NORA

NATIONAL OCCUPATIONAL RESEARCH AGENDA (NORA)

NATIONAL MINING AGENDA

FOR OCCUPATIONAL SAFETY AND HEALTH RESEARCH AND PRACTICE IN THE U.S. MINING SECTOR

February 2024

Developed by the NORA Mining Sector Council

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List of Abbreviations

AMS	Atmospheric monitoring systems
BMP	Best management practices
CABA	Compressed air breathing apparatus
CBRN	Chemical/biological/radiological/nuclear
CPDM	Continuous personal dust monitor
CO	Carbon monoxide
CO_2	Carbon dioxide
COPD	Chronic obstructive lung disease
CWP	Coal workers' pneumoconiosis
ECWHSP	Enhanced coal workers' health surveillance program
EMI	Electromagnetic interference
EMT	Emergency medical technician
FCR	Fine coal refuse
FSR	Filter self-rescuer
IC	U.S. Bureau of Mines Information Circular
ILO	International Labor Organization
ISO	International Standards Organization
MCP	Miners' choice program
MEO	Mine Emergency Operations
MERD	Mine emergency response development
MERITS	Mine emergency response interactive training simulation
MESA	Mining Enforcement and Safety Administration
MFIRE	Mine fire and ventilation simulator
MINER Act	Mine Improvement and New Emergency Response Act
MSHA	Mine Safety and Health Administration
NAICS	North American Industrial Classification System
NIOSH	National Institute for Occupational Safety and Health

NORA	National Occupational Research Agenda
RI	U.S. Bureau of Mines Report of Investigations
SCBA	Self-contained breathing apparatus
SCSR	Self-contained self-rescuer
SHMS	Safety and health management systems
SME	Society for Mining, Metallurgy & Exploration
SMS	Safety management system
UFCR	Ultra-fine coal refuse
U.S.	United States

INTRODUCTION

What is the National Occupational Research Agenda?

The National Occupational Research Agenda (NORA) is a partnership program to stimulate innovative research and workplace interventions. In combination with other initiatives, the products of this program are expected to reduce the occurrence of injuries and illnesses at work. Unveiled in 1996, NORA has become a research framework for the National Institute for Occupational Safety and Health (NIOSH) and the United States. Diverse parties collaborate to identify the most critical issues in workplace safety and health and develop research objectives for addressing those issues.

NORA entered its third decade in 2016 with an enhanced structure. The 10 sectors formed for the second decade will continue to prioritize occupational safety and health research by major areas of the U.S. economy. In addition, NORA's seven cross-sectors will continue to focus on the major health and safety issues affecting the U.S. working population. While NIOSH serves as the steward to move this effort forward, it is truly a national effort. NORA is carried out through councils comprised of members with many diverse interests that are developing and implementing research agendas for the occupational safety and health community over the third decade (2016-2026) of NORA. Councils address objectives through information exchange, partnership building, and enhanced dissemination and implementation of evidenced-based solutions.

NORA groups industries into 10 sectors using North American Industry Classification System (NAICS) codes. The Mining Sector encompasses NAICS code grouping 21xxxx where "xxxx" represents the different subcodes of the mining "21" classification. Mining encompasses the extraction of solid mineral and mineral-like substances from their place in the Earth's crust and supplies them to processing industries that produce economically valuable materials. It does not include oil and gas extraction. The Mine Safety and Health Administration, MSHA separates mining into coal, underground and surface, and metal and nonmetal, underground and surface.

What are NORA Councils?

Participation in NORA councils is broad, including membership from universities, large and small businesses, professional societies, government agencies, and worker organizations. Councils are co-chaired by one NIOSH representative and another member from outside NIOSH. Current and past Mining Sector Council members are listed in an appendix A.

Statement of Purpose:

NORA councils are a national venue for individuals and organizations with common interests in occupational safety and health topics to come together. Councils started the third decade of NORA by identifying broad occupational safety and health research objectives for the nation. These research objectives will build from advances in knowledge in the last decade, address emerging issues and originate from council member and public input. Councils will spend the remainder of the decade working together to address the agenda through information exchange, collaboration, and enhanced dissemination and implementation of solutions that work.

NIOSH is just one of many partners that make NORA possible. Councils are not an opportunity to give consensus advice to NIOSH, but instead a way to maximize resources towards improved nationwide occupational safety and health. Councils are platforms that help build close partnerships among members and broader collaborations between councils and other organizations. The resulting information sharing and leveraging efforts promote widespread adoption of improved workplace practices based on research results.

Councils are diverse and dynamic and are open to anyone with an interest in occupational safety and health. Members benefit by hearing about cutting-edge research findings, learning about evidence-based ways to improve safety and health efforts in their organization, and forming new partnerships. In turn, members share their knowledge and experiences with others and reciprocate partnerships.

Mining Sector Council:

NIOSH established a NORA Mining Sector Council in 2005 and then re-established it with new membership and a renewed focus in 2009. The annual meeting of the Mining Council is held at the Society for Mining, Metallurgy, and Exploration Annual Conference. SME has been a strong a supporter of the Council since its formation and includes the Sector Council Co-Chair in the Executive Committee of its Health and Safety Division. Membership is open to all interested parties and includes academic, governmental, and industrial experts.

The Mining Sector Council used a road-mapping exercise to create the first Mining Research Agenda, which was released in draft form in 2012, with a final version released in 2015. A new update for the Research Agenda was started in 2020 and based upon the revised 2016 draft. Two working parties, one directed toward health concerns and the other focusing on safety, added a number of specific sub-objectives that recognize the substantial changes occurring in the mining industry. The membership of the working parties is listed in the appendix C on subcommittees. This current document is the final Research Agenda based upon the 2020 work.

What does the National Research Agenda for Mining represent?

The National Research Agenda for Mining is intended to identify the research, information, and actions most urgently needed to prevent occupational injuries and illnesses in the Mining Sector. This National Agenda for Mining provides a vehicle for interested industry partners to describe the most relevant issues, gaps, and safety and health needs for the sector. It is meant to be broader than any one agency or organization. It is a strategic plan for the entire country and all of its research and development entities, whether government, higher education, or industry.

Because the National Research Agenda for Mining is intended to guide national occupational health and safety efforts for the Mining Sector, it cannot at the same time be an *inventory* of all issues worthy of attention. The omission of a subject does not mean that the subject was viewed as unimportant. Those who developed this agenda did, however, believe that the number of major objectives should be few enough so that resources could be focused on a manageable set of objectives, thereby increasing the likelihood of real impact in the workplace.

NIOSH used the draft agendas created by the sector and cross-sector NORA councils as an input into the development of a NIOSH Strategic Plan. Programs used the burden, need and impact method to write research goals that articulate and implement the components of the NORA sector and cross-sector agendas that NIOSH will adopt. NORA agendas and the NIOSH Strategic Plan are separate but linked.

Who are the target audiences?

The National Mining Agenda provides guidance on significant safety and health issues to industry; labor; and federal, state, and local governments, as well as to experts in professional associations, academia, and public interest/advocacy groups. It can be used to improve the health and safety of mine workers by providing areas of focus for partnering efforts. It is intended for those researchers who can create solutions with a strong chance of implementation. The National Mining Agenda will provide guidance to investigators about current information gaps and areas to address in future research.

How was the National Research Agenda for Mining developed?

In creating the NORA Mining Sector Council, NIOSH considered the long and tragic history of fatal and disabling accidents in the Mining Sector. It also noted the United States' response to this record when it created in 1910 the U.S. Bureau of Mines, and then, in 1995-1997, transferred the responsibility for research in mining safety and health to NIOSH. Additionally, the United States created and enforced rigorous safety and health codes for the mining industry, first through the U.S. Bureau of Mines, then by the Mine Enforcement and Safety Administration (MESA), and since 1977 with the passage of the Mine Act, the Mine Safety and Health Administration (MSHA) within the Department of Labor. The most recent piece of legislation, the MINER Act (Mine Improvement and New Emergency Response Act) of 2006 was passed after several tragic disasters. Hence, unlike many decentralized industries in the United States, mining has had a research focus for over a century and a national enforcement focus for more than 50 years. It should be noted that the individual states had provided safety enforcement much earlier than national involvement and continue to fulfill that role vigorously to this day.

In the last decade, mining in the United States has had a remarkable reduction in accidents and fatalities. Data supporting this statement can be found at the MSHA website under the Data & Reports heading. Regrettably, the same good record is not true in other mining-oriented countries. Turkey has had two substantial disasters, with the worst in Soma in 2014, when 301 miners died, and the most recent in 2022, when 42 people died. In this same decade, however, health and safety experts have recognized that new mining methods employing automation and advanced mechanization have created the potential for new forms of accidents. The safety-oriented work group concentrated on identifying these accidents and creating research sub-objectives for their reduction, if not elimination. Simultaneously, the health experts on the Mining Sector Council indicated that many existing health problems, such as coal workers' pneumoconiosis and hardrock miners' silicosis, had not been resolved and needed more research. Other respirable diseases have been identified and need research. Additionally, changes in work schedules raise questions on fatigue and its impact on safety.

If the United States is to continue its admirable trend in the reduction of the hazards of mining and the improvements in mine safety, it will need an organized and concerted research effort to do so. Increased enforcement of existing laws may partially achieve this result, but different forms of enforcement may also be necessary, recognizing that NIOSH and NORA are research institutions (not enforcement institutions).. . The mining industry in the United States cannot afford another mine disaster. Further technical advances in mining systems, accompanied by advances in safety management systems (SMS), that increase their inherent level of safety are needed. The NORA Mining Sector Council has much defined for it to do.

In this current version of the Research Agenda, Mining Sector Council leadership has implemented a new strategy in the document to insert, for each subobjective, citations of relevant publications that document progress toward meeting that subobjective. While attempts were made to determine the progress of research on each objective or subobjective, they do not all have relevant publications to document their progress. This may not necessarily mean that no work has been completed for that objective/sub objective. Instances may occur where relevant publications to that particular objective or subobjective were unknown. The Mining Sector Council leadership strived to document the progress in all objectives and subobjectives and realizes some relevant publications may be missed. They invite the membership to provide notification of additional relevant publications that may not have been identified The appended comprehensive relevant publication section collates the individual publications into a single set and includes citations for each relevant publication in their related subobjectives.

