elongate mineral particles that may cause asbestosis, lung cancer, and mesothelioma. Exposure to respirable coal and respirable crystalline silica dust may cause coal workers' pneumoconiosis (CWP) and silicosis, and both respirable crystalline silica and diesel emissions are classified as carcinogens by the International Agency for Research on Cancer (IARC). In relation to chemical hazards, one of the primary hazards experienced by mine workers results from exposure to diesel emissions in confined spaces with inadequate levels of ventilation, which may lead to lung cancer and cardiovascular health problems. Physical hazards include exposure to high levels of noise, heat, and tasks that require forceful exertions, awkward postures, and repetition rates that pose a risk of musculoskeletal disorders. Over half of the mining workforce has experienced one symptom of heat stress or strain in the previous year, and nearly one-third reported four or more symptoms. This problem has become exacerbated by mining into deeper, hotter environments. Finally, extraction of ore in confined spaces with high-horsepower equipment results in miners having a higher level of hearing loss than workers in any other major industry.

Below, in support of [Strategic Goal 1](#), each intermediate goal is followed by a series of activity goals—as defined earlier in the Plan—then a table, then an analysis of burden, need, and impact. The table lists the health and safety concerns; describes the research focus areas; identifies the mining sectors or worker populations affected; defines the research type used to address the concerns, and links to key Mining Program research projects that target solutions.

*Intermediate Goal 1.1: Workplace solutions are adopted to reduce miner overexposure to hazardous airborne dust and diesel contaminants*

**Activity Goal 1.1.1:** (Basic/Etiologic Research) Conduct studies to improve measurement of exposures to elongate mineral particles, diesel emissions, respirable crystalline silica, and other dusts, and to better understand the risks for respiratory diseases among mine workers.

**Activity Goal 1.1.2:** (Intervention Research) Conduct studies to develop and assess the effectiveness of interventions and technologies to prevent overexposure to elongate mineral particles, diesel emissions, respirable crystalline silica, and other hazardous dusts to reduce respiratory diseases among mine workers.

**Activity Goal 1.1.3:** (Translation Research) Conduct studies to improve the adoption of control interventions and technologies to reduce overexposure to hazardous airborne contaminants in the mining environment.

**Activity Goal 1.1.4:** (Intervention Research) Conduct studies to assess the effectiveness of foamed or slurried rock dust to minimize respirable dust generation during applications of rock dust in underground coal mines.

**Activity Goal 1.1.5:** (Basic/Etiologic Research) Conduct studies to assess health effects of exposure to treated and untreated rock dusts.

**Activity Goal 1.1.6:** (Intervention Research) Conduct studies to develop interventions that reduce dust (including respirable crystalline silica) at transfer points of ore haulage conveyors.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Asbestos-related diseases	Exposure to elongate mineral particles	Industrial minerals; metal; stone, sand, and gravel	Intervention Basic/Etiologic	<a href="#">Mineral reference materials</a>
Risk management; respirable dust-related diseases	Organizational and worker practices	Metal/nonmetal; stone, sand, and gravel; coal; underground mining	Intervention Basic/Etiologic Translation	<a href="#">Health and safety management (ended in 2019)</a>  <a href="#">Health and safety indicators (added in 2019)</a>
Silica-related diseases	Exposure to respirable crystalline silica	Coal; industrial minerals; metal; stone, sand, and gravel	Intervention	<a href="#">Exposure monitoring</a>  <a href="#">Interventions to reduce respirable hazards (ended in 2019)</a>  <a href="#">Dust sensing and control (added in 2019)</a>  <a href="#">Conveyor system safety (added in 2019)</a>
COPD; lung cancer; cardiovascular disease	Exposure to diesel aerosols and gases	Underground coal; industrial minerals; metal; stone, sand, and gravel	Basic/Etiologic Intervention	<a href="#">Diesel aerosols</a>  <a href="#">Diesel particulate matter</a>  <a href="#">Exposure monitoring (added in 2019)</a>
Coal workers' pneumoconiosis; chronic obstructive pulmonary disease; diffuse fibrosis	Exposure to coal respirable dust	Coal	Intervention Translation	<a href="#">Respirable dust (ended in 2019)</a>
Lung irritation	Exposure to rock dust	Underground coal	Intervention	<a href="#">Treated rock dust</a>
Silica-related diseases	Exposure to respirable crystalline silica and respirable coal dust	Underground coal mining; surface coal mining	Basic/Etiologic Intervention Translation	<a href="#">Silica dust control (added in 2019)</a>

### *Burden*

Extracting and processing mined materials can result in overexposures to several hazardous airborne contaminants, including elongate mineral particles, coal dust, respirable crystalline silica dust, and diesel exhaust. Analysis by NIOSH researchers of publicly available MSHA compliance data demonstrates overexposures to these airborne contaminants at rates as high as 27% [MSHA 2019a]. Overexposure to respirable coal dust can lead to CWP, and exposure to respirable silica dust can lead to silicosis—both irreversible, disabling, and potentially fatal lung diseases. From 1970 through 2015, CWP caused or contributed to the

deaths of over 74,000 miners [CDC 2017], with over \$46 billion paid to compensate them and their families [U.S. DOL 2018]. Recent investigations show that progressive massive fibrosis (PMF), the most severe form of CWP, occurs at rates three times higher than any previously reported levels [CDC 2016], and researchers believe that crystalline silica exposure may have contributed to these PMF cases. Exposure to diesel exhaust can affect both respiration and circulation. The International Agency for Research on Cancer (IARC) classifies both diesel engine exhaust and respirable crystalline silica as carcinogenic to humans. Miners suffer from higher rates of asbestosis, lung cancer, and mesothelioma than other workers. In 2007, a mesothelioma cluster of 58 cases was found in 72,000 former taconite miners who worked in the iron range in Minnesota, even though the expected occupational mesothelioma rate is much lower at 1 per 200,000 workers. This higher rate was attributed to exposure to elongate mineral particles associated with the taconite [MDH 2007].

### *Need*

Miners experience incidences of respiratory illness and disease that are much higher than the general population, and the standards for exposures to airborne hazards continue to be lowered based on new medical evidence. To that end, a need exists to advance the ways in which health data are being collected and used to prevent exposures. Most recently, the 2016 reduction of the respirable coal mine dust standard from 2.0 to 1.5 mg/m<sup>3</sup> created a heightened need for effective controls [MSHA 2014]. To address these needs, the NIOSH Mining Program continues to develop more effective methods to monitor and control hazardous airborne contaminants in mines. In developing such methods, it is critical to effectively identify and use leading indicators within health programs and interventions [Almost et al. 2018]. NIOSH is uniquely qualified to conduct this research due to its state-of-the-art laboratories for development and testing of dust controls, including full-scale longwall and continuous mining galleries where dust can be generated and measured without putting workers at risk. For diesel-powered equipment, the need is to reduce hazardous emissions from older engines being used in mines. NIOSH has recognized the need to focus on leading indicators in occupational health and safety with a posting on NIOSH's science blog [Inouye 2016] touting the use and measurement of leading indicators to evaluate trends over time and to improve interventions. To further the identification of necessary leading indicators around dust exposure and control, NIOSH has extensive laboratories for developing and testing diesel controls, and these facilities are served by a dedicated team with two decades of experience and worldwide recognition for their diesel expertise.

### *Impact*

NIOSH has developed technologies including monitoring and measuring devices and improved control methods to reduce exposure to respirable coal dust, respirable crystalline silica, diesel particulate matter, and elongate mineral particles. These technologies include the PDM 3700, a real-time respirable coal dust monitor commercialized by Thermo Fisher Scientific and required for MSHA compliance sampling; the Airtec, a real-time diesel particulate monitor commercialized by FLIR; and the Helmet-CAM and EVADE software

monitoring technology that merges recorded video of worker activities and personal exposure data to identify sources of overexposure [NIOSH 2016b]. An end-of-shift crystalline silica monitoring technique that is in the final stages of development enables mines to perform silica analysis onsite and in near real-time. This technique replaces the traditional laboratory analysis method that required mines to wait weeks for the results [Lee et al. 2017]. Current research related to respirable coal mine dust exposures addresses over 60% of the overexposures experienced by coal miners. NIOSH is establishing a repository of characterized elongate mineral particles samples to support toxicology research [NIOSH 2018e] and developing monitoring technologies to provide real-time data that can be used to prevent overexposures from occurring. NIOSH is addressing DPM exposure by researching retrofitted diesel exhaust technology to help companies prepare for full integration of Tier IV EPA-rated low-emission engines into mines.

*Intermediate Goal 1.2: Workplace solutions are adopted that reduce miner overexposure to noise*

**Activity Goal 1.2.1:** (Intervention Research) Conduct studies to remediate barriers to full implementation of hearing conservation programs designed to reduce noise-induced hearing loss among mine workers.

**Activity Goal 1.2.2:** (Intervention Research) Conduct studies to develop and assess the effectiveness of noise controls for reducing noise exposure from mining equipment.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Noise-induced hearing loss	Exposure to occupational noise	Surface stone, sand, and gravel; equipment operators	Intervention	<a href="#">Hearing conservation</a>

*Burden*

Mining has a higher prevalence of hearing loss than any other major industry. A NIOSH analysis of over 1 million audiograms from 2000 to 2008 showed that 27% of miners had a material hearing impairment versus 18% for all industries [Masterson et al. 2013]. Mining has the highest prevalence of noise overexposure (76%) according to a NIOSH analysis of the 1999–2004 National Health and Nutrition Examination Survey (NHANES) [Tak et al. 2009]. Common equipment used in mines, such as continuous mining machines, rock drills, and roof bolting machines, generate sound levels over 100 decibels, which can lead to hazardous exposures within minutes. Companies implement hearing conservation programs (HCPs) to address these issues; however, lack of expertise or funding may leave some HCP components under-performing. There are currently no requirements for mine equipment manufacturers to produce quieter equipment or state the noise levels of their equipment.

Therefore, the burden is with the end user to either reduce equipment noise levels by installing aftermarket noise controls or to limit operator exposure. Based on NIOSH project research, about 50% of jumbo drill machines used in the United States do not have cabs [NIOSH 2018m]; therefore, operators are directly exposed to the noise generated by the machine. Although hearing loss does not typically result in loss of life, it greatly impacts the quality of the worker's life, both on and off the job.