The Objectives

As the Research Agenda was developed, the research ideas, referred to formally as sub-objectives, coalesced into eight major research areas, as listed below. Each of these objectives has been refined and detailed as shown in the following major sections of this Research Agenda. The Mining Sector Council has reviewed these objectives and associated subobjectives and has included relevant publications to define the status of the research.

Objective 1: Reduce the Likelihood of Disasters in Mines

Objective 2: Improve Mine Disaster Response

Objective 3: Prevent Illness from Occupational Health Hazards

Objective 4: Improve Ventilation Systems and Atmospheric Control In Mines

Objective 5: Improve Health and Safety Through Behavioral Research

Objective 6: Improve Mine Design, Systems Operations, and Management Performance to Enhance Mine Health and Safety

Objective 7: Apply Human Factors Engineering, to Mining to Increase Health and Safety

Objective 8: Surveillance

Disclaimer

Mention of any company or product name does not imply endorsement of that product by NIOSH.

THE OBJECTIVES

OBJECTIVE 1: REDUCE THE LIKELIHOOD OF DISASTERS IN MINES

Before beginning the discussion of this objective, it is helpful to delineate several terms of Relevant Publication. A disaster in mining is an accident that results in multiple fatalities, normally three or more. An investigation into the causes of mine disasters shows that they are one of, or a combination of, four things: fire, explosion, collapse of ground, and inundation (flooding). Disasters are usually, but not exclusively, associated with underground mining. A great deal of research has been dedicated over the past century to the prevention of mine disasters, leading to substantial rewards in terms of the reduction of fatalities in the United States from disaster events. Unfortunately, disasters still continue to occur at an unacceptable frequency. As noted in the introduction, disasters around the world still occur at an alarming frequency and with deadly results. The topic of disaster prevention remains core to the agenda of research needed in mine safety and health.

The discussion for Objective 1 recognizes that many of the sub-objectives throughout the Mining Sector Council's agenda are aimed at preventing disasters. Nonetheless, disaster prevention can be more effective when considered as a whole, rather than attacking individual pieces of the problem separately. Therefore, while many subobjectives may seem redundant, they are a necessary specific element of the main objective. The integrated report is more complete by allowing this redundant approach of listing sub-objectives similar in nature under different objectives. Because the Mining Sector Council looked at the problem in an integrated way, the sub-objectives in Objective 1 may be similar to others and need to be examined in the same integrated fashion in which they were created.

1.1 Tailings Dam Design

Normally, surface mining or surface facilities associated with underground mining are not as prone to disasters as are underground mines. Nonetheless, in recent history, four of the worst disasters ever recorded were related to surface facilities: Aberfan in Wales, UK, in 1966 (144 fatalities), Buffalo Creek in West Virginia, U.S., in 1972 (125 fatalities), Samarco in Brazil in 2015 (17 fatalities), and Brumadinho, sometimes referred to as Feijao, also in Brazil, in 2019 (270 fatalities). All were due to the collapse of refuse piles and tailings (fine wastes generated during processing of the ore) dams compounded by improper management of surface water. A substantial publication on proper construction methods was issued by the Mining Enforcement and Safety Administration (MESA), the predecessor to MSHA, and it has been recently revised and re-issued [MSHA 2009]. The Mining Sector Council members believe that the science and technology needed to build safe impoundments exists, but that vigilance is needed to prevent the recurrence of such disasters. Subsequent events have shown that this concern for vigilance is warranted. Three recent failures of mine-tailings dams—Mount Polley in British Columbia in 2014, Samarco (with 17 fatalities) in Brazil in 2015, and Brumadinho (with 270 fatalities) also in Brazil in 2019 reinforce the need for good design that is executed well and inspected regularly. The development of early warning systems and an intensive study of today's tailings characteristics are worthy research topics for tailings dams. The Society for Mining, Metallurgy, and Exploration (SME) has added "Increase knowledge transfer of tailings storage stewardship" to its Strategic Plan. The "Global Industry Standard on Tailings Management," August 2020, was developed under the support of the United Nations Environment Program (UNEP) in 2020 and is the subject of an SME webinar, which is available from SME. In 2022, SME published a thousand-plus-page Tailings Management Handbook organized by Kim Morrison.

Relevant Publications:

[Morrison 2022; United Nations Environment Programme 2020]

1.1.1 Investigate Flowability of Mine Tailings

With recent tailings dam failures worldwide and past releases of fine coal refuse, a research goal is to define the term "flowable" or "flowability" of mine tailings (coal and noncoal) and then to evaluate the flowability of mine tailings under various in-situ conditions. In addition, research should develop correlations between measurable parameters of coal and noncoal tailings' characteristics (such as shear strength) and flowability in the hopes of creating easily performed tests on potential stability.

1.1.2 Investigate Mine Tailings Characteristics

Fine coal refuse (FCR) material characteristics have changed with improvements to the coal preparation process, and the rate of deposition has also increased with improved capacity of the preparation plants. There are an increasing number of preparation plant circuits that produce FCR with minus-325-sieve-sized particles. This ultra-fine coal refuse (UFCR) has produced unfavorable conditions for upstream construction of dams and for capping them during abandonment. The UFCR is a very soft (i.e., very weak) and compressible clay-like material with low permeability and low coefficient of consolidation. The UFCR takes longer to settle and longer to self-consolidate, yielding relatively deep zones of UFCR in suspension with essentially zero shear strength. In the early to mid-1970s, the U.S. Bureau of Mines tested and produced

Reports of Investigation (known as RI) on the properties of both coarse and fine coal refuse. The following offers potential research topics

1.1.2a Develop Correlations for Undrained Strength Parameters

Research is suggested to develop correlations for estimating undrained strength parameters, S_u or S_u/S'_v, and the coefficient of consolidation, C_v, for UFCR based on laboratory tests or index properties. Other researchers have developed correlations for estimating S_u/S'_v ratios and C_v of natural soils based on liquid limit, and Huang et al. [1987] developed a correlation for estimating values of C_v for FCR based on grain size D_{15}. However, FCR has a significantly lower specific gravity than most natural soils, and previous correlations were not developed for the very fine, sand-deficient UFCR found at some disposal sites today.

Relevant Publication

[Huang et al. 1987]

1.1.2b Develop Guidelines for Constructing Upstream Embankments

Research is needed to develop guidelines for FCR and UFCR for constructing upstream embankments. The guidelines should cover conditions favorable and unfavorable to upstream construction (minimum requirements for shear strength or consistency of the FCR where the construction will occur). Additionally, research is needed on the appropriate method(s) to evaluate the maximum rate of vertical loading on the underlying FCR (excess pore pressures develop, which lead to reduced, even minimal, effective stress, and dissipate in the underlying FCR).

1.1.2c Investigate Methods to Increase Consolidation Rate of Mine Tailings

New methods need to be developed to increase the consolidation rate for mine tailings. The degree of consolidation is directly related to strength gain in fine refuse. This issue is critical when considering the stability of upstream pushouts and impoundment caps. A better understanding of these properties and conditions is paramount to the safety of miners constructing coal refuse disposal facilities using the upstream construction method. In addition, having a reliable means of estimating the undrained strength for UFCR would help deliver a safe, economical, and seismic design of coal refuse embankment dams. The mining industry may benefit, in terms of both cost and increased miner safety, if other mining and geotechnical engineering experts (besides MSHA) evaluate the issue of short-term stability of upstream-constructed embankments.

1.1.3 Update Guidelines for Mining Under Bodies of Water

In 1977, the U.S. Bureau of Mines published Information Circular 8741 titled "Results of Research to Develop Guidelines for Mining Near Surface and Underground Bodies of Water." This document has been the primary guidance for evaluating the safety of mining near bodies of water. There has been nearly 45 years of mining experience since the document was published. An investigation of updated research, considering additional case history, may lead to improved ground control techniques and mining methods and technology. The IC 8741 recommended solid strata thicknesses, which is likely conservative in many instances.

Relevant Publication:

[Babcock and Hooker 1977]

1.2 Develop Early Warning Systems, i.e., Mine-Wide Monitoring Systems to Prevent Mine Disasters

Various forms of monitoring systems are applied routinely in mining. Perhaps the oldest and most consistent of these systems is the interruption of electrical supply by circuit breakers and ground-fault interrupters when they sense electrical short circuits. Circuit breakers are designed to protect equipment from electrical overloads, and ground fault interrupters protect workers from shock. The past several decades have seen the development of atmospheric monitoring systems (AMS), including remotely monitored fire and carbon monoxide (CO) detectors. Remote monitoring is also routinely performed on the operational status and condition of transportation systems, particularly of conveyor belts.

1.2.1 Identify Steps to Make AMS Reliable Tools for The Prevention of Disasters

A conservative attitude toward protecting miners from risk prevents major changes in ventilation circuitry from occurring while miners are underground. This means that current AMS normally observe (monitor) but do not react (control). The degree of intelligence built into current systems is minimal compared to other non-mining industrialized applications. Several coordinated research steps will be needed to make AMS into reliable tools for the prevention of disasters.

1.2.2 Link Monitoring Data with Interactive Mine Simulators

A research step underway is the linkage of monitoring data with interactive digital mine ventilation simulators. This will allow the simulator to state whether the data are consistent with the model and, also, to predict the consequences when contaminants are detected in the ventilating air stream. An intelligent AMS should reduce risk.

Relevant Publications:

[Bednarz, James, et al. 2015; Bednarz, Widzyk-Capehart, et al. 2015; Chatterjee et al. 1986; Danko et al. 2019; Geier et al. 2014; Hope and Rico 2019; Immersive Technologies 2020; Moridi et al. 2018; Pinedo and Espinoza 2019; NIOSH 2001]

1.2.3 Develop AMS That Provide Accurate and Reliable Data to Operators on a Real-Time Basis

A related research task is to make AMS accurate and reliable. We know that humans tend to ignore warning signals if exposed to a series of false positives. Humans do not want to be responsible for an expensive cessation of mining for what turns out to be a false alarm. Research is needed to drive opportunities for error out of the system and to create a strong sense of confidence in the system. A research goal is to have intelligent and reliable AMS that give real-time feedback.