### *Need*

NIOSH Mining Program research specifically addresses a knowledge gap in noise overexposure that affects miners. A process of objective data analysis and subjective interviewing is needed to identify the underlying issues to full, effective implementation of HCPs and in turn to provide solutions to improve those areas. Some inspectors, specialists, and MSHA Technical Support conduct field engineering studies to identify sound levels and noise sources, and although MSHA collects noise exposure data via dosimetry for compliance determination, MSHA does not evaluate the actual noise levels produced by the machinery during operating conditions as part of its routine exposure compliance sampling. NIOSH fills that gap by conducting laboratory and field research to determine overall sound levels and identify primary noise-generating components of machinery, and in turn developing suitable noise control solutions. The NIOSH Mining Program is ideally suited to develop these solutions, with a large hemi-anechoic chamber and a National Voluntary Laboratory Accreditation Program (NVLAP)-accredited reverberation chamber, large enough to test working mining equipment. The hemi-anechoic chamber is used in conjunction with an 84-microphone beamforming array to identify the physical location and the frequency content of dominant noise sources in mining equipment. This essential information helps NIOSH to develop effective noise controls that directly address the dominant noise sources. The reverberation chamber is used to obtain accurate measurements of the sound power radiated by a mining machine before and after the newly developed noise controls are installed. This allows NIOSH to evaluate the performance, in terms of noise reduction, of the developed noise controls. These state-of-the-art facilities, instrumentation and software, relationships with original equipment manufacturers, and expertise to develop engineering noise controls for mining equipment, uniquely position NIOSH as a leader in mining noise control development and testing.

### *Impact*

NIOSH noise control technologies address hazardous noise at the source. NIOSH partnerships with manufacturers allow the Mining Program to act as a close collaborator to develop and evaluate the feasibility of noise control properties, while allowing manufacturers to market and distribute the end products. Joy Global has manufactured a longwall shearer drum to include design modifications and engineering developed by NIOSH. Other NIOSH-developed commercially available noise control technologies include coated flight bar conveyor chains and dual sprocket conveyor chains, to reduce continuous miner conveyor noise levels [NIOSH 2008a], and drill bit isolators, to reduce noise exposure during underground coal roof bolt drilling [NIOSH 2012a]. These controls, when installed, used, and maintained properly, can reduce the overall daily noise doses of the machine

operator by 30–50%, as shown by the collective findings from three NIOSH studies on coated flight bars for a continuous mining machine (CMM) [Smith et al. 2007], a dual sprocket chain on a CMM [Kovalchik et al. 2008], and noise controls for roof bolting machines [Azman et al. 2015]. Future research will expand on the quiet-by-design approach through partnerships with manufacturers to design controls into machines during production. Current NIOSH research is also identifying primary noise sources and noise-hazardous areas at surface mining facilities and addressing actual and perceived barriers to full implementation of HCPs at surface stone, sand, and gravel mines [NIOSH 2018h]. The results will demonstrate a broad context fit across the surface mining industry, with potential application to similar machines and tasks in construction and other heavy industries.

*Intermediate Goal 1.3: Workplace solutions are adopted to reduce the effects of environmental factors on miners*

**Activity Goal 1.3.1:** (Basic/Etiologic Research and Intervention Research) Conduct studies to determine and reduce the occupational risk factors associated with heat illness in the mining industry.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Heat illness	Detecting and preventing heat stress in mine workers	All	Basic/Etiologic Intervention Translation	<a href="#">Heat strain</a>

*Burden*

Heat stress is a challenge in many industries, including mining, and can lead to heat strain among workers. A total of 139 heat exposure/illness incidents among metal and nonmetal miners were reported to MSHA during 2006–2015 [NIOSH 2018k]. However, heat illness incidents among miners are likely underreported, especially if they do not lead to lost work days. Many symptoms, such as difficulty concentrating, poor motor control, and chronic fatigue that could be attributable to heat strain are likely ignored, with workers not recognizing the causal relationship. As one example of the scope of the problem, in one study of heat strain prevalence, 56% of miners reported at least one symptom of heat strain or heat stroke while working during the previous year, and 31% had experienced four or more symptoms in the previous year [Hunt et al. 2013]. Mine rescue operations in the United States resulted in a heat-related double fatality in October 2002. With the coolant canisters of their breathing apparatus not properly outfitted with gel packs, two members of a team exploring an abandoned mine slope in Nevada were fatally overcome by heat exhaustion [MSHA 2003]. As underground mines expand into deeper, hotter environments, and surface mines continue to operate in hot climates, heat stress and strain among miners are likely to increase.

## *Need*

The extent and magnitude of heat strain among miners have not been well characterized, nor have the environmental and personal risk factors in relation to effects such as cognitive function and performance declines. Heat stress refers to the total heat load placed on the body from external environmental sources and from physical exertion, whereas heat strain refers to the physical strain the body experiences as a result of heat stress. In addition to immediate effects that can increase the risk of injury (e.g., impaired reaction time, sweaty palms, etc.), heat strain can lead to adverse heat-related conditions of varying severity, such as the development of rashes, syncope, heat exhaustion, and heat stroke, which can be fatal or induce long-term impairment. Given the Mining Program's established history of collaborating with mining companies, and expertise in medicine, industrial hygiene, and epidemiology, NIOSH is well positioned to define issues that accurately describe the incidence of heat-related illnesses as well as target and conduct research that may reduce the potential for such illnesses and can be translated to industry. This research will analyze the contributing factors and the symptoms experienced by heat-exposed miners in order to identify, develop, and evaluate targeted solutions and guidance.

## *Impact*

A better understanding of the environmental, physiologic, and cognitive attributes related to individual heat strain will inform the NIOSH Mining Program's guidance and development of mitigation strategies, as well as evaluations of their effectiveness. Advancing knowledge in this field will help to train miners and supervisors on effective heat stress monitoring techniques and heat illness prevention and will inform policies on work organization to prevent heat illness. As one example, NIOSH project research to establish methods to evaluate the cognitive effects and predictive indicators of heat strain [NIOSH 2018n] can assist workers in identifying imminent decreases in mental performance and increases in risk of illness or injury among themselves as well as their peers. Recent Mining Program publications such as a series of heat stress fact sheets offer practical advice that workers can use to stay safe while performing their duties in hot environments [NIOSH 2017a]. Collectively, information on heat stress will fill an important gap in heat research and can help to direct improvements to work/rest cycles, hydration frequency, and job tasks to prevent heat illness, thus helping to maintain worker performance and mining production.

### *Intermediate Goal 1.4: Workplace solutions are adopted that enable mines to remediate risk factors for musculoskeletal disorders*

**Activity Goal 1.4.1:** (Intervention Research) Conduct studies to develop and assess the effectiveness of interventions to reduce musculoskeletal disorders among mine workers.

**Activity Goal 1.4.2:** (Intervention Research) Conduct studies to understand barriers and improve the adoption and implementation of evidence-based interventions, design recommendations, and work practices to reduce musculoskeletal disorders at mine sites.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Cumulative and traumatic injury from slips, trips, and falls	Ladders and walkways; boot wear	Surface stone, sand, and gravel; mineral processing plants; coal preparation plants	Intervention	<a href="#">Slips, trips, and falls (ended in 2019)</a>
Musculoskeletal disorders	Hazard recognition; shoulder overexertion injuries, hand and finger injuries, manual materials handling	Surface stone, sand, and gravel; all	Intervention	<a href="#">Hazard recognition (ended in 2019)</a> <a href="#">Manual materials handling (added in 2019)</a>

### *Burden*

Of all nonfatal occupational injuries and illnesses reported to MSHA between 2006 and 2015, just over one-third (34%) were musculoskeletal disorders (MSDs) [Weston et al. 2016]. The median number of days lost, which is the sum of days lost from work and the number of days with restricted work activity, was 19 for all reported MSD cases. Musculoskeletal disorders have direct costs (medical plus compensation payouts) and indirect costs (lost wages, fringe benefit losses, training, hiring, and disruption costs, etc.). Older workers, and those with more mining experience, show more days lost from work—defined in the article cited above as the sum of days lost from work and days of restricted work activity—as compared to their younger, or less experienced, counterparts, who show a higher frequency of injury. Further, having a past MSD places a worker at a higher risk for developing a future injury, and re-injury rates can be especially high in some jobs, leading to the loss of a worker from his or her specific occupation. MSDs affect the quality of life of workers, limiting their physical capabilities, vitality, and even negatively impacting their mental health.

### *Need*

From an ergonomics standpoint, mining tasks that require forceful exertions, awkward postures, and repetition rates that pose a risk of musculoskeletal disorders are ubiquitous, and these tasks are present across mining commodities [NIOSH 2004]. Unusual postures and restricted spaces often exacerbate the exposure and risk [NIOSH 2006]. The NIOSH Mining Program is well-positioned to address these problems and has been a significant contributor globally to mining ergonomics research over the past two decades. NIOSH’s research team of biomechanists, ergonomists, and engineers uses an interdisciplinary focus to develop practical solutions to mining industry problems. In addition to work physiology, strength assessment, and motion analysis laboratories, NIOSH’s unique Human Performance Research Mine can be configured to mimic various underground mining scenarios, including operation of actual mining equipment, with state-of-the-art data acquisition capabilities that measure human performance parameters during simulated work. This research mine allows NIOSH to conduct carefully controlled yet highly relevant studies that are not feasible in typical mining environments due to often harsh environmental conditions. NIOSH

researchers also maintain working relationships with mine operators that facilitate the access needed to conduct field assessments on site, and to determine the necessary characteristics for laboratory simulations. Working directly with mine operators helps NIOSH to fill knowledge gaps and ensure that the work is timely and targeted to reducing MSD risk factors.

### *Impact*

NIOSH’s proven history of helping mines address ergonomics issues includes the publication Ergonomics and Risk Factor Awareness Training for Miners, which has been used extensively to educate miners about how their bodies’ age and steps they can take to protect their musculoskeletal health [NIOSH 2008b]. More recently, ErgoMine, an Android application created by NIOSH, has delivered over 2,200 recommendations to miners in the first year after being published [NIOSH 2016a]. ErgoMine 2, currently under development, will be available on Android and Apple platforms and is planned for release in 2020. ErgoMine provides customized recommendations for addressing observed ergonomics and safety issues detected while answering a series of easy-to-understand questions or inputting weight and distance measurements. Future impact will be made in the area of slips, trips, and falls (STFs) through research to develop tools to identify, report, and remediate STF hazards in the workplace [NIOSH 2018r]. These impacts will be achieved through significant field studies and interaction with miners, laboratory studies, and continued surveillance of injury and illness data.

### *Intermediate Goal 1.5: Workplace solutions are adopted that reduce morbidity and mortality of chronic diseases in mining*

**Activity Goal 1.5.1:** (Surveillance Research) Conduct analyses of secondary data sources to determine the occupational health issues affecting the mining industry.

**Activity Goal 1.5.2:** (Intervention Research) Develop human-centric lighting interventions to address occupational health issues associated with shift worker circadian disruption.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Chronic disease	Worker health	All	Surveillance	<a href="#">Miner health evidence-based framework</a> (added in 2019)
Chronic disease	Worker health	Underground coal and metal mines	Intervention	<a href="#">Circadian disruption</a> (added in 2019)
Chronic disease	Leading indicators	All	Surveillance	<a href="#">Health and safety indicators</a> (added in 2019)

## *Burden*

There is limited information about the current health status of the mining population in the United States, and the information that is available varies across the mining sub-sectors (e.g., coal, metal/nonmetal [M/NM], stone/sand/gravel). No comprehensive or narrowly focused health surveillance systems exist for this population. Approximately 80 different commodity types are mined and processed in the United States. Because these commodities are derived from a broad range of rock types that may be compositionally heterogeneous, they pose a range of exposure hazards (inhalation, ingestion, contact, etc.). Despite research-based advances in knowledge of health problems such as black lung and hearing loss, gaps exist in empirical understanding on the health effects of acute and chronic exposures to hazards common in mining, such as airborne contaminants, noise, heat, and repetitive stresses. Greater knowledge is critical to addressing the morbidity and mortality of chronic diseases among miners. Further, the mining industry often uses shiftwork to ensure a productive working mine around-the-clock. The top two mining sub-sectors using shiftwork are coal mines (68.3%) and metal mines (64.7%). According to a recent study, the health risks related to shiftwork include type 2 diabetes, obesity, heart disease, stroke, and cancer [Kecklund and Axelsson 2016].

## *Need*

Surveillance of worker health remains fundamental to the mission of the NIOSH Mining Program. Despite clear programmatic expertise in occupational health surveillance, no surveillance efforts are specifically dedicated to the systematic examination of injury and illness burden within the mining industry. With expertise in mining engineering, industrial hygiene, and epidemiology, and given NIOSH's proven history in collaborating with industry, NIOSH is uniquely positioned to lead and coordinate the necessary efforts for obtaining, managing, and analyzing several data sources that will aid in describing what is currently known about the health of miners. Initial data sources planned for analysis include the Wyoming Miners' Hospital, Miners' Colfax Medical Center, Kennecott Utah Copper, MSHA, the National Health Interview Survey (NHIS), and the Behavioral Risk Factor Surveillance System (BRFSS) as well as cumulative analyses of big data efforts being led by NIOSH throughout the industry. Health data are collected daily by various members of mine management and, with so much data available, NIOSH has the capability to take advantage of advanced machine-learning statistics, improved infrastructures for managing big data, and helping mines adapt on a continual basis in response to unforeseen risks. Therefore, a methodology for regular and systematic review of available health-related data sources must be instituted in order to establish baseline measures and build a more robust surveillance program that can evaluate the efficacy and effectiveness of implemented health and safety strategies. NIOSH researchers have a strong rapport with companies and know that future guidance must come to them in a more tangible way to help measure progress and encourage longevity of health surveillance. As one example, human-centric lighting interventions are an effective means of addressing circadian disruption from shiftwork given that circadian rhythms depend upon the natural light and dark cycles. NIOSH has distinct advantages and unique resources for conducting lighting intervention research. Mine lighting

research involving the testing of human subjects has been conducted for at least a decade; thus, researchers have extensive experience with mining equipment, mine lighting, human subject protocols, and the human factors of lighting. NIOSH also has unique resources that include a lighting laboratory and highly specialized photometry instrumentation.

### *Impact*

The NIOSH Mining Program has a long history of providing analyzable data files and summary statistics for the mining industry for public use, including MSHA data files and documentation [NIOSH 2018k]. Building on this resource, the proposed work will help to establish a foundation for a surveillance program called the Miner Health Program [NIOSH 2018b], which will identify workers and collaborators in developing health and safety initiatives and will routinely monitor and assess miner health. A structure and procedure for securing and analyzing health-related data will be instituted, thus enabling a systematic assessment of what is currently known about miner well-being and the potential hazards that may contribute to adverse health effects. Among several outcomes, these assessment methods will aid in identifying specific knowledge gaps in miner health and in prioritizing health issues and hazards that are ready for intervention or require new primary and secondary data collection to improve risk estimates. The primary human-centric lighting outcomes include a reduction in circadian disruption and new knowledge about human-centric lighting efficacy in mining applications.

## Strategic Goal 2: Reduce mine workers' risk of traumatic injuries and fatalities

The mining sector utilizes a wide range of tools, stationary equipment, and mobile equipment to extract and process mined materials, many of which can pose immediate harm or death to miners. The mine itself can also pose significant hazards by way of roof and rib falls in underground mines and ground failures at surface mines. Surface and underground mines and the associated processing plants pose a variety of hazards, some of which change as mining progresses. Unintended interactions between miners and these hazards can result in outcomes ranging from acute traumatic injuries to life-threatening trauma and fatal injuries.

In 2018 there were 31,305 underground coal workers, 48,404 surface coal workers, 13,391 underground M/NM workers, and 207,778 surface M/NM workers exposed to the various hazards in the mining industry. These 300,878 workers worked approximately 516 million hours during 2018 [NIOSH 2018i]. Also in 2018, powered haulage and machinery were involved in 17 fatalities and 766 lost time injuries in underground and surface mines, while falls of ground were involved in 3 fatalities in underground and surface mines. [NIOSH 2018i].

Slips, trips, and falls remain a significant factor in traumatic injuries, and fatigue and other fitness-for-duty issues play a significant role in increasing risk of injury. Although work-related deaths in the mining industry were at an historic low in 2016 [U.S. DOL 2017], the need for research devoted to preventing fatalities remains. Specifically, research to address fatalities caused by machinery and powered-haulage accidents—as well as fatalities caused by slip or fall of a person; falls of ground; and falling, rolling, or sliding rock—remains critical in reducing traumatic injuries in mining.

Below, in support of [Strategic Goal 2](#), each intermediate goal is followed by a series of activity goals—as defined earlier in the Plan—then a table, then an analysis of burden, need, and impact. The table lists the health and safety concerns; describes the research focus areas; identifies the mining sectors or worker populations affected; defines the research type used to address the concerns, and links to key Mining Program research projects that target solutions.

*Intermediate Goal 2.1: Workplace solutions are adopted to eliminate fatalities and injuries related to mobile and stationary mining equipment*

**Activity Goal 2.1.1:** (Intervention Research) Conduct studies to develop and assess effectiveness of interventions aimed to improve mine worker hazard recognition and risk assessment capabilities.

**Activity Goal 2.1.2:** (Intervention Research) Conduct studies to develop and assess the effectiveness of interventions to reduce machine-related injuries and fatalities in mining.

**Activity Goal 2.1.3:** (Intervention Research) Conduct studies to determine barriers to manufacturers’ implementation of evidence-based design criteria for interventions to reduce machine-related injuries and fatalities in mining.

**Activity Goal 2.1.4:** (Intervention Research) Form partnerships and alliances to develop products to prevent machine entanglements during maintenance and repair activities.

**Activity Goal 2.1.5:** (Basic/Etiologic Research) Conduct basic/etiologic research to better understand the human-machine interface and injuries among mine workers.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Traumatic Injuries	Lighting technologies; hazard recognition; mobile equipment ingress/egress; human-centric lighting	All	Intervention	<a href="#">Situational awareness (ended in 2019)</a> <a href="#">Slips, trips, and falls (ended in 2019)</a> <a href="#">Hazard recognition (ended in 2019)</a> <a href="#">Circadian disruption (added in 2019)</a>
Risk management	Organizational and worker practices	All	Translation	<a href="#">Health and safety management (ended in 2019)</a>
Machinery entanglement	Situational awareness; human-machine interaction	Stone and gravel with application to all mining; underground coal	Intervention	<a href="#">Conveyor system safety (added in 2019)</a> <a href="#">Electromagnetic interference (added in 2019)</a>
Hazard recognition and risk assessment	Leading health and safety indicators; risk management	All	Intervention	<a href="#">Health and safety indicators (added in 2019)</a>
Haul-truck-related traumatic injuries	Haul Trucks; situational awareness; emerging technologies	All	Basic/Etiologic	<a href="#">Haul truck safety (added in 2019)</a>

## *Burden*

According to MSHA data analyzed by NIOSH [NIOSH 2018k], from 2006 to 2015, a total of 465 fatalities occurred in mining. Metal/nonmetal mining operations (including stone, sand, and gravel) had 177 fatal accidents and coal operations had 188. Of this total (465), 49% (177) were related to machinery or powered haulage. Other causes of fatalities included entanglements with conveyor systems, especially for tasks associated with machine maintenance, repair, or cleanup. Maintenance accidents made up a large portion of machine-related incidents with about 37% (65) of total fatalities in mines, primarily due to entanglements and falls from height during maintenance. Maintenance activities also include building/property maintenance, underscoring the fact that maintenance and repair can include any tasks or activities required to repair equipment that stopped working or was not working properly, to replace or recondition components (scheduled maintenance), or to complete upkeep of facilities (e.g., cleaning up spillage). Circadian disruption and fatigue resulting from shiftwork, which is common in coal mines and metal mines, can also contribute to traumatic injuries. Recent data on risks associated with mining shiftwork are sparse; however, an analysis of various industry sectors, including mining, concluded that relative risk for accidents increases across three shifts, with the first shift being the lowest and the third shift being the highest [Folkard and Akerstedt 2004].