1.2.4 Develop Rapid and Error-Free Methods of Data Entry That Provide Real-Time Updates

Mining systems are dynamic. Every day sees changes in the structure of a mine that, cumulatively, are substantial. Intelligent AMS need to have real-time updates in the various computer-based simulators that give them their intelligence. The system must have enough information to give real, understandable, messages. Rapid and error-free methods of data entry are needed so that, should an alarm be sounded, the system correctly identifies the source of the alarm and predicts the correct steps to be taken to remedy the condition. For example, resolving the question of whether to fight a local fire or to withdraw personnel rapidly may hinge critically on the simulator knowing the actual configuration of entries around the fire. The device used by miners for input/output is expected to be similar to the hand-held data-entry devices that express-delivery workers use to instantly enter and receive information. These devices would be required to be intrinsically safe for mining.

1.3 Integrate Engineering (Technical) Controls into Mine Design to Reduce Risk

The discussion in 1.2 Develop Early Warning Systems, i.e., Mine-Wide Monitoring Systems to Prevent Mine Disasters leads naturally into the concept of reducing risk by re-engineering the system. Major hazard risk-assessment methods should be utilized to identify conditions that need attention. In this regard, two issues arise. The first is the question of the consequences of change; unintended consequences should be avoided. The second is the limited opportunity to create equipment changes when so much mining is undertaken in existing mines rather than by opening new mines. The introduction of longwall mining in coal increased levels of safety at the coal mine face but also introduced new forms of accidents. For example, the automation of longwall face advance has contributed to injuries to workers who were in the wrong place when the shields advanced; as a result, alarms are required when shields initiate movement. However, risk analysis should be completed prior to design and implementation of the system to prevent such an occurrence. The topic of mine design for enhanced safety is pursued further in Objective 6 for issues of safety and health that, while significant, do not necessarily involve a disaster.

1.3.1 Research Non-Inhibitory Ways to Expand the Explosion Protection of Equipment (MSHA Permissibility) Beyond Ignition Sources Into All Sources of a Disaster

Usually, advances in technology are introduced by manufacturers to enhance the sale of their equipment. Researchers should be developing protocols to be used by equipment designers and manufacturers that compare technological developments to the causes of all major disasters and serious injuries. A review should be completed to find non-inhibitory ways to expand explosion protection of equipment into other potential sources of a disaster. The Mining Sector Council is aware that all new equipment for certain mining applications must be submitted to MSHA for an assessment for explosion protection (intrinsic safety) against ignitions.

1.3.2 Develop Safety Protocols for Retrofitting Old Mines and For Extending the Life of Existing Mines

Price rises in metals, both noble and base, has resulted in strong activity in re-opening old, previously abandoned mines. Increased material values also cause older and deeper mines to be kept in production. Extending the life of older mines requires different designs than do new mines. The research into re-engineering mine systems for improved safety should include protocols for retrofitting old mines and for extending the life of existing mines. The reactivation or extension of a mine should not expose workers to an increased level of risk.

1.3.3 Determine the Handling Characteristics of Biodiesel and Alternative Fuels

If advances in equipment design are routinely compared to the causes of disaster, then designers might avoid pitfalls. For example, the use of biodiesel fuels for their improved emission characteristics has led to increased incidences of equipment fires. Biodiesel is a solvent for rubber and has caused weakening of hoses and gaskets, which, in turn, leaks fuel onto ignition sources. In parallel to the research into the health effects of biodiesel, there should be research into its handling characteristics.

1.3.4 Degradation of Flame-Resistance in Conveyor Belts

The potential for a degradation of the flame-resistance properties in conveyor belts over time is unknown and represents a needed research area. Research should be completed on conveyor belt materials to address the issue of degradation of flame-resistant properties.

1.3.5 Spontaneous Heating of Polyurethane Coatings

Issues have arisen with the use of polyurethane foam causing a heating event in the mine. Causes of the heating include chemicals not mixing properly, quantity of foam used, proprietary content, and coal characteristics. Research into the causes of spontaneous combustion of polyurethane coatings and insulating foams may help to resolve these issues.

Relevant Publications:

[Bugarski et al. 2006; Bugarski et al. 2017; De Rosa and Litton 2007; Coronado et al. 2014]

1.4 Determine the Impact of Depth on Mine Design

Life extension for mines includes the very real potential for going deeper for both surface and underground mining. For a period in the history of mining, surface mining of massive low-grade deposits provided the expansion needed by the marketplace. While surface mining will continue, projects such as the Resolution Copper mine, utilizing block caving 5,000 to 7,000 feet below the ground surface, open up a whole new range of research issues. Whether intended for coal or for copper, future underground mines will be deeper, hotter, gassier, and have more ground-control issues.

1.4.1 Define the Challenges and Associated Risks of Coal Mining at Depth Using Risk/Benefit Analyses for Safety Improvements

Coal mining, particularly in the Western United States, is already going into depths that are greater than current systems can handle safely. The effect of depth is compounded by pre-existing tectonic stresses that create a complex ground-control problem. For example, advancing longwall systems were used by the British National Coal Board to deal with depth impacts and the mitigation of subsidence. This mining method was expensive and labor intensive and ultimately abandoned. We know of one advancing longwall mine that was tried in the United States. While we are tempted to suggest research programs for mining coal at depth, the Mining Sector Council believes that the first research step should be to define the challenges of mining at depth, collect information on various technologies that respond to these challenges, define the risks associated with these challenges, and then, based on the best risk/benefit analyses, determine the research that is needed.

Relevant Publications:

[Hicks et al. 2020; Lawson et al. 2017; Wang et al. 2021]

1.4.2 Research Potential Heat and Ground-Stress Conditions for Block and Panel Cave Zones That Are Deep Enough to Avoid Singularities from The Surface

In hardrock mining, a major concern is that there is little information about block and panel caving systems applied at depth. Previous systems were shallow such that the cave zone intersected the surface. Research should be undertaken into the potential stress conditions for cave zones that are deeper to avoid singularities from the surface. The reduction of heat in deep mines by ventilation controls, including cooling systems, has been prohibitively expensive and has led to the abandonment of mining in deep deposits such as Butte, Montana, and at the Homestake Mine in South Dakota. Concerns exist related to the impact of high-levels of heat in the wall rock on the safety and efficacy of chemical explosives.

1.4.3 Identify the Challenges of Deep Mining in Metal and Nonmetal Mining and Then Define the Research Needed to Reduce Hazards

Similarly to the recommendation for deep coal mining, a research project should define the challenges of deep mining in metal and nonmetal mining and then define the research programs needed to respond to these challenges.

1.4.4 Study the Challenges of Underground Mining for Thick Coal Deposits.

Finally, in concert with consideration of the questions of going deeper for the recovery of mineral deposits, it can be observed that some of our western coal deposits, now mined by surface methods, were much thicker than mined by traditional eastern U.S. coal-mining methods. A similar study of the challenges of underground mining for these thick deposits should be undertaken. Versions of top-slice mining have been developed for thick coal seams, also multiple-lift longwalls, which suggests that issues of ground control, ventilation, and worker safety should be submitted to a thorough risk-analysis review to produce an active list of needed research projects.

1.5 Reduce the Risk of Mine Explosions

Research is needed to further reduce the risk of gas ignitions and consequent dust explosions in underground coal mines.

1.5.1 Reduce the Risk of Methane Ignitions in Continuous Miner Development and Production Faces

Continuing research is needed on face ventilation systems in continuous-miner sections, including improved water sprays and the use of active water barriers mounted on the machine. Such barriers as active explosion-suppression systems have been applied in European coal mines, and their efficacy in U.S. conditions should be investigated.

1.5.2 Reduce the Risk of Methane Ignitions in Longwall Production Sections

Research into improved ventilation around shearer cutting drums and improvements of water sprays for these drums should be undertaken to see if the incidence of ignitions on powered longwall faces can be lowered.

1.5.3 Reduce the Risk of Ignitions in Gob Areas

Research into gas composition patterns in gob areas along with ventilation flows in the gob might lead to better decisions on ventilating, sealing, or inertization of liberating gases of these gob areas.

1.5.4 Reduce the Risk of Coal-Dust Explosions

Current U.S. practice is to dilute and render harmless coal dust by adding low-silica, inert rock dust to at least 80 percent incombustible content by weight of the total. A major issue is maintaining the dispersibility of the applied rock dust. Research on the efficacy of this 80-percent standard should be undertaken along with the benefit of the installation of water and/or rock-dust barriers in ventilating-air courses. Sampling methods for validation of the 80-percent standard should be reviewed and research into improvement of these methods undertaken if the review suggests that current methods lead to false results. Additionally, treated rock dusts, foaming rock dusts, or other materials for rock dusting should be investigated.

Relevant Publications:

[Barone et al. 2019; Brown et al. 2018; Cashdollar and Sapko 2006; Cybulski 2013; Harris and Sapko 2019; NIOSH 2016; Perera et al. 2019; Perera, Harris and Sapko 2021; Perera, Harris, Sapko, et al. 2021; Rayyan et al. 2018; Sapko et al. 2019]

1.6 Reduce the Risk of Disasters through Health and Safety Behavioral Research

Human behavior and organizational factors have contributed to accidents and disasters. That is why OBJECTIVE 5: IMPROVE HEALTH AND SAFETY THROUGH BEHAVIORAL RESEARCH, OBJECTIVE 6: IMPROVE MINE DESIGN, SYSTEMS OPERATIONS, AND MANAGEMENT PERFORMANCE TO ENHANCE MINE HEALTH AND SAFETY, and OBJECTIVE 7: APPLY HUMAN FACTORS ENGINEERING IN MINING TO INCREASE HEALTH AND SAFETY are included in this Research Agenda. Attention is directed to these objectives with the comment that they are relevant to all accidents including those that lead to a disaster.

OBJECTIVE 2: IMPROVE MINE DISASTER RESPONSE

The tragic disasters in the United States led to a substantial revision of mine-safety legislation and regulation. . The council, in reaction to the revised regulations, and proposed revisions, to them, hopes to be able to differentiate among the three broad concerns that will arise during the formulation of this objective: research needs, enforcement methods, and the political issues derived from recent mine disasters.

The discussion was dominated by underground coal-mining issues because that is where the recent disasters have occurred. The group did not lose sight of the fact that metal and nonmetal underground mines and surface mines of all types need to have input into this critical objective.

2.1 Improve Communications and Tracking Systems in Mines

2.1.1 Develop Communication Systems That Can Survive Any Disaster in Which Workers Can Survive

As a general conclusion, the most pressing area for research is a communication system that can survive any disaster in which workers can survive. A large-scale effort should be carried out to test various systems of communications and the methods to harden these communication systems against violent disruptions. Perhaps it will require cable embedded in a trench in the mine floor or roof or in barrier pillars or periodic hard links to the surface. However, if there is any single item that will improve nearly every aspect of disaster response, it is the ability to locate and communicate with potential survivors. A miner's ability to use these systems while escaping, navigating, and wearing breathing apparatus is necessary to take advantage of the technology advances.

Relevant Publications:

[Brune 2013; Damiano et al. 2014; Jacksha and Zhou 2016; Manfredini 2018; NIOSH 2007a; Wisniewski and Schafrik 2014; Yarkan et al. 2009; Yenchek et al. 2012; Zhou and Damiano 2021]

2.1.2 Develop Integrated Communication Systems and AMS Capable of Sensing and Relaying Information in Real Time About the Conditions Existing in The Mine

Secondarily, such a communication system should be capable of sensing and relaying information about the conditions existing in the mine without providing additional ignition sources. Research concerning what this information should be and what is needed to feasibly obtain it in both emergency and everyday operations should be considered.

2.1.3 Develop Hand-Held Displays for Communication Systems and AMSs

Repeatedly, members of the Mining Sector Council have said that reliable and current information about the status of a mine needs to be in the hands of miners. Research into MSHA-approved permissible or intrinsically safe hand-held displays that are linked to the AMS and other such monitoring systems that might be developed (e.g., roof control) is important. If these devices can be integrated into normal operations, will they be maintained and will they gain acceptance by the miners?

2.1.4 Develop Real-Time Analytical Programs for AMS Data

Development of real-time analytical programs for those data that will give up-to-the-minute condition reports for the mine is important.

2.1.5 Investigate Inertial Guidance Systems to Determine Their Utility for Tracking

Inertial guidance systems based on gyroscopes are being tested by at least one manufacturer for miner location devices. These need to be evaluated and prototype devices tested. NIOSH noted that they have a vigorous program to develop communications and tracking devices, and the group supported this work while emphasizing device portability and survivability.

Relevant Publications:

[Arumugam et al. 2020; Arumugam 2016; Bloomquist and Hinton 2001; Roberts et al. 1998; Ralston et al. 2010; Reid et al. 2013; DHS 2021; Polotski and Cohen 2003; Schütz et al. 2007]

2.1.6 Study the Feasibility of Establishing a Mine-Wide Emergency-Response System That Would Provide tThe Information Needed By Responders

One component of a mine-wide information system during an emergency is a functioning mine-wide information system in normal conditions. Research should be conducted into the feasibility of establishing a mine-wide system that would provide the information needed by responders for the various types of disasters that might be encountered. The system could doubly function as a means of preventing disasters by informing workers of potentially hazardous conditions in parts of the mine not normally visited.

2.1.7 Identify Unintended Consequences That May Occur with New Advanced Communication systems

Research, development, and implementation of advanced mining communications systems are well underway. Research is needed to identify unintended consequences that may occur with these new systems. For example, how well do they work, if at all, when the miner is wearing a self-contained self-rescuer (SCSR)? What maintenance and reliability complexity will be added to the overall mining system with these communication systems? The new communication systems are not passive; will their internal power requirements, often provided by batteries, create new challenges? Natural and synthetic noise interferes with electronic communications; therefore, are mines adopting electromagnetic interference (EMI) control practices consistent with other industries? Is there a need for the development of EMI controls or practices that are unique to mining?

2.1.8 Investigate the Development of a Low-Cost, Minimal-Infrastructure, Survivable Means of Communicating with Trapped Miners

Research to establish low-cost and minimal communication infrastructure systems is needed. These systems could be used in the event that electronic communications systems fail. For example, seismic signaling has been a research area that deserves reexamination based on advances in technology.

2.1.8a Evaluate the Use of Geophones in Different Material Types

There is a challenge using geophones in loose soil because they may not have good contact, hence signal conductivity. Research into the best practices for placing geophones in all material types should be conducted.

2.1.8b Evaluate the Use of Boreholes and Temporary or Existing Exploration Holes for Use in Communications Systems

During the exploration phases of a mine (which often continue throughout the mine lifecycle), exploration boreholes could be outfitted for use in an emergency communication system prior to being closed or sealed. Similarly, quick temporary boreholes created immediately after a disaster should be evaluated for use in communications with the trapped miners underground.

2.2 Improve Command and Control during Mine Disasters

During an emergency that has the potential to become a disaster (three or more fatalities), it is critical that the command-and-control structure be in place quickly and understood by all. Because of the number of entities involved—mining company, federal and state enforcement bureaus, local and state first responders, miners' representatives, media, and family members—the lines of authority and responsibility are not always clear. To be of value, research in this domain must consider the current federal and state regulations that control activity during a disaster response.

Current federal mining regulations require that, on each shift, underground coal mines employ a Responsible Person who will take charge during an emergency, and who will have been trained each year in the following areas, as prescribed by MSHA's Office of Educational Policy and Development:

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

In addition, the Responsible Person is charged with having current knowledge of the assigned location and expected movements of miners underground, the operation of the mine ventilation system, the locations of the mine escapeways and refuge alternatives, the mine communication system, any mine monitoring system, locations of firefighting equipment, the mine's Emergency Response Plan, the Mine Rescue Notification Plan, and the Mine Emergency Evacuation and Firefighting Program of Instruction. The recently required tracking systems now provide the Responsible Person with the location of the miners at least up to the time of the disaster. The regulations further require that each miner is trained in evacuation procedures, including the donning of SCSRs in smoke at least once each year.

Each mine must also have a written Emergency Response Plan that is reviewed at least every six months by MSHA (MINER Act, 2006). This plan would typically include crucial telephone numbers of responders, and must include, for example, the phone number of a driller who has agreed to quickly respond to an emergency for the purpose of drilling an escape hole.

The current requirements form a sensible approach on how to be prepared for rare events. One primary problem is that a complete list of items may be difficult to be included in an emergency plan for two major reasons: (1) the widely varying nature of the emergencies; and (2) the volume of material would grow so large that it would be unlikely to be read during an emergency. Except for referring to phone numbers and a brief checklist, realistically it is unlikely that the entire emergency plan will be studied during an emergency in any case; thus, there is a need for pre-training of the responsible persons and support personnel. Updating the information for the many contacts in the emergency plan is a further problem, partly because some of the information will change slowly and the changes will be easy to overlook.

2.2.1 Create Comprehensive Operational Protocols for Emergency Responses

MSHA has established four centers for Mine Emergency Operations (MEO), located in Pittsburgh, Pennsylvania; Madisonville, Kentucky; Beckley, West Virginia; and Price, Utah, to respond to mine disasters nationwide. These centers are equipped with specialized equipment for communications and mine-atmospheric sampling to quickly assess the nature of the disaster.

The MEO has organized a great deal of information about mine emergencies. There is a feeling among the Mining Sector Council members, based largely on past experience, that research may be needed to create comprehensive and operational protocols that can be implemented quickly and assuredly at the time of an emergency and that are applicable to large and small mines. These protocols should clearly define, delineate, and systematize lines of responsibility and authority in both the mining company and the safety agencies such that the response may be implemented quickly at minimum risk.

During an emergency, a key issue is cooperation between the company personnel and regulatory personnel. Under section 103j of the Federal Mine Safety and Health Act of 1977, Public Law 91-173, MSHA may supervise and direct the rescue and recovery activities in the mine in order to protect the life of any person (103k requires the mine operator to obtain approval from MSHA for all rescue and/or recovery activities). However, MSHA may not be intimately familiar with the mine, thus cooperation among mine personnel, state regulators, and MSHA is crucial.

The company must also organize the key supporting functions. These functions include supporting and updating the families, the security providers, and the media; getting medical assistance and possibly coroners; organizing staging areas for rescuers; providing the needed maps and other information; providing general and specific instructions to rescuers both before and during the in-mine activity; and obtaining needed equipment such as pumps or nitrogen tankers. An additional key supporting function is providing food and drinks for all of the above. While the Responsible Person is responsible for the workers in the mine, it is obvious that this person will, at the very least, need staff support during the time of the emergency. As soon as the Responsible Person becomes aware of a reportable emergency, multiple tasks must be accomplished in a very short time. Researchers could develop and evaluate a system for delegating duties and a local emergency response structure to address these tasks efficiently and to develop a credible response plan.

2.2.2 Determine the Benefits and Effectiveness of Comprehensive Operation Protocols

A section of the protocol should be dedicated to communication with emergency first responders (local and state police, emergency medical technicians (EMTs), fire departments, etc.), also with family members, miners' representatives, and representatives of the media. Moreover, simulations and drills will be needed to see if these protocols can be followed during times of stress. A critical part of this research will be to see if these protocols can improve on the existing system. Although a few regulations in the mine safety laws deal with how to proceed at the time of a disaster, the actual structure is often, by nature, *ad hoc* and this may lead to mistakes and delays. The Council is cognizant, as noted earlier, that long written protocols are unlikely to be read in the midst of an emergency, so the challenge will be for the implementation to be ingrained in the entire response team by effective training before the emergency. New training, competency assessment, and exercise design methods may require research for improvement. The Responsible Person must lead the response until the command center is staffed and functioning.

2.2.3 Develop the Responsible Person's Training Needed for Emergency Responders

How best to train and assess the competency of the Responsible Person during the stress of an actual emergency is another area that is open to research.