## *Need*

The NIOSH Mining Program is uniquely positioned to perform research on machinery, maintenance, and powered haulage safety, with significant experience in designing engineering controls to prevent pinning and striking accidents. NIOSH has completed extensive research in proximity detection systems technology to improve the performance of proximity systems being used in underground mines [NIOSH 2018o]. The research findings have been incorporated in MSHA regulations and proximity detection systems for continuous mining machines (CMMs) in underground coal mines [MSHA 2015a]. This research is being extended to proximity detection systems for mobile equipment. For mobile equipment, the main categories of fatalities and injuries suggest that specific machine interventions such as stopping a vehicle before it strikes a pedestrian, detecting berms and edges, and detecting pedestrians around corners and through curtains, are necessary to preclude these types of accidents from occurring in the future. NIOSH also has the facilities to conduct full-scale testing on mining machines and equipment using specialized equipment such as different proximity detection technologies, spectrum analyzers, and magnetic field probes in a controlled environment. Human factors also play a critical role in investigating routine and non-routine maintenance activities, including risk perception and situational awareness considerations for the use of new technologies [Yorio et al. 2015], and the acceptance and safe maintenance of these technologies. A strong need exists for improving performance- and system-based standards around workers, technologies, and the organization. Initial research sought to understand what specific leading indicators and respective practices operated under certain risk management elements and how they could best be measured [Haas and Yorio 2016]. Additional work needs to consider how technology acceptance and integration impacts operationalized risk management practices. NIOSH's

industry partnerships allow for rapid development and implementation of technologies based on Mining Program research, with an understanding of the end user's perspective on accepting these technologies. NIOSH lighting intervention research can also potentially reduce traumatic injuries. Researchers have extensive human subjects research and the needed equipment, lighting, and protocols.

### *Impact*

MSHA references NIOSH findings in numerous regulations, giving evidence to the NIOSH Mining Program's impact on machine safety research for both mobile and static equipment. Specifically, MSHA cited NIOSH research in promulgating the use of proximity detection systems on CMMs and in the final rule for the use of these systems on other mobile equipment [MSHA 2015a]. The industry has adopted emerging technologies and engineering controls based on NIOSH research, which has also guided manufacturers in the design of commercially available systems. As one example, the Hazardous Area Signaling and Ranging Device (HASARD), invented by NIOSH, has been adopted by manufacturers of all MSHA-approved systems installed on CMMs and other types of mobile equipment [Schiffbauer 2001]. MSHA predicts that as many as 70 injuries could be prevented and 15 lives could be saved over the next ten years by utilizing proximity detection systems on mobile haulage equipment in underground coal mines [MSHA 2015b]. Based on MSHA's economic analyses on regulatory impacts, this equates to approximately \$512,000 for each injury prevented and \$9.2 million for each life saved, for a total of over \$173 million. Broadly, this research can identify leading indicators that are more realistic in relation to technology development, measurement, and improvement, as well as show the safety advantage of having an operational risk management system through the application of human-technology organization-level interventions. The primary human-centric lighting intervention outcomes include a reduction in circadian disruption and new knowledge about human-centric lighting efficacy in mining applications. In summary, NIOSH research will help the mining industry reduce incidents of injuries and fatalities involving mobile and stationary mining equipment.

### *Intermediate Goal 2.2: Workplace solutions are adopted to eliminate fatalities and injuries caused by global geologic instabilities at underground and surface mines*

**Activity Goal 2.2.1:** (Basic/Etiologic Research and Intervention Research) Conduct studies to recognize and determine characteristics associated with ground instability to reduce injuries and fatalities in mining.

**Activity Goal 2.2.2:** (Intervention Research) Conduct studies to develop and validate stress assessment models and mine design guidelines and software to reduce global ground control-related injuries among mine workers.

**Activity Goal 2.2.3:** (Intervention Research) Conduct studies to develop and assess global stability recommendations for mine development near gas well casings to reduce injuries and fatalities in mining.

**Activity Goal 2.2.4:** (Intervention Research) Develop guidelines and best practices and determine barriers to effective implementation of methods to reduce dynamic failures to reduce injuries and fatalities in mining.

**Activity Goal 2.2.5:** (Intervention Research) Develop mine design and ground control recommendations and determine barriers to effective implementation of methods for challenging underground mining conditions to reduce injuries and fatalities in mining.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Fatal and nonfatal injuries from ground falls	Quantifying support needs and designing appropriate supports for gateroad entries under variable loading conditions	Underground coal (coal mine longwall gateroads)	Basic/Etiologic Intervention	<a href="#">Gateroad ground control (ended in 2019)</a>
Fatal and nonfatal injuries from ground falls	Engineering solutions for ground control hazards	Underground coal; underground metal (deep and weak rock mass)	Basic/Etiologic Intervention	<a href="#">Roof support</a>
Fatal and nonfatal injuries from ground instability	Longwall-induced stresses and deformations	Underground coal; gas	Intervention	<a href="#">Gas well stability in pillars</a>
Fatal and nonfatal injuries from ground instability	Monitoring and mitigating dynamic failure; Remote ground stability monitoring	Western underground coal; underground metal	Intervention	<a href="#">Dynamic failure of ground</a>  <a href="#">Ground stability Informatics (added in 2019)</a>
Fatal and nonfatal injuries from ground instability	Ground control hazard recognition	Stone, sand, and gravel	Intervention	<a href="#">Hazard recognition (ended in 2019)</a>
Fatal and nonfatal injuries from ground falls and bursts	Ground control methodologies for new mining methods	Underground metal (deep and weak rock mines)	Intervention	<a href="#">Alternative mining methods</a>
Fatal and nonfatal injuries from pillar instability	Loading of pillars in dipping and multiple-level mining; analysis of coal pillar and entry stability	Underground stone; underground coal	Basic/Etiologic Intervention	<a href="#">Stone pillar design</a>  <a href="#">Coal pillar and entry stability (added in 2019)</a>

### *Burden*

Although the total number of mines, miners, fatalities, and injuries has been on a downward trend in recent years, the near misses, injuries, and fatalities associated with and attributable to ground control failures are distributed among many failure types. These include rib falls, roof falls, massive collapses, bursts, bumps, back failures, dynamic failures, skin failures, highwall failures, slope failures, pillar failures, rock outbursts, insufficient barrier pillars, insufficient standing support, and intrinsic support. Injuries from ground falls

are reported to MSHA, while reported ground fall incidents show the potential for exposure to ground falls that could result in injury or fatality. In relation to ground fall injuries, between 2009 and 2018, there were 48,108 surface injuries and 26,800 underground injuries among all sectors, with 46 surface and 3,593 underground injuries related to ground control failure [NIOSH 2018k]. Of the 46 surface injuries, 45 were failures of highwall; 9 of the 45 were fatalities and 20 resulted in lost time. Of the 3,593 underground injuries, 42 were fatalities and 2,042 resulted in lost time. Of the total, 3,060 (85.2%) were in coal, 285 (7.9%) were in metal and nonmetal, and the remaining 248 (6.8%) were in other sectors. In relation to ground fall incidents, between 2009 and 2018, there were 50,107 surface incidents and 35,011 underground incidents among all sectors, with 87 surface and 9,572 underground incidents related to ground control failure [NIOSH 2018k]. Of the 87 surface incidents, 86 were failures of highwalls; 9 of the 87 were fatalities and 20 resulted in lost time. Of the 9,572 underground incidents, 42 were fatalities and 2,004 resulted in lost time. Of the total, 8,851 (92.4%) were in coal, 428 (4.5%) were in metal and nonmetal, and the remaining 296 (3.1%) were in other sectors. This 10-year data provides insight into how ground control failures contribute to accidents and fatalities in mines. As near-surface mineral deposits are depleted, underground mining is occurring in more challenging conditions at depth. Conditions in deep mines stretch the limits of current mining practices, and geologic instabilities become a primary hazard for underground miners among the most difficult problems to mitigate. The depth of mining results in high stress from both in situ tectonic loads and overburden. The altered stress field can also cause rock mass movement, such as triggering slip along geologic faults.

### *Need*

To address geological instabilities leading to ground-control related fatalities and injuries, a mix of basic, intervention, and translation research is needed. Although significant advancements in the understanding of global failure mechanisms that lead to large-scale instability and rock falls have been made, some underlying factors and triggers have yet to be discovered. Further, the physical properties of the strata surrounding the mined opening, which contribute significantly to the stability of the openings and the need for additional support, need to be better understood. Previous projects conducted by NIOSH have investigated these problems, and future projects will continue to improve miner safety through refined models, better risk assessments, and additional knowledge and understanding. The new information combined with the historical research conducted by NIOSH and the United States Bureau of Mines (USBM) provide the best opportunity to eliminate mining injuries and fatalities related to ground control failures. There is also a need to establish a new ground control safety standard for the deep underground metal mining sector. This would involve developing new technologies and methodologies to manage the highly stressed rock mass at depth. Data from seismic networks and geotechnical instrumentation need to be analyzed and interpreted in real time using advanced hazard analysis software to help alert miners to emerging hazards. Furthermore, advanced mechanical excavation and automation technologies need to be developed to reduce many of the current health and safety risks by ultimately removing the underground miner from hazardous working conditions. Several resources unique to NIOSH provide the

Mining Program with the most comprehensive research abilities in the world, such as the mine roof simulator (MRS), the high-energy-high-displacement test apparatus, two research/experimental mines to test, calibrate, and experiment with instrumentation, and experts in the various facets of ground control [NIOSH 2018f]. Currently, NIOSH research efforts have developed and continue to bolster cooperative relationships with numerous mining companies (in all commodities), all 13 universities with accredited mining engineering programs, several consulting groups, various support and equipment manufacturers, and industry stakeholders.