Relevant Publications:

[Connor and Gallick 2018; Ryan et al. 2018]

2.2.4 Identify the Best Methods for Transferring Decisions to Rescue Teams and Keeping Real-Time Records of These Messages

Emergencies may unfold over time such as when underground firefighters find that they cannot control a fire and must evacuate. In other incidents such as structural collapse, inundations, or explosions, the emergencies occur nearly instantaneously, yet knowledge and understanding of the emergency may unfold only over time. Hence, the first problem for the Responsible Person is to recognize early that a potential disaster is in the making and that they need to immediately call MSHA and the state agency, as required by law.

Related to this problem is the planning of a credible response that satisfies MSHA in that all persons are being protected. While MSHA will issue a “k or j” Order and may take charge of the mine, more often the company, as owner of the mine and the entity first on the scene of the emergency, has a continuing responsibility for it and will name the executive(s) to fulfill this responsibility during the emergency. MSHA has authority to approve all response plans involving personal safety. Again, looking at recent past experiences, while there is a Responsible Person somewhere at the mine at the time of the incident, they may be superseded by a company official who becomes the lead person in the command center. During this time of uncertainty, key decisions may not be made or, if made, approved by MSHA and implemented in a timely fashion. Research into ways of streamlining this decision-and-approval process is needed. As noted earlier, cooperation between the company, and federal and state officials is key. Decisions must be made quickly and must be the consensus of all three groups. A further complication is that small mines may not have the capacity to mount a full-scale response and may immediately need additional support. This is often true in establishing external communication systems because landlines become blocked by incoming calls.

As stated above, emergencies may take many forms and the protocols will need to be tailored to each major kind of emergency. Even though the protocol itself may be comprehensive, hence lengthy, its abstract into checklists must be brief and understandable in times of stress. Because needed contact data (telephone numbers and e-mail addresses) change so rapidly, there needs to be a regular update and verification of this information. Studying the best methods for transferring decisions to command center participants, approval agencies, and rescue teams and keeping real-time records of these messages may be a worthwhile area of research.

2.2.5 Determine If Electronic Telephony Can Be Used Effectively in Breathing Apparatuses

High-quality voice and data communications, utilizing electronic telephony to and within response teams from the operations command center, could reduce errors and speed reporting. Investigations into the use of new technology to improve communications among mine rescue teams, the fresh air base, and operations command center are needed.

Relevant Publications:

[Brodersen et al. 2016; Fernando 2016; Kushner et al. 2006]

2.2.6 Improve the Location and Tracking of Mine Structures and The Personnel Within Them to Provide for Rapid Response During an Emergency.

Research on improved location and tracking of mine equipment, infrastructures, and personnel is essential to provide low-risk rapid response during an emergency. Normal mine mapping needs to become real-time and verifiable. Mobile machinery and its operators need to be located at any time. If these developments can enhance normal operating conditions, they will be maintained so as to be available at the time of an emergency. Because refuge alternatives are designed to be moved from time to time, each move needs to be documented as it happens. Automating this process with survivable machine tracking may improve daily-operations' efficiency and assist timely response planning.

Relevant Publications:

[Arumugam 2016; Arumugam et al. 2020; DHS 2021; Schütz et al. 2007]

2.2.7 Determine How Emergency Response Drills Can Be Enhanced By Virtual Reality Technology.

Drills for emergency evacuation are a current coal-mining requirement. Research is needed to see how these drills and emergency response scenarios can be enhanced by virtual reality technology. This research will need to be guided by assessments of effectiveness.

Relevant Publications:

[Orr and Girard 2002; Orr et al. 2009; Ryan et al. 2018]

2.2.8 Assess the Effectiveness of Current Mine Rescue Exercises and Propose Improved Versions.

Mine Emergency Response Development (MERD) training may be provided to groups or as contests approved by MSHA for mine rescue teams. Research can assess the effectiveness of current exercises, degree of standardization achieved, and propose improved versions. Full-scale emergency drills that engage all potential responders are necessary to confirm emergency system functionality. Additional benefit may be achieved if independent audits and reporting on lessons learned and best practices are made available to the industry.

Relevant Publications:

[Mischo et al. 2014; Slaughter and Tien 2015; NIOSH 2015]

2.2.9 Assess the Effectiveness of Current Mine Emergency Training Program (MERITS) Exercises and Propose Improved Versions

NIOSH developed a mine emergency training program (Mine Emergency Response Interactive Training Simulation or MERITS) in which participants from a mine act out a simulated emergency in a control-room setting using a computer program that responds to the actions of those in the exercise. The trainees are provided with information about a small coal mine, its emergency response plan, and its communication system, and are then given information about an incident as if it was realistically unfolding. This software must be upgraded for modern computer operating systems so that it may be more widely applied. There may be opportunities to expand the number of scenarios modeled and to expand the capability of the software to include all Responsible Persons and staff each year.

Relevant Publications:

[Brnich Jr et al. 2002; Eppley and Reinke 2002; NIOSH 2002b]

2.2.10 Create Guidelines for Preparing Comprehensive Mine Emergency Response Plans

Mine emergency response plans are required for each coal mine and are meant to be a valuable resource during an emergency. The results of the various research recommendations should be written in a way that they can make these plans realistic, locally applicable, easily followed, and beneficial during an emergency. These plans need to consider each major type of emergency that may unfold for the mine in question.

Relevant Publication:

[Hoebbel et al. 2019]

2.3 Survivability

The Mining Sector Council recognizes that current mining technology cannot protect miners against certain kinds of high-impact emergencies, particularly explosions. Consequently, prevention of emergencies is an extremely high priority; it is noted that this critical subject was discussed in several of the major objective areas.

2.3.1 Develop Design Protocols for Mine Planning That Consider the Types of Emergencies That Could Occur in Specific Types of Deposits and At The Particular Mine Locations

Mine designs and the consequent mine plans need to consider most carefully the types of emergencies that could occur in the type of deposit and geographic location: explosions, fires, major structural collapse, ventilation failure, and inundation. It is recognized that all mining operations are by nature adapting to changing geologic and operational conditions; therefore, it is essential that when the mine plan is modified, the original design assumptions are reviewed by competent professionals before changes are instituted. Possible processes for doing this are completing a Major Hazard Risk Assessment or utilizing a Management of Change procedure. This assessment should be connected to the real-time collection of mine-status data suggested in sub-objective 1.2.4, Develop rapid and error-free methods of data entry that provide real-time updates.

2.3.2 Develop Rugged, Redundant Location and Tracking Sensors That Can Survive Disasters

The issue of survivability of personnel cannot be considered in isolation. Survivability of the mine structure, its infrastructure, and its communication systems is a critical part of the discussion on refuge structures and evacuation and escape that will follow. Repeatedly, the group identified the need to know in-mine conditions during an emergency. Survival of sensors and monitors is a critical part of acquiring this knowledge (see 2.1.1 Develop Communication Systems That Can Survive Any Disaster in Which Workers Can Survive). Intelligent and real-time analysis of the data that come from these sensors is also needed to assess the conditions during the emergency. Location, environmental, and tracking sensors that can survive an incident are needed. Design for ruggedness, low maintenance, intrinsic safety, and redundancy is a research topic. Equally, if a sensor fails, the time and cause of failure and, in the case of mobile ones, its location at the time of failure are data that can be analyzed in a simulator to produce useful information about the emergency.

2.3.3 Conduct Research to Improve the Survivability of All of The Elements Of Mine Infrastructure

If miners are to respond appropriately during or after an emergency, they will need power, water, ventilation, and communication links. Research into which structures are essential to the survivability of these elements and how infrastructure can be made more resilient is important.

2.4 Improve Refuge Alternatives and their Use

A refuge alternative is a structure, either fixed or mobile, close to the working face or spaced out along the escape route into which miners can go for survival during a disaster. Seeking refuge is a secondary alternative to escape. The use of a refuge alternative is now mandated by federal regulation, but many questions remain for which research is needed.

2.4.1 Identify Requirements for the Next Generation of Refuge Alternatives

Research is needed on the next generation of refuge alternatives; NIOSH and MSHA personnel are aware of this need. Refuge alternatives are required in coal mines.

Mines have different refuge needs depending on their mining conditions, seam height or vein thickness, rates of advance, and number of expected refuge occupants, which makes airlock sizing critical. Low coal mines have other criteria that may make inflatable refuges more attractive. Mines with elevated ambient temperatures could face undesirable environmental conditions such as elevated temperatures inside of portable refuge alternatives if adequate cooling is not provided. Post-disaster environments including smoke, limited visibility, the wearing of SCSRs, and presence of injured workers may make finding, deploying, and entering a refuge difficult. In addition, mine rescue teams may need additional training or improved protocols when refuge chambers are present, including reaching the refuge within 96 hours and extracting groups of miners, some possibly injured, from a refuge. A number of design, operation, and occupation issues are identified and need research as the next generation of refuge alternatives evolve. These issues include postural conditions, control interface, survivability, tolerability, mine rescue, training, and psychological needs. Additionally, new technology should be developed to allow each refuge to automatically identify the miners who enter it and determine and monitor their health status. Design protocols for this census should be developed.

This research should include the study of any refuge alternatives that may have been involved in recent mine emergencies or exposed to the mine environment over a long time period (>five years). Recommendations for future design requirements should be based on observations, tests, and sound scientific research.

Relevant Publications:

[Bauer and Kohler 2009; Rau 2013; Wang et al. 2013]

2.4.2 Assess Criteria for Deciding Whether to Remain in a Refuge Structure or to Evacuate From The Mine And Evaluate The Decision-Making Criteria Implementation

Entering a refuge is a last recourse. It is a decision that should be based on good knowledge that evacuation and escape contains more risk than does barricading (in the structure) and awaiting rescue. The more knowledge that miners have about conditions during and after the emergency, the more likely they are to make a good decision about leaving or staying. It was noted that today's miners have doubts about using a refuge for protection. NIOSH has developed a collection of training material (https://www.cdc.gov/niosh/mining/content/refugechambers.html), but research is needed in the effectiveness of the implementation of the criteria and the training material.

A secondary concern is how miners perceive approaching rescuers, how best to rescue multiple miners in a possibly hazardous atmosphere, and how to treat injured miners.

Relevant Publication:

[Hoebbel et al. 2019]

2.4.3 Develop Survivable Data Displays and Their Supporting Systems

The development of survivable displays that will give miners information about conditions is also needed. These displays may be portable or fixed within the refuge alternatives (this recommendation links back to sub-objective 2.1.1.).

2.4.4 Determine the Optimal Location for Refuges and Caches of Safety Gear

Research is already underway on the optimal location and spacing of caches of rescue gear and refuges. This research needs to be continued and expanded and should include an assessment of similar efforts in other countries that have underground mining.

Relevant Publication:

[Office of Miners' Health 2019]

2.4.5 Evaluate the Use of Boreholes and Temporary 0r Existing Exploration Holes for Use with Refuge Chambers

Investigate the potential to connect refuge chambers to boreholes or existing exploration holes to provide additional breathable air and provisions from the surface as miners await rescue.

2.5 Improve Escape and Rescue Procedures

The alternative to seeking refuge is for workers to seek to escape the disaster site within the mine. This decision should be fact-based but also needs to consider human concerns about the unknown; a number of research issues are involved in making this decision wisely.

2.5.1 Determine if Mine and Ventilation Plans Needed to Select Escape Routes Can Be Built into Tracking and Communication Devices That Miners Could Wear

Again, it is critical that workers involved in an emergency have information on the status of the mine and rescue plans, reinforcing the recommendations for research on location and tracking devices along with survivable atmospheric monitors. Based on information received from those who have escaped disasters, it is critical that miners know the mine and ventilation plans well enough to select alternative routes for escape if available. Perhaps research would be worthwhile to determine if these plans can be built into tracking and communication devices that miners would wear.

2.5.2 Identify Effective Forms of Escape Training

Escape drills need to be made rigorous and comprehensive, incorporating situations where miners are challenged with decision-making, the necessity for team-building, change of leadership, and handling of stressful situations. Research into forms of varied drill simulation would enhance the effectiveness of the training. This is especially critical given the limited time for training and the wide variety of topics in which miners may be required to be trained.

Most experts agree that escape is the first option miners should try after an emergency. In the case when miners may be injured or unable to escape, they may need assistance. The first available miners for assistance are coworkers. This is referred to in Australia as “inseam assisted escape."   It is a natural response to want to help colleagues, but training may not have taught miners how to protect their own safety first.

Relevant Publications:

[Hoebbel et al. 2018; Kovac et al. 1990; Orr et al. 2009]

2.5.3 Develop Technology to Provide Face-Located or Mobile Displays of Mine Conditions That Allow Workers to Evacuate Even Through Obscurant Fog

Research to provide face-located or mobile displays of mine conditions would allow workers to evacuate even through obscurant fog.

2.5.4 Determine If Existing Devices That Can See Through Obscurant Fog Can Be Made Intrinsically Safe

Vision systems that can see through dust, fog, or smoke exist within the military. Thermal imaging cameras are used successfully in a variety of applications including coal-mine trouble shooting, rescue, and firefighting. Research might be undertaken to see if these devices can be made intrinsically safe for application in the mine.

Relevant Publications:

[MacKenzie 2007; Robinson and Green 2016; Yadav et al. 2014]

2.5.5 Investigate the Escape, Communications, Danger Assessment, and Rescue Functions That Robots Are Better Suited to Accomplish Than People

The use of robots for locating or removing workers from the mine should be investigated further. A review of available robotic technology, both ground- and air- (unmanned aerial vehicles: drones) based, should serve to guide future research and should include exploration and surveillance functions for underground mines and assessment of surface mine dangers. For example, rapidly emplaced robots could potentially act as communication nodes and should be examined to see if workable prototypes can be developed.

Relevant Publications:

[RESPEC 2022; Australiandroid 2022]

2.5.6 Investigate the Use of Trained Animals, Including Insects, to Assist Escape and Rescue operations

Search-and-rescue dogs have been trained to locate injured miners in advance of mine rescue teams. Other animals, including insects, may have characteristics that can be used to enhance the effectiveness of mine rescue.

2.6 Improve the Use of Self-Contained Self-Rescuers (SCSR), Self-Contained Breathing Apparatus (SCBA), and Filter Self Rescuers (FSR) Used Hardrock Mines

It was mentioned that most models of self-contained self-rescuers (SCSR) are not comfortable to wear or to use. Personnel in the midst of an emergency may never have experienced this discomfort over long periods of time and may misinterpret it to mean that the instrument is not working properly. Resistance to breathing and increased temperatures of the air could cause a miner to believe that the apparatus should be removed.

2.6.1 Develop Improved SCSR Simulators to Allow Miners to Experience Their Use in an Emergency

Low-cost SCSR simulators are available, but research is needed to allow miners to experience realistically what it is like to wear an SCSR during an emergency.

2.6.2 Develop SCSRs and SCBAs That Are Easier to Use and That Accommodate Voice Communication

Subsequently, research should be undertaken to develop SCSRs and SCBAs that are easier to use and that accommodate voice communication by eliminating the mouthpiece. For example, a transparent breathing hood or a full-face mask could provide protection and replace the goggles and nose clips, although such a device would also have to accommodate the wearing of a hardhat.

2.6.3 Study Problems That Might Be Encountered While Removing and Re-Donning SCSRs

Miners may need to change SCSR units in the midst of conditions such as smoke or a highly noxious atmosphere. Studies of the problems that might be encountered while removing and re-donning the units are valuable.

2.6.4 Develop New Technologies for The Next-Generation Escape Breathing Apparatus (SCSRs And SCBAs)

Innovations in breathing apparatus technologies that improve efficiency of on-demand delivery; optimize the size-to-duration ratio; utilize new chemicals for oxygen generation or dosing; design dockable oxygen supplies, filters, and catalysts; and improve carbon dioxide (CO_2)

scrubbers may lead to design improvements. Cryogenics (liquid air and liquid oxygen), compressed air breathing apparatus (CABA) and refill systems, chemical/biological/radiological/nuclear (CBRN) filters, and CO/CO_2 catalysts are examples of known technologies that could be applied to breathing apparatus in mining. Further research into next-generation breathing apparatuses would be valuable.

Relevant Publications:

[Doerr et al. 2016; Kilinc et al. 2014; Kimball and Chambers 2015]

2.7 Understand the Impact of Fire On Normal Operations, Ventilation Changes, and Byproducts

In terms of disaster response, the group considered the special conditions of fire in creating changes to the ventilation system.

2.7.1 Develop Ventilation Simulators That Can Predict Ventilation Changes Caused by The Fire

MFIRE (https://www.cdc.gov/niosh/mining/works/coversheet1816.html) is a computer mine fire and ventilation simulator developed by NIOSH. If research provided ventilation simulators with better input from the principles of fire dynamics, then those simulators might be able to predict likely changes that occur during a fire. This prediction could be based on information received from the AMS during a real fire or it could be based on conditions that were input into the simulator by the mine ventilation system designers initially and during any subsequent evaluation/modification. This also fits in with the earlier recommendation that research could be initiated into the feasibility of and requirements for a mine-wide monitoring system, which may include any potential links to early warning fire hazard identification.

Relevant Publications:

[Stewart 2021; Dziurzynski et al. 1997; Wu and Li 1993; Gillies et al. 2005]

2.7.2 Create Easily Accessed, Interactive Ventilation Models That Can Be Used to Model Failure Modes in Ventilation Systems

Research is needed to create easily accessed, interactive ventilation models that could be used to model failure modes in ventilation systems. These models could be used to evaluate alternatives such as location and direction of air moving along “neutral” splits or of pressures and velocities at various nodes and along various entries during both normal and abnormal operation of the mine.

2.7.3 Investigate the Effectiveness of Game-Like Ventilation and Other Emergency Response Simulators for The New Generation of Miners

Research is needed on new learning methods such as ventilation or other emergency response simulators presented as competitive computer games. Such an initiative could introduce an entire new generation of better-prepared mine workers into mining.

Relevant Publications:

[Braun and Safety Solutions Internation 2017]

OBJECTIVE 3: PREVENT ILLNESS FROM OCCUPATIONAL HEALTH HAZARDS

Preventing occupational illness is an extensive objective that encompasses several categories of disease. One category includes respiratory disease such as coal workers' pneumoconiosis, silicosis, asbestosis, chronic obstructive lung disease (COPD) and lung cancer. Other categories are musculoskeletal disorders and hearing loss. Additionally, there are many cross-cutting sub-objectives, shown below.

3.1 Reduce Exposures that Lead to Respiratory Diseases

The primary cause of occupational respiratory diseases in miners is dust. In this sub-objective, the Council considers ways to identify and then reduce, or eliminate, the incidence of respiratory diseases in miners.

3.1.1 Eliminate Coal Workers' Pneumoconiosis (CWP).

Since 2000, the prevalence of CWP has increased among experienced miners with longer working tenure in mining. Additionally, miners with shorter working tenures are also developing CWP despite new and stricter controls on dust. Increases have been particularly prominent in Central Appalachia. Several causes have been suggested, including excessive exposure to silica and longer working hours. Until recently, productivity (tons/hour worked) has increased also. Other issues include the long latency for CWP, generation of smaller dust particles with new mining equipment and methods, and potential noncompliance with regulations. Research objectives include an evaluation of the relative contribution of these causes and development of new or improved means of reducing miners' exposure to respirable dust including silica dust. Evaluation of these causes may be dependent on epidemiologic data concerning miners' exposures and associated burden of disease.

Some mineral dusts, e.g., asbestos and silica, will need real-time assessments of exposure to assess risk of disease and to install additional engineering controls rapidly.

Relevant Publications:

[Beamish et al. 2017; Blackley et al. 2018; Hall et al. 2019a; Hall et al. 2019b; Huang et al. 2013; Joy et al. 2012; Schenk 2013; Suarthana et al. 2011; Frost et al. 2019; Reynolds et al. 2018; NIOSH 2021a, 2003, 2011b]

3.1.1a Use the CPDM for Assessment of Miners' Personal Exposure to Respirable Dust.