### *Impact*

As evidenced by previous Mining Program ground control research, impact can range from dissemination of information to small groups of stakeholders to influencing policies and standards. The most immediate anticipated impact is dissemination of information for improved designs, understanding, or follow-on research. NIOSH-developed software programs—e.g., Analysis of Longwall Pillar Stability (ALPS), Analysis of Retreat Mining Pillar Stability (ARMPS), and Analysis of Multiple Seam Stability (AMSS) [NIOSH 2018g]—are outputs of a well-developed research program that led to policy changes, ultimately resulting in a major reduction in injuries, fatalities, and difficult mining conditions. Similarly, numerous standing supports, roof bolts, shield designs, mine designs, shotcrete guidelines, and pillar designs developed through NIOSH research efforts have been adopted by the mining industry. Instructive material on roof bolting, screen installation, and best practices have been adopted by mining industry trainers, and most recently the software program S-Pillar has been applied to the underground stone sector. Current projects will continue to increase the awareness of issues with rear abutment, stone pillar design, full extraction load redistribution, and entry design through discussions with stakeholders, presentations, and other dissemination techniques. Research in the metal/nonmetal sector will improve the overall safety of deep metal mines by evaluating and developing alternative mining and backfilling methods. These methods will help mines to manage the high-stress fields created by excavating rock at depth and reduce ground falls resulting from both time-dependent deformation and sudden dynamic failures.

*Intermediate Goal 2.3: Workplace solutions are adopted to eliminate fatalities and injuries caused by rock falls between supports or loss of containment from damaged ribs*

**Activity Goal 2.3.1:** (Intervention Research) Conduct studies to develop and assess the effectiveness of ground control systems and rib support guidelines to prevent ground and rib failures.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Fatal and nonfatal injuries from ground falls	Effective ground and rib support and installation recommendations; remote ground support capacity monitoring	Underground metal; western underground hardrock; coal	Intervention	<a href="#">Roof support</a> <a href="#">Ground stability Informatics</a> <b>(added in 2019)</b>

### *Burden*

Ground falls remain a leading cause of fatalities in underground coal mines. From 2009 through 2018, a total of 31 ground fall fatalities and 2,205 nonfatal days lost (NFDL) injuries were reported by MSHA [NIOSH 2018k]. Of these ground fall-related incidents, 18 fatalities and 534 NFDL injuries were caused by rib falls. The injuries and fatalities attributable to ground control failures are distributed among causes ranging from pillar failures to rock outbursts to insufficient standing support. Coal rib stability will continue to become a greater challenge as mining operations move into deeper reserves and encounter more adverse multiple seam stress conditions. Rib-related hazards are most likely to occur in the eastern coal basins of Appalachia and Illinois, which, according to a 2017 Annual Coal Report from the U.S. Energy Information Administration, represent 84% of all underground coal mined in the United States [U.S. EIA 2018]. Ground falls in underground metal, nonmetal, and stone mines resulted in 11 fatalities and 205 nonfatal days lost from 2009 through 2018 [NIOSH 2018k]. Falls of ground are caused by a breakdown in the ground control system, which is designed to stabilize the rock surrounding an underground opening. Causal factors are often related to seismicity, corrosion, support density or capacity, span opening, and rock mass structure. Several of the fatalities and many of the injuries were related to installing and/or rehabilitating support, especially where this work was accomplished with jackleg drills.

### *Need*

To address fatalities and injuries resulting from ground falls due to the failure of support systems, a mix of basic, intervention, and translation research is needed. This research requires an improved understanding of the mechanisms and the root causes that lead to rock and rib falls; a practical protocol to quantify the structural integrity of coal ribs; an engineering-based coal rib design approach; and a definition of the minimum design requirements for rib control. Previous NIOSH Mining Program research has led to improved recommendations, best practices, and risk reduction methods. Nevertheless, lab testing, field instrumentations and observations, statistical analysis of empirical data, and numerical modeling are needed to expand knowledge and datasets beyond current experience. Several resources unique to NIOSH provide the Mining Program with the most comprehensive mining research abilities and facilities in the world, including a mine roof simulator; two research/experimental mines to test, calibrate, and experiment with instrumentation; and recognized experts in the various facets of ground control [NIOSH 2018f]. In addition, strategies and tactics for identifying and managing geologic features that increase the risk of rock mass failures in underground bedded deposits are needed for both coal and

nonmetal mine operators. By identifying the critical characteristics of near-seam features associated with dynamic failure events, operators would be able to target preventative support systems and mitigation procedures prior to worker exposure.

### *Impact*

Recent NIOSH research provides a specialized model to simulate the stress-driven coal rib failure mechanisms observed in U.S. underground coal mines. NIOSH is currently using this model to identify critical parameters affecting coal rib stability and to develop an engineering-based design methodology [NIOSH 2018c]. A design procedure will be provided that is similar to the NIOSH software products—e.g., the Coal Mine Roof Rating (CMRR), Analysis of Roof Bolt Systems (ARBS) [NIOSH 2018g], and Support Technology Optimization Program (STOP) [NIOSH 2018s]—which have led to improvements in the analyses of ground conditions and improved control techniques, ultimately resulting in a major reduction in injuries and fatalities and facilitating solutions to address difficult mining conditions. The developed rib design product will enable the mining industry and enforcement agencies, such as MSHA and state agencies, to assess rib integrity and to design appropriate rib controls. Other research projects are actively exploring the development of design criteria for durable support systems and detecting and managing dynamic failures resulting from anomalous geologic features near coal seams [NIOSH 2018d]. Detailed geologic characterization of near-seam features will aid in the identification of specific mine locations at risk for dynamic failure phenomena. A full understanding of hazard location and ground support systems performance will provide a foundation for developing measures to control or remove ground control hazards. The impact of this research will be measured directly by the safety performance achieved, and the long-term impact will be measured by the surveillance of ground control injury data for the underground mining industry when the new technologies and best practices are generally adopted. A reduction in the number of injuries and fatalities due to ground falls in underground mines will be expected to result from this research. For the metal/nonmetal sector, impact will be assessed by working with several western underground mines to install new durable support systems at their mines and qualitatively monitoring their performance over time to determine if there is the predicted reduction in ground falls. Improvement is anticipated in the overall stability of the mine and of the individual stopes and drifts, as well as the long-term survivability of the support system elements.

### *Intermediate Goal 2.4: Workplace solutions are adopted that enable mines to remediate risk factors for slips, trips, and falls*

**Activity Goal 2.4.1:** (Basic/Etiologic Research) Conduct studies to determine environmental factors associated with slips, trips, and falls.

**Activity Goal 2.4.2:** (Intervention Research) Conduct studies to develop tools and interventions to allow mine workers to identify and remediate slip, trip, and fall hazards.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Traumatic and cumulative injury from slips, trips, and falls	Environmental slip, trip, and fall hazard identification and recognition	Underground mining; surface stone, sand, and gravel; mineral processing plants; coal preparation plants	Basic/Etiologic Intervention	<a href="#">Slips, trips, and falls (ended in 2019)</a> <a href="#">Situational awareness (ended in 2019)</a> <a href="#">Hazard recognition (ended in 2019)</a>
Traumatic injury from slips, trips, and falls	Tools to identify, recognize and remediate slip, trip, and fall hazards	Surface stone, sand, and gravel; mineral processing plants; coal preparation plants	Intervention	<a href="#">Slips, trips, and falls (ended in 2019)</a> <a href="#">Hazard recognition (ended in 2019)</a>

### *Burden*

Slips, trips, and falls (STFs) of a person are the second largest contributor to nonfatal injuries in the U.S. mining industry. Slips, trips, and falls accounted for 20.9% of nonfatal injuries and led to 644,308 days lost from work during the period from 2009 to 2018. Slips, trips, and falls also led to fatalities, and accounted for the deaths of 24 miners at surface coal and surface metal/nonmetal facilities between 2009 and 2018 [NIOSH 2018j]. Publicly available MSHA reports describing fatalities at surface mining facilities [MSHA 2018b] reveal that mechanic/maintenance man, laborer/utility man, welder/blacksmith and sizing/washing/cleaning plant op/worker were the job categories associated with a large proportion of fatalities. Maintenance and repair, climbing scaffolds/ladders/platforms, getting on or off equipment/machines, and welding/cutting have been shown to be hazardous tasks, and were also found to result in STF fatalities. The most common contributing factor was the lack of adequate fall protection or inappropriate use of a personal fall arrest system. Inadequate barriers, equipment-related factors, and a lack of adequate operating procedure were also identified as contributing factors.

### *Need*

Although well established as a major source of injury, STF hazards are still widespread in the mining industry. Several factors contribute to workplace STFs, including environmental factors such as inadequate lighting and poor housekeeping, personal factors such as not maintaining three points of contact when climbing ladders or wearing fall protection, and equipment-related factors such as limited equipment access and damaged or poorly designed ingress/egress systems. There are few mining-specific resources available that can be readily used to prevent STFs at mine sites. Hence, there is a need to investigate and provide recommendations and tools to identify and remediate the environmental, personal, and equipment-related factors that contribute to STF injuries and fatalities in mining. In its well-established Human Performance Laboratory, NIOSH is actively pursuing project research to develop recommendations for footwear based on empirical evidence from lab testing, and to identify features of mobile equipment ingress/egress systems that pose an STF risk [NIOSH 2018r].

## Impact

Guidance is needed to inform mining companies about how to change the workplace or work practices to prevent STFs. Current Mining Program research will inform the development of a toolkit, with multiple tools, to identify, report, and remediate STF hazards in a timely manner. A study by NIOSH's Human Performance Laboratory will identify if there are changes in gait, toe clearance, and heel clearance when wearing metatarsal boots as compared to regular safety toe shoes during ascent and descent from stairs and inclined walkways. Results from this study will inform mine policy and practices by providing miners and mine managers with the knowledge to determine when to replace footwear based on wear patterns and decreased tread depths. Reducing risk factors for STFs by modifying the environment, improving personnel practices through effective training and policies, and utilizing safer equipment will directly impact the mining industry. Providing mine sites with tools and recommendations that can be used to identify and remediate STF risk factors will have a significant impact on costs to the industry and improve the health and safety of miners.