The Continuous Personal Dust Monitor (CPDM) is a powerful tool for exposure assessment. It should be used for evaluating exposure for the purposes of epidemiologic research. Integration of CPDM data to tracking data and equipment operational data should be investigated.

An assessment should be taken of an expansion of the ability for the CPDM to measure amounts of crystalline silica in coal dusts.

3.1.1b Evaluate the CPDM, a Near Real-Time Instrument, for Use As an Aid for Reducing the Concentration of Respirable Dust.

The ability of the CPDM to identify specific dusts could be used to develop measures and controls that would reduce miners' exposure. Research may be needed to bring this concept to practice.

CPDMs should be able to transfer data seamlessly into digital networks for rapid understanding of integrated mine-wide ambient condition.

3.1.1c Develop New or Improved Means of Reducing Miners' Exposure to Silica.

Exposure to silica in coal mines likely contributes to the development of CWP. There is a need for research and development for controlling not only respirable dust but also the respirable crystalline silica component of respirable dust. This research applies to both underground and surface coal mines where cutting rock with continuous miners, roof bolting, material loading, and surface blasthole drilling can generate silica-laden respirable dust. Considerable work has been done developing dust controls for these specific mine operations. However, there is always a need to develop better, more innovative methods for dust control. For example, there is a need to determine how much, if any, respirable silica dust escapes current dust-control methods in surface, overburden drilling. It is necessary to conduct research on methods designed to specifically capture the silica component of dust. Research for new innovative scrubber designs for use on continuous miners and longwall shearers is recomended.

Relevant Publications:

[NIOSH 2019; Page et al. 2008]

3.1.1d Improve Secondary Prevention By Increasing Participation Rates in X-Ray and Radiographic Surveillance.

Research into ways to increase participation rates in the current voluntary x-ray/radiographic surveillance program for coal miners is necessary. Similarly important is research into ways to increase utilization of x-ray and radiographic surveillance for detection of occupational respiratory disease in miners. Surveillance programs similar to the Miners Choice Program (MCP) and the Enhanced Coal Workers Health Surveillance Program (ECWHSP) can be used to increase participation.

3.1.1e Improve Secondary Prevention by Enhancing Radiographic Techniques.

Research is needed for improved radiographic techniques. Research demonstrates digital chest images are an acceptable method of surveillance, produce results comparable to analog films, and are significantly easier to store and transmit. Their use should be encouraged. Also, automated computer algorithms utilizing modern image processing techniques, such as rib shadow removal and coloration of opacities, should be investigated.

Relevant Publication:

[Franzblau et al. 2009; Halldin et al. 2014; Laney et al. 2011; Laney et al. 2010; Mao et al. 2011; Sen et al. 2010; Frost et al. 2019]

3.1.1f Nanometric-Sized Dusts

The impact of nanoparticles on the lung, particularly of substances known to cause disease, should undergo investigation. Research is needed into these impacts as well as the development of instruments that measure nanoparticles in a mine's environment.

3.1.2 Eliminate Silicosis and Other Diseases Related to Silica Exposure.

An occupational respiratory disease of hardrock miners is silicosis. Exposure to silica also is associated with lung cancer, COPD, kidney disease, and some autoimmune disorders. The use of water sprays on drills for dust control and environmental cabs on the jumbo drills and other mining equipment to provide a clean air environment can reduce exposure to silica dust. There are still open questions about the causes and the occurrence of silicosis and other health effects in miners.

3.1.2a Establish the Prevalence of Silicosis in Metal and Nonmetal Miners.

The prevalence of silicosis in metal and nonmetal miners is unknown. There is no systematic surveillance system that estimates the prevalence of silicosis. It is difficult to evaluate prevention efforts without such a metric. Opportunities to prevent the progression of silicosis in its early stages are missed. Estimates should be developed of the incidence and prevalence of silicosis in metal and nonmetal miners. Because of the long latency between exposure and disease, surveillance of retirees for the prevalence of silicosis is important. . Investigate the use of biomarkers to assess silica exposure in miners.

3.1.2b Establish Whether There Is Excess Burden of Silica-Related Diseases Other Than Silicosis in Metal and Nonmetal Miners. Determine Their Sequence of Development and Exposure Concentration/Risk of Adverse Health Outcome.

It's unclear whether metal and nonmetal miners are susceptible to diseases related to crystalline silica exposure other than silicosis. Estimates of the incidence and prevalence of such diseases (e.g., COPD, lung cancer, autoimmune disorders) in metal and nonmetal miners are necessary. Because of the long latency between exposure and disease, consider surveillance of retirees .

Relevant Publications:

[Van Houtven et al. 2010]

3.1.2c Create Accurate and Reliable Silica Exposure Monitoring Systems to Reduce The Incidence of Silicosis.

Work that has been completed for monitoring coal dust needs to be performed for silica dusts. The CPDM could be used as a real-time monitor for silica-containing dusts, and with the knowledge of the dust silica content it could be used to monitor exposure to silica. Alternatively, new technology to measure directly respirable crystalline silica in real time would be highly desirable. This exposure information could be used to focus on dust control methods. Prevention strategies, including the use of technology to prevent exposures and worker isolation, would be helped if there were silica-exposure monitoring systems for mining workplaces.

Relevant Publications:

[Harb et al. 2021]

3.1.3 Eliminate the Incidence of Asbestosis, Mesothelioma, and Related Diseases Such As Talcosis in Mining.

While asbestos is no longer mined in the USA, mineral products such as vermiculite, talc, marble, dolomite, volcanic ash, dimension stone, roadstone, and clays continue to be mined and quarried. These products can contain; asbestos; fibrous serpentine and amphibole minerals not included as asbestos; cleavage fragments of serpentine and amphibole minerals; or other elongate mineral particles (e.g., mordenite, erionite, and palygorskite). In addition, fibrous minerals and elongate cleavage fragments may occur in association with metallic minerals. Exposure to asbestos also may occur as a result of other activities such as vehicle maintenance and use of asbestos for electrical insulation. The research that is needed to investigate the potential hazards posed by various elongate mineral particles and to reduce the risks of possible disease in these situations has been summarized in the NIOSH Current Intelligence Bulletin 62: Asbestos Fibers and Other Elongate Mineral Particles: State of the Science and Roadmap for Research. In addition, population-based surveillance of mesothelioma, considering geographical areas where exposure may be an issue, should continue. In this surveillance, the acquisition of job and industry information about mesothelioma cases is essential in order to identify occupational risk groups.

Talcosis is a respiratory disease that can occur due to exposures to talc dust. Talc dust can be especially difficult to control since is it hydrophobic. Therefore, the use of water sprays for talc dust control would not be feasible. Research should occur to determine the prevalence of talcosis in the mining industry and to develop feasible methods to control talc dust.

Relevant Publications:

[Asgharian et al. 2018; Ribak and Ribak 2008; Schmitz 2017; Gamble and Gibbs 2008; Ilgren, Ramirez, et al. 2012; Ilgren, Van Orden, et al. 2012; NIOSH 2011a]

3.1.4 Reduce Diesel Particulate Matter (DPM) Exposure in Mines.

With a continuing regulatory effort to reduce DPM exposure, this research is important and should continue. For example, operators will seek the most cost-effective means for compliance with the 160 $\mu g/m^3$ total carbon standard. At present, compliance is met with good maintenance, ventilation, the use of biodiesel fuel, and the replacement of diesel equipment with battery-powered equipment. However, research is necessary to determine the biological responses to biodiesel or fuel additives such as Cerium. Field observations suggest that there is less emphasis on the use of filters of various types. Ventilation for dilution of DPM concentrations below the allowable threshold is most important. Eventually, EPA Tier 4 off-highway vehicles will be available for surface mines and their engines will be available for underground vehicles. These will have installed filters. As they become available and old diesel equipment is phased out in mines, the Tier 4 vehicles will become more commonplace. Despite the improvement that should result from equipment substitution, there are research sub-objectives that define work needed on the issue of DPM and health.

Relevant Publications:

[Gillies and Wu 2012; McCullough et al. 2015; Volkwein et al. 2017; Zhang et al. 2019]

3.1.4a Clarify the Influence of Carbon Interferences on Accurate DPM Determinations When Using NIOSH Method 5040.

Although the regulations and practices for control of DPM in underground coal mines are not too controversial, a controversy persists over the Permissible Exposure Limit (PEL) and best implementation for controls for DPM in underground metal and nonmetal (M/NM) mines. At present, the majority of underground M/NM mines are complying comfortably with the 200 $\mu g/m^3$ DPM (160 $\mu g/m^3$ total carbon) standard; however, some mines are not. It appears that the controversy persists over carbon interferences with the accurate determination of DPM. More research is needed to clarify the influence of carbon interferences on accurate DPM determinations when using NIOSH Method 5040. Also, a cost-benefit study on the use of different combinations of control technologies in maintaining DPM concentrations comfortably below the standard would prove useful.

3.1.4b Survey the Implementation of DPM Control Technologies in Metal and Nonmetal Mines to Determine Current Levels of DPM and The Percent Reduction From Past Levels.

A study to determine the level of implementation of new control technologies for DPM, including the introduction of Tier 4 vehicles, and their impact on miner health would be useful. This survey of technologies being used and the results of the implementations which demonstrate the level of DPM and potential percent reduction of DPM when using those technologies can be used to determine future research directions in DPM reduction.

3.1.4c Determine the Effect of Biodiesel, Cerium Oxide Additives and Filters on Exhaust Characteristics and Human Toxicity.

Preliminary data suggest that the mix of contaminants in engine exhaust changes with substitution of biodiesel. Biodiesel usage can modify particle size distribution and aldehyde generation. In addition, nanoparticle counts may increase with the use of exhaust filters and certain fuel additives. The nature of these exposures of nanoparticles and their associated health effects should be investigated.

3.1.4d Characterize the Impact of Improved Engine Pollution-Control Systems on Workers.

As diesel engines are modified using pollution control systems, investigations characterizing the emissions from these engines should be completed. An unwanted side effect of pollution control systems may be the creation of unwanted emission products or of emission particulates that are finer, hence more reactive, than before.