### *Intermediate Goal 2.5: Workplace solutions are adopted to identify, measure, and improve miners' readiness for work*

**Activity Goal 2.5.1:** (Basic/Etiologic Research and Intervention Research) Conduct studies to develop, assess the effectiveness of, and identify barriers to utilizing fatigue management systems to reduce the effects of fatigue on mine workers.

**Activity Goal 2.5.2:** (Basic/Etiologic Research and Intervention Research) Conduct studies to determine and reduce the occupational risk factors associated with inexperience in the mining industry.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Worker fatigue	Fatigue monitoring and management; lighting interventions	All	Basic/Etiologic Intervention	<a href="#">Interventions for fatigue</a> (added in 2019)  <a href="#">Circadian disruption</a> (added in 2019)
Injuries and fatalities from miner inexperience	Organizational and work practices	All	Intervention Basic/Etiologic	<a href="#">Inexperience and injury</a>

## Burden

Many work and non-work factors can contribute to an individual's readiness for work on a daily level. Broadly speaking, these factors can include fatigue from shiftwork, long commutes, sleep disorders, physical fitness or limitations, experience in a job position or task, and stress, mental health, and cognitive impairments. As mining technologies have

evolved toward a greater amount of automation, job tasks for individual miners have also evolved, and the spectrum of required work capacity has broadened. Several studies have described the increased workload capacities required during specific mining activities [Harber et al. 1984; Stewart et al. 2008; Saha et al. 2011]. Mining is susceptible to worker fatigue due to a combination of environmental, organizational, and personal factors; however, the exact burden of fatigue in mining is largely unknown. Fatigue can be influenced by dim lighting, high temperatures, loud noise, highly repetitive and monotonous tasks, long work hours, sleep disorders, and circadian disruptions resulting from shiftwork, long work hours, and generally poor sleep habits. Similarly, physically demanding jobs require a certain level of physical fitness to maintain readiness and performance. As the physical and mental demands of mine work activities continue to be studied, the knowledge, skills, and abilities acquired through prior job and task experience have increasing importance in managing work safety. Inexperience is a known risk factor for workers in many industries, including mining [Butani 1988]. Experience levels for injured workers are tracked by the Mine Safety and Health Administration. In 2017, MSHA and other NIOSH stakeholders have expressed concerns about the higher number of injuries and fatalities for miners with less experience [MSHA 2017]. Preliminary analysis of incident data from 2006 to 2017 shows that miners with less experience make up a high number of injured workers in both coal and non-coal sectors. However, workplace promotion of fitness or readiness for work has recently expanded its context to include focal areas such as improved nutrition, eliminating drug or alcohol use, emphasizing the importance of rest and sleep to combat fatigue, and training. Nevertheless, the application of worker initiatives to monitor or improve miner readiness for work has not been widely institutionalized or promoted in the United States, nor has any strategic guidance been provided.

### *Need*

Whether considering the contributing factors to worker fatigue or physical fitness levels, the current knowledge of mining workforce readiness is limited. Information is often (1) anecdotal and unsupported with reliable measures; (2) focused on a specific sub-population of the workforce (e.g., underground coal, haul truck operation, mine rescue); (3) based on cross-sectional data representing one point in time; or (4) limited with respect to shiftwork details. A multilevel approach based on research and implementation may help address mineworker readiness for work. Best practices, or solutions toward improving and maintaining a worker's readiness, are needed in the mining industry. In order to provide informed guidance, components of readiness need to be characterized along with measuring any associations with injury, illness, or recovery, and return-to-work time. These efforts should evaluate for differences in job task demands and individual age, along with how these and other non-work factors change over time and over the course of one's career. Then, appropriate resources and targeted workplace solutions can be designed and evaluated for effectiveness to help improve and maintain miner performance and quality of life. There is also a need to understand the relative effectiveness of specific interventions for managing mineworker fatigue depending on the type of fatigue, the type of mine, and the individual variation between workers. With respect to shiftwork, lighting interventions are effective for reducing circadian disruptions and fatigue because the day/night cycle of light

impacts circadian rhythms. NIOSH also has distinct advantages and unique resources for conducting research involving the testing of human subjects; thus, researchers have extensive experience with mining equipment, mine environments, job demands, human subject protocols, and human factors applied research. NIOSH has a history of collaboration with industry and expertise in industrial hygiene and epidemiology, positioning the Mining Program to lead efforts to obtain and analyze data, consider privacy issues, and clearly communicate program objectives. The recent establishment of the NIOSH Miner Health Program [NIOSH 2018b] will provide the mechanism for conducting this work.

### *Impact*

Since 1957, the National Health Interview Survey (NHIS) has provided data that can be used to track health status, health care access, and progress toward achieving national health objectives in the United States [CDC 2018]. Numerous studies have demonstrated how a healthy workforce will improve production, job satisfaction, reduce the burden of injury and illness for both the employee and employer, and promote longevity and functionality of individuals into retirement. Health promotion programs can help prevent work-related illness or injury, and numerous workplaces have instituted policies, programs, and incentives to enable and promote a healthier workforce. Establishing systems to regularly assess the health and well-being of miners will enable individual companies to design and evaluate worker health programs that target inefficiencies in employee readiness for work, while reinforcing continued maintenance of healthy behaviors and components of well-being. Mining Program solutions and strategies that are proved to be effective and sustainable will be highlighted and disseminated across mining sectors and other appropriate industries. Given that inexperience is a known risk factor for injury, the impact of efforts to reduce the safety gap related to inexperience will be tangible both to the miner and the mine operators. Improved information and tested training products for operators, supervisors, and/or line workers, delivered to industry via the NIOSH website and conferences, will enable industry to address key areas identified through the research. Through systematically evaluating the effectiveness of multipronged mineworker fatigue initiatives, NIOSH and the mining industry could develop validated tools to attenuate fatigue health and safety issues through concrete translational solutions and scientific validation. If these tools are properly implemented and disseminated, NIOSH could have the opportunity to recommend evidence-based guidance for fatigue management systems in the mining industry. Together, these efforts should lead to a reduction in inexperience-related injury rates.

### Strategic Goal 3: Reduce the risk of mine disasters and improve post-disaster survivability of mine workers

Historically, mine disasters such as fires, explosions, inundations, and roof falls have been the driving force behind both enactment of mining laws and regulations and government investment in mining health and safety research. Fatalities have occurred as a direct result of these events but have also occurred when workers were unable to successfully escape, to isolate themselves from toxic atmospheres to await rescue, or when rescuers perished during a rescue attempt. Although mine disasters have become less frequent, the hardship arising from recent mine disasters is still strongly felt by the families of the 12 miners who barricaded themselves at the Sago mine following the 2006 explosion, with 11 suffocating in the toxic atmosphere ; the 6 miners and 3 rescuers who died in the Crandall Canyon pillar collapse in 2007; and the 29 miners who perished in the Upper Big Branch explosion in 2010 [MSHA 2019b].

Lives can be saved through improved technologies and practices to limit the occurrence of mine disasters. These technologies and practices include more effective applications of rock dust and improved control of float coal dust to limit accumulations of the explosible fuel source; more effective bleeder designs to limit accumulations of methane gas in bleeder entries and to maintain the proper split of ventilation airflow at longwall tailgate corners; improved techniques for identifying incipient stages of a mine fire and the spread of toxic contaminants throughout active workings; and improved identification of conditions and mechanisms that lead to instability of rock masses. Improvements in post-disaster escape strategies and technologies such as mine refuge alternatives, emergency communications, emergency evacuation decision-making, and survivability of critical systems such as mine-wide atmospheric monitoring, communication, and tracking systems could increase the chances of worker survival.

NIOSH disaster prevention research can reduce the human toll of mine disasters by removing or limiting the conditions under which a disaster can occur. Improved strategies and technologies for self-escape and for use by mine rescue personnel will provide the industry with much-needed tools to enhance miner survivability in the event of a disaster. Accordingly, this work addresses accumulations of combustible and explosible materials; detection of hazardous conditions; catastrophic failure of mine pillars, stopes, and critical structures; mine worker self-escape; and post-disaster survival and rescue of mine workers.

Below, in support of [Strategic Goal 3](#), each intermediate goal is followed by a series of activity goals—as defined earlier in the Plan—then a table, then an analysis of burden, need, and impact. The table lists the health and safety concerns; describes the research focus areas; identifies the mining sectors or worker populations affected; defines the research type used to address the concerns, and links to key Mining Program research projects that target solutions.

*Intermediate Goal 3.1: Workplace solutions are adopted to reduce the risks associated with accumulations of combustible and explosible materials*

**Activity Goal 3.1.1:** (Intervention Research) Conduct studies to design, develop, and assess the effectiveness of standardized rock dust testing procedures and protocols.

**Activity Goal 3.1.2:** (Intervention Research) Conduct studies to develop, assess the effectiveness of, and identify barriers to utilizing anti-caking rock dust.

**Activity Goal 3.1.3:** (Intervention Research) Conduct studies to develop and assess the effectiveness of float dust controls to reduce the risk of injury associated with coal mine dust explosions.

**Activity Goal 3.1.4:** (Intervention Research) Conduct studies to develop guidelines for mine development near gas wells and casing design criteria to reduce the likelihood of gas migration into underground mines.

**Activity Goal 3.1.5:** (Intervention Research) Conduct studies to reduce the risk of explosions caused by emissions of methane gas from gobs.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Injuries and fatalities from explosions	Float dust control	Underground coal	Intervention	<a href="#">Improved float dust controls</a> <b>(new in 2019)</b>
Injuries and fatalities from explosions	Rock dust effectiveness	Underground coal	Intervention	<a href="#">Treated rock dust</a>
Injuries and fatalities from explosions	Gas well/longwall coal mine interaction	Underground coal	Intervention	<a href="#">Gas well stability in pillars</a>

*Burden*

According to MSHA accident data [MSHA 2019a], since 2009, 29 U.S. mine workers have been killed and 23 injured as a result of fires or explosions in underground workings. Float coal dust, generated during coal mining, serves as fuel that can propagate an explosion flame, and the explosibility of float coal dust is controlled by applying “rock dust”—i.e., ground limestone dust—on all mine surfaces as an inerting agent. However, based on data from MSHA’s Mine Data Retrieval System [MSHA 2019c], the industry received nearly 1,600 violations in 2018 for failure to maintain rock dust levels sufficient to limit float coal dust explosibility. Accumulations of methane gas are also a constant threat to the safety of underground mine workers. From 2009 to 2018, roughly 100 methane ignitions occurred during coal mining, generally during longwall mining [NIOSH 2018k]. Ventilation airflow is the primary means of controlling methane levels, but such controls are challenged by more rapid mine development that liberates greater methane quantities, larger mining areas that create greater exposed coal surfaces, and larger gob areas under the influence of a single

ventilation district. Finally, fires in a confined underground mine environment can produce catastrophic consequences. From 2009 to 2018, approximately 830 fires were reported that resulted in one fatality [NIOSH 2018k]. When the fire source cannot be readily diagnosed or remedied, the mine may be temporarily sealed by a mine operator until diagnostics indicate that the fire is extinguished. Such an action can greatly stress or ruin the local economies, which are dependent upon mine worker wages.

### *Need*

Federal regulations mandate that all underground coal mine surfaces be rock dusted [MSHA 2011]; however, no standard protocol exists for evaluating the inerting performance of rock dust. A previous NIOSH study collected rock dust samples from various mining regions and discovered that nearly half of the samples did not meet minimum particle size requirements; of those that did meet the requirements, some did not inert coal dust [NIOSH 2011a]. This study calls into question the effectiveness of rock dust products being used in underground coal mines, demonstrating the need for standard test protocols for use by manufacturers. To reduce disaster risk, effective ventilation on longwall mining units is also critical to controlling the large amounts of methane gas liberated during mining. Specifically, research is needed to quantify potential accumulations of methane at the longwall tailgate corner. Guidance on mine monitoring is also needed so that sensors can be properly deployed to maintain the effectiveness and utility of a monitoring system. Sensor deployment strategies must be developed and evaluated using performance-based metrics to ensure early detection of a combustion incident. The NIOSH Mining Program is uniquely qualified to conduct this disaster prevention work due to the high level of expertise of its researchers and the availability and access to the required laboratory apparatuses and in-mine facilities.

### *Impact*

NIOSH Mining Program successes in reducing the risk of disaster are evidenced by the development of the coal dust explosibility meter [NIOSH 2012b], recommendations for a new rock dusting standard [NIOSH 2010], software products such as MFIRE [NIOSH 2016c], and research on "smart ventilation" [NIOSH 2017b]. Continued research in these areas will develop technologies that limit the generation and transport of float dust at the source and throughout mine workings. In addition, standard test protocols developed by NIOSH will be available to industry suppliers to assess rock dust effectiveness for inerting a propagating coal dust explosion. Mine operators will use NIOSH research findings to improve ventilation to minimize accumulations of methane gas at longwall tailgate corners, and NIOSH will develop new strategies that provide earlier detection of such accumulations along the longwall face area, thus reducing the number of face ignitions [NIOSH 2018p]. Improved NIOSH-developed sensor deployment strategies will be performance-based, permitting early detection of fires and heating in the incipient stages of combustion and, perhaps, forestalling the long-term closure and sealing of the mine.

*Intermediate Goal 3.2: Workplace solutions are adopted to improve detection of and reduce the risk of hazardous conditions associated with fires and explosions and ground instabilities*

**Activity Goal 3.2.1:** (Intervention Research) Conduct studies to develop sensor deployment strategies to detect levels of combustible gases to prevent fires and explosions and ground instabilities.

**Activity Goal 3.2.2:** (Intervention Research) Conduct studies to develop sensor deployment strategies to detect unstable mine opening conditions for prevention of ground control failures.

**Activity Goal 3.2.3:** (Intervention Research) Conduct studies to develop and assess the effectiveness of interventions to prevent hot surface ignitions on mining equipment.

**Activity Goal 3.2.4:** (Intervention Research) Conduct studies to develop and assess the effectiveness of interventions to suppress mining equipment fires.

**Activity Goal 3.2.5:** (Intervention Research) Conduct studies to characterize factors that influence Li-ion battery ignition pressures within sealed enclosures and to develop design recommendations for explosion-proof or flameproof battery enclosures.

**Activity Goal 3.2.6:** (Intervention Research) Conduct studies to characterize fire in Li-ion ion battery-powered mining equipment to determine appropriate fire suppression agents/systems and to develop ventilation recommendations for preventing smoke and toxic gas spread in a mine.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Fatalities from mine fires	Combustible gas detection	Underground mining	Intervention	<a href="#">Characterizing mine fires</a> <b>(ended in 2019)</b>
Fatalities from ground falls and bursts	Ground detection conditions	Underground coal mining; underground metal (deep and weak rock mines)	Intervention	<a href="#">Stone pillar design</a>  <a href="#">Alternative mining methods</a>
Fatal and nonfatal injuries from equipment fires	Hot surface ignition mitigation	Underground mining	Intervention	<a href="#">Equipment fires</a> <b>(added in 2019)</b>
Fatalities from mine fires; injuries and fatalities from explosions	Lithium-ion battery safety	Underground mining	Intervention	<a href="#">Lithium-ion battery hazards</a> <b>(added in 2019)</b>

## *Burden*

Mine fires and dynamic rock and coal failures continue to be serious hazards threatening the safety of the mining workforce. According to MSHA accident data, approximately 380 coal burst events were reported from 1983 to 2013 [NIOSH 2018k]. Of those, 20 resulted in fatalities, with 33% in longwall mines. From 2009 to 2018, there were 25 bursts reported, with 12% of these resulting in fatalities [NIOSH 2018k]. The large majority of these events (64%) were in longwall mines. There were two additional fatalities in a single event in 2014 during room-and-pillar (R&P) retreat mining. MSHA mine accident data [NIOSH 2018k] indicate that during 2009-2018 there were 830 reported fires, one fatality caused by mine fires, and 238 injuries caused by flame, fire, and smoke. In metal/nonmetal mines, combustible liquids including diesel fuel, engine oil, and hydraulic fluid come into contact with hot engine exhaust components such as exhaust manifolds and turbochargers. Further, increased use of lithium-ion (Li-ion) battery technologies in mines brings potential failure modes, intensities, and toxicities of large-format Li-ion battery fires that are not well understood [Dubaniewicz and Ducarme 2003]. In addition, dynamic rock and coal failures, known as coal "bumps" or "bursts," pose a significant hazard during full extraction coal mining. According to MSHA accident data [MSHA 2019a], from 2009 to 2013, there were 20 bursts reported, resulting in one fatality. The large majority of these events (75%) were in longwall mines. There were two additional fatalities in a single event in 2014 during room-and-pillar (R&P) retreat mining. The two most recent coal burst fatality events occurred in R&P retreat mining operations with distinct multi-seam interactions evident at the accident sites.

## *Need*

Mine monitoring remains one of the biggest assets to improve detection of and reduce the risk of hazardous conditions, but sensors must be appropriately deployed to ensure the efficacy of the monitoring system and the information it provides. MSHA regulations on sensor deployment are limited and prescriptive in nature. Performance-based deployment strategies are needed for critical underground locations, including battery charging stations and diesel fuel storage areas. In relation to Li-ion batteries, current MSHA battery fire prevention requirements were developed to address lead-acid battery hazards [Battery Assemblies 2018], but do not take into consideration known fire hazards associated with Li-ion batteries. Research is needed to study the failure modes of these batteries, heat release rates of battery fires, gaseous products of combustion, the appropriate fire suppression agents/systems, explosion-proof enclosure design criteria, and overall risk assessment. The continued occurrence of dynamic events with the potential to cause multiple fatalities underscores the need for further understanding of the conditions and mechanisms that lead to those events. Detailed geological characterization of the surrounding rock mass and the determination of the complete stress redistribution experienced during R&P retreat and longwall mining are needed to understand and eliminate these rare but catastrophic events. NIOSH is ideally suited to address these issues due to its breadth of knowledge and experiences in developing sensors and sensor arrays to detect hazardous accumulations of combustible gases. Furthermore, NIOSH has the expertise and industry contacts necessary

to understand coal bursts and related phenomena and to develop methodologies for predicting and identifying potentially adverse mining conditions.

*Impact*

Research on mine monitoring will help to address the industry’s major fire safety issues [Yuan et al. 2017]. The development of sensor deployment strategies will help mine operators install those sensors appropriately to detect a mine fire or a hazardous condition in a timely and effective manner [NIOSH 2018p], thus reducing injuries or fatalities from the fire or toxic byproducts. Improved sensor deployment strategies will be performance-based, permitting early detection of fires and heatings in the incipient stages of combustion. Lithium-ion battery safety research will advance fire-related knowledge in this area, improving reactions to fires caused by such batteries. This work will also establish a solid foundation for developing prevention measures and avoidance forecasting to eliminate burst catastrophes.

*Intermediate Goal 3.3: Workplace solutions are adopted to prevent catastrophic failure of mine pillars, stopes, and critical structures*

**Activity Goal 3.3.1:** (Basic/Etiologic Research and Intervention Research) Conduct studies to determine characteristics associated with and development of mine design guidelines to prevent massive or catastrophic failures of mine structures.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Fatal and nonfatal injuries from ground failure	Pillar failure in dipping and multiple-level mining	Underground stone mining	Basic/Etiologic Intervention	<a href="#">Stone pillar design</a>
Fatal and nonfatal injuries from ground failure	Pillar failure in underground coal mines; failures in rockburst-prone or weak ground conditions	Underground coal; underground metal (deep and weak rock mines)	Basic/Etiologic Intervention	<a href="#">Coal pillar and entry stability (added in 2019)</a> <a href="#">Alternative mining methods</a> <a href="#">Roof support</a>

*Burden*

Current NIOSH Mining Program research related to this intermediate goal focuses on underground stone mines. Historically, the large majority of limestone mining has been accomplished through surface mining operations. NIOSH reported that 3,334 crushed stone mines were operating in 2019 [NIOSH 2018f]. Of that total, 101 were underground mines. Over the last two decades, the number of surface operations has been decreasing while the number of underground mines is gradually increasing. Since 2009, fatalities related to

ground control in underground stone mines have accounted for 4 of the 55 total fatalities [MSHA 2019a]. The reduction in ground fall injury rate in limestone mining has been significantly less than that achieved in coal mining during the past decade, and the injury rate has increased significantly over the past two years. Likewise, the fatality rate in the underground stone sector has increased overall during the past decade, while the underground coal sector fatality rate has declined.

### *Need*

NIOSH developed and made public the first pillar design software program (S-Pillar) for underground stone mining in 2011 [NIOSH 2011b]. This software is designed to meet the pillar design needs of the majority of the underground stone mine industry but does not address several uniquely challenging environments. Stakeholder discussions have indicated that these environments will likely be encountered more often at future mining operations. Further analyses of case histories are necessary to provide detailed assessments of the hazards associated with these insufficiently studied environments. NIOSH is uniquely qualified to undertake this research effort. The organization has had a long history of impactful research in this area, including development of software for analysis of stone pillar stability. Continued efforts will only improve the predictive capabilities of this product.

### *Impact*

A successful stone pillar stability project will establish a solid foundation for the development of revised or supplemental guidelines for underground stone pillar design [NIOSH 2018t]. Research will likely be performed in underground limestone mines but may be applicable to other hard rock room-and-pillar mines with similar dimensions, depths, mechanical properties, and lithology.

## *Intermediate Goal 3.4: Workplace solutions are adopted to improve miner self-escape, rescue, and post-disaster survival*

**Activity Goal 3.4.1:** (Intervention Research and Translation Research) Conduct studies to develop and determine barriers to effective implementation of a standardized mine emergency self-escape system.

**Activity Goal 3.4.2:** (Translation Research) Conduct studies to determine barriers to effectively incorporating self-escape competency profiles into assessment activities.

**Activity Goal 3.4.3:** (Intervention Research) Conduct studies to improve the integrity of atmospheric monitoring systems following a disaster.

**Activity Goal 3.4.4:** (Translation Research) Conduct studies to determine barriers to the effective use of atmospheric monitoring tools.

**Activity Goal 3.4.5:** (Intervention Research) Conduct studies to improve post-disaster survivability and self-escape capability by interfacing MFIRE 3.0 with real-time mine fire simulations with information generated from atmospheric monitoring data.

**Activity Goal 3.4.6:** (Intervention Research) Conduct studies to assess the performance of refuge alternatives to improve post-disaster survivability and self-escape capability.

Health and Safety Concern	Research Focus Area	Mining Sector/ Worker Population	Research Type	Related Project Research
Survivability during self-escape	Technologies and standardized practices to improve self-escape	Underground mining	Intervention Translation	<a href="#">Situational awareness</a> (ended in 2019)
Fatal and nonfatal injuries from fire	Fire detection	Underground mining	Intervention	<a href="#">Characterizing mine fires</a> (ended in 2019)
Fatal and nonfatal injuries	Refuge alternatives	Underground coal	Intervention	<a href="#">Refuge alternatives</a>
Emergency management/disaster prevention	Leading health and safety indicators	Underground mining	Intervention Translation	<a href="#">Health and safety indicators</a> (added in 2019)

### *Burden*

Mine emergencies have resulted in fatalities even when self-rescue responses and rescue activities were attempted, which raises a number of serious concerns about the preparedness of the U.S. mining industry to respond to mine emergencies. There is evidence that inadequate training of the workforce to effectively identify and respond to the related risks is among the root causes associated with these tragedies. [U.S. DOL 2002, 2007, 2011; Mine Safety Technology and Training Commission 2006; U.S. GAO 2007]. Less than optimal technologies are also at fault. For example, MSHA evaluated accident and fatality data from 1900 through 2006 and estimated that 221 lives could have been saved over the 107-year period if refuge alternatives (RAs) had been available [MSHA 2008]. To continue improvement of refuge alternatives, the MSHA final rule provides guidance for the design and implementation of these structures, including structural integrity of RAs, breathable air supplies, air monitoring, the removal of harmful gases, effective communications, and provisions for lighting, sanitation, food, water, and first aid [Refuge Alternatives 2008]. While a significant amount of work has been conducted in the development and integration of technologies to fulfill these requirements, validation of the designs and commercially available products must be investigated.

### *Need*

While it is difficult to quantify or predict the economic and human costs associated with mine disasters, the resulting fatalities serve as a reminder of the critical need to balance investments in resources to reduce the likelihood of high-probability but low-severity events with investments focusing on response to infrequent but high-severity events. NIOSH is an industry leader in the development and testing of emergency response systems [NIOSH 2018q]. As such, the Mining Program can provide the mining industry with critical guidance on future modifications and evaluations of improved systems. Fatalities can be reduced through improved solutions for mine worker self-escape and for survivability of those who

fail to escape from an underground mine fire, explosion, or fall of ground. Because of its past research in the areas of self-escape, mine rescue, and post-disaster survivability, the Mining Program is well-positioned to make critical advances in these areas to support mine workers who could be endangered in future events. Success depends on monitoring systems, which accurately provide information of contaminated underground atmospheres after a mine disaster; technologies that provide a safe location for refuge with an atmosphere where trapped miners can wait for rescue; miners who evaluate their situations correctly and take appropriate self-protective actions; and mine rescuers who make decisions so they can safely assist miners during emergency events.

### *Impact*

Building on past successful research and development efforts will improve the survivability and applicability of underground post-disaster monitoring systems. For example, rather than drilling boreholes to enable monitoring of the underground atmosphere, which can take days to complete, research will develop more robust environmental sensors strategically located in underground workings that can collect real-time mine data to monitor and lower the risk of hazardous conditions. Such advances will allow the continued flow of critical atmospheric information to mine rescue teams and to underground mine workers. Additional study by NIOSH in miner competence in the knowledge, skills, abilities, and other attributes (KSAOs) required for self-escape post-disaster will develop new self-escape training protocols. Through the application of evidence-based NIOSH recommendations and incorporation of self-escape performance-based training and assessment criteria, mine safety and health training professionals will have the tools necessary to bring all miners to mastery in the physical tasks required for self-escape. Further investigation of refuge alternatives will enable the mining industry to perform accurate evaluations of RAs and to submit approval applications required by MSHA [NIOSH 2018a]. Research on the validation of the designs and commercially available RA products will provide life-sustaining solutions to miners who fail to escape and must take refuge to await rescue.

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## Appendix

Table representing five major mining subsectors served by the Mining Program: metals, industrial minerals, crushed stone, coal, and sand and gravel. The table represents these subsectors as classified by MSHA and Standard Industrial Classification (SIC).

MSHA Canvass Code	MSHA Canvass Description	SIC Code	SIC Description
1	<b>Coal</b>	123100	Coal (anthracite)
2	<b>Coal</b>	122100	Coal (lignite)
2		122200	Coal (bituminous)
5	<b>Sand &amp; Gravel</b>	144200	Construction Sand and Gravel
5		144201	Sand, common
6	<b>Stone</b>	141100	Dimension stone NEC*
6		141101	Dimension granite
6		141102	Dimension limestone
6		141103	Dimension marble
6		141104	Dimension sandstone
6		141105	Dimension slate
6		141106	Dimension traprock
6		141107	Dimension Basalt
6		141110	Dimension quartzite
6		142200	Crushed, broken limestone NEC
6		142300	Crushed, broken granite
6		142900	Crushed, broken stone NEC
6		142901	Crushed, broken marble
6		142902	Crushed, broken sandstone
6		142903	Crushed, broken slate
6		142904	Crushed, broken traprock
6		142905	Crushed, broken basalt
6		142907	Crushed, broken quartzite
6		324100	Cement
6		327400	Lime
7	<b>Nonmetal</b>	131111	Oil shale
7		131112	Oil sand
7		142906	Crushed, broken mica
7		144600	Sand, industrial NEC
7		144601	Ground silica
7		144605	Quartz, ground
7		145500	Kaolin and ball clay

7		145900	Clay, ceramic, refractory minerals
7		145901	Aplite
7		145902	Bentonite
7		145904	Common clays NEC
7		145905	Feldspar
7		145906	Fire clay
7		145907	Fuller's earth
7		145908	Kyanite
7		145909	Magnesite
7		145910	Common shale
7		147400	Potash, soda, borate minerals NEC
7		147401	Boron minerals
7		147402	Potash
7		147404	Trona
7		147405	Potassium compounds
7		147500	Phosphate rock
7		147900	Chemical and fertilizer minerals NEC
7		147902	Barite barium ore
7		147904	Fluorspar
7		147906	Pigment minerals
7		147908	Salt
7		149900	Miscellaneous nonmetallic minerals NEC
7		149904	Diatomaceous earth (Diatomite)
7		149905	Gilsonite
7		149906	Graphite
7		149907	Gypsum
7		149908	Leonardite
7		149909	Mica
7		149910	Perlite
7		149911	Pumice
7		149912	Pyrophyllite
7		149913	Shell
7		149914	Soapstone, crushed dimension
7		149915	Talc
7		149916	Tripoli
7		149917	Vermiculite
7		149918	Zeolites
7		149920	Wollastonite
7		149931	Gemstones
7		149932	Agate
7		149935	Emerald

7		149938	Olivine
7		149939	Quartz, crystal
7		149941	Sapphire
7		149943	Turquoise
7		289900	Salt, brine evaporated
8	<b>Metal</b>	101100	Iron ore
8		101102	Magnetite
8		102100	Copper ore NEC
8		103100	Lead-zinc ore
8		103103	Zinc
8		104100	Gold ore
8		104400	Silver ore
8		106101	Chromite chromium ore
8		106102	Cobalt ore
8		106104	Manganese ore
8		106105	Molybdenum ore
8		106106	Nickel ore
8		109401	Uranium ore
8		109402	Vanadium ore
8		109900	Miscellaneous metal ore NEC
8		109901	Aluminum ore-bauxite
8		109903	Beryl-beryllium ore
8		109905	Platinum group ore
8		109906	Rare earths ore
8		109908	Titanium ore
8		281901	Alumina

NEC = not elsewhere classified