3.1.5 Eliminate Lung Cancer from Uranium Mining.

An increased global interest in generating electricity from nuclear sources means that there may be a concomitant increase in uranium mining. There may be a future need for research to study the control of radon gas and to eliminate lung cancer from potential future uranium mining.

3.1.5a Determine the Extent to Which in-Mine Radon Exposures Cause Lung Disease.

With exposure to the radioactive decay products of radon gas comes the potential for lung cancer. We need to apply contemporary exposure assessment methods, including real-time methods, for a more sophisticated understanding of exposure to radionuclides in the radon and thoron decay series in mines and the associated risk of lung cancer in order to develop preventive strategies.

3.1.5b Improve Ventilation Practices and Controls Needed to Protect Miners from Radon Gas.

Ventilation research and dissemination of current best practices are needed to devise improved preventive technologies in the underground uranium mine. This would include studying the control of radon gas to inform new mine operators on best practices to control radon exposures of miners.

3.1.5c Determine Whether Uranium Surface Miners Are at Risk from Radon Gas.

Industrial hygiene research is needed to see if uranium surface miners are at risk from radon gas. If they are found to be at risk, a new sub-objective for their protection will need to be written.

3.1.5d Consider Undertaking an Updated Risk Assessment to Assess the Impact of Radon and Its Progeny on Miners.

The limit for radon exposure (30 CFR 57.5037 *et seq*) was first promulgated in 1973 and was amended in 2006. Mixed exposures involving alpha radiation, diesel exhaust, and respirable dusts should be investigated. Improved monitoring devices for alpha radiation may prove to be useful.

3.1.6 Identify, Reduce, or Eliminate Hazards from Airborne Chemicals Found in The Mining Workplace.

3.1.6a Characterize the Impact of Airborne Oil Aerosols Used in The Lubrication of Pneumatic Drills and Hand-Held Equipment.

There are concerns about the impact of fine oil aerosols used in the lubrication of pneumatic hand-held equipment, such as jack-leg and sinker drills, in confined underground operating environments. Studies are needed to determine the toxicity of rock drill oil, the dose-response relationship, and potential contribution to disease. Based on research on machinists exposed to metal working-fluid, potential health effects include chronic bronchitis, emphysema, asthma, and hypersensitivity pneumonitis.

Relevant Publications:

[Jaakkola et al. 2009; Godderis et al. 2008; Bracker et al. 2003]

3.1.6b Determine If Fugitive Dust Liberated from The Wear of Mechanical Contact Tools and Equipment wear Surfaces Represents a Health Concern.

Numerous new alloys, crystalline and composite materials, and coatings are being used in the fabrication of mechanical contact tools, such as bits, ripper tips, and disc cutters, and wear surfaces, such as haul truck beds and the buckets of excavators. In most cases, little consideration or analysis has been devoted to assessing the possible health implications associated with fugitive dust created as a consequence of material wear. A number of physical metallurgists have raised concerns given the physical characteristics and chemical composition of some of these materials. Research into potential harmful metallogenic species such as manganese, associated with engine wear, that are found in DPM is related to this objective.

3.1.6c Determine the Toxicity and Respiratory Health Effects of Welding Fumes.

The toxicity of welding fumes is not completely understood, and neither is exposure in the mining environment, where pulmonary and systemic (cardiovascular, neural, and immune) effects should be studied. This is of particular concern in confined environments associated with activities like maintenance/repair, construction, and/or mobilization/demobilization of equipment, facilities, and infrastructure. In addition, the relative toxicity of fumes generated by different welding processes and types of electrodes and base materials should be determined. . .

Relevant Publications:

[McIlwain and Neumeier 1987; Monaghan 2010; Wang et al. 1999]

3.1.6d Determine If There Are Health Effects from Blasting Fumes.

The gaseous products of blasting are normally dissipated in surface mining. In underground mining, the gaseous products may be confined in high concentrations inside the underground environment. In addition, blasting gases can also be confined in the muck piles generated through activities such as underground drift development and stoping. In these situations, the muck degasses over time and can contribute to exposures in workers not assigned to production areas. These blasting gases can vary as a function of the specific explosive products being used and the operating conditions of the blast round (e.g., oxygen balance, hole diameter, presence of water, etc.). In most applications, these gases include very high but short-lived concentrations of oxides of nitrogen (NOx), which are known irritants that can create pulmonary inflammation and edema with acute exposure, as well as loss of lung function after long-term exposure, carbon monoxide, which is an asphyxiate, and respirable and nonrespirable dusts, which may contain silica. Chronic disease outcomes associated with worker exposure to blasting gases and other constituents are poorly reflected in the MSHA accident/illness database. As such, research is needed to assess the chronic, as well as acute, impact of these fumes on miners.

Relevant Publications:

[Bakke et al. 2004; Bakke et al. 2001; Bahrami et al. 2019; International Society of Explosives Engineers 2011]

3.1.6e Determine Whether By-Products of Blasting at Mining Operations, Including Coal Dust, Gases, Fumes, and Residual Explosive Compounds, Represent a Health Risk to The General Public.

From an environmental perspective, research is needed to determine if blasting by-products and gases generated at mining operations represent a health risk to the general public and surrounding communities. Fugitive blasting gases are routinely liberated after large surface blasts and through ventilation shafts in underground mining, particularly if water is present or the oxygen balance of explosive detonation is poor. Under certain atmospheric conditions, gas clouds can form and travel large distances before dissipating. New formulations of explosives have additives and intensifiers that may create toxic post-blast contaminants, and they should be studied for their impact on humans. In addition, most mining applications use water-soluble blasting agents that have the potential to degrade and enter surface waters and subsurface aquifers used for municipal and agricultural purposes. Research is needed to quantify these potential hazards.

3.1.6f Research the Health Risks to Mechanics Associated with the Removal and Exchange of Welded Wear Plates and Liners.

The removal of wear plates and liners from mobile and fixed equipment exposes mechanics and other personnel responsible for repair and maintenance to a host of different chemical and dust exposures. These exposures are associated with the removal and installation procedures for replacing wear plates and liners. They include welding, air-arc cutting, etc. and can be dependent upon the wear materials that are being replaced. The impact of this activity on worker health needs to be studied, while alternative methods of removal and replacement need to be devised.

3.1.6g Develop Improved Mobile Equipment Cabins to Protect Operators from Airborne Particulates and Gases.

Data show a continued overexposure of miners to coal and silica dust, as well as high temperature environments that have the potential to result in heat stress. While the implementation of engineered cabins has demonstrated a tremendous potential in facilitating disease prevention and improving overall safety, research is necessary to overcome challenges associated with limited visibility and operator awareness of environmental indicators of potential hazards (e.g., air blasts, sound/noise, smells, and changes in ventilation). (See 3.2.4 Ensure Sufficient Visual and Aural Feedback for Safe Operation of Equipment With Improved Cabins or Other Forms of Tele-Operation.)

Relevant Publications:

[Morin et al. 2017; NIOSH 2018]

3.1.6h Determine the Full Suite of Chemicals Used in Mills, Concentrators, and Preparation Plants and Improve Methods to Communicate Chemical Impacts on Worker Health and Safety.

Information on all chemicals used in mining, processing facilities, and preparation plants should be evaluated. The methods to control worker chemical exposures can then be determined based on safety data sheet (SDS) information or possibly the European Union REACH (Registration, Evaluation, Authorisation, and Restriction of Chemicals) data. The evaluation would be used to develop improved communication of chemical hazards to miners along with methods of prevention of exposure.

A survey should be completed of wastes generated from the mine site, processing facility, and preparation plant. For example, this survey could include the effect of wastes incinerated in cement plant kilns. These waste streams should be characterized for their toxicity to miners, and controls developed to prevent exposure.

Relevant Publications:

[NIOSH 2005; Scott et al. 2009]

3.1.6i Determine If There Are Harmful Components in Rock Dust.

Rock dust (ground lime or limestone) has been used for decades to reduce or eliminate the threat of explosions in coal mines. Lately, additives have been used to reduce caking and increase the ease of application of rock dust. Research is needed to determine the impact of the dust itself and of the additives on human health.

Relevant Publications:

[Harris et al. 2017; Huang et al. 2015; Morin et al. 2017; Sapko et al. 1991]

3.1.7 Use Surface Chemistry and Toxicity Research to Better Characterize the Human Toxicity of Mine Dusts.

The surface reactivity of a dust may have a great deal of impact on its disease causation. Research is needed to determine if variation in surface reactivity correlates to toxicity or the incidence of disease in humans. If it does, then research should be undertaken into the Reactivity of the various dusts that could reasonably be found in mines. For example, research is currently being conducted on the impact of nano-sized particles on humans, and findings from this research should be transferred to mining.

3.1.8 Refine Recommendations for Personal Protective Equipment Related to Atmospheric Control: Respirators, Powered Air Purifying Respirator (PAPR), Etc.

3.1.8a Investigate the Application of PAPR or Face Masks and Their Compliance with the New Respirable Dust Standards.

If a 1.0 mg/m^3 respirable coal mine dust standard is implemented by MSHA, research may be needed to determine the appropriate role for positive-pressure airstream helmets and face masks. The research should delineate the advantages and disadvantages of this technology as well as the feasibility of its adoption.

It is recognized that the airstream helmet used in underground coal mining has been discontinued due to its inability to maintain MSHA approval for intrinsic safety. Investigate and/or develop a new technologically advanced airstream helmet for use in underground coal mining.

3.1.8b Study If Respirators Should Be Used in Areas That Are Not in Compliance.

Section 202h of the Federal Mine Safety and Health Act of 1977 requires that approved respiratory equipment be made available to all persons whenever respirable dust concentrations in excess of the respirable dust standard occur. However, these respirators are not to be used as a substitute for environmental control measures. In settings where specific overexposure conditions occur, should respirator use be mandated until engineering controls can remedy the exposure? Research is needed to make recommendations.

3.1.9 Examine Potential Toxicities of Other Materials in Mines

Metallic ores often contain arsenic, mercury, and other heavy metals. Research is needed to determine if concentrations of these elements reach current Threshold Limit Values (TLV®) established by the ACGIH.

Little is known about the health impacts of long-term exposures to many nonmetallic minerals, such as salt, potash, trona, phosphates, lithium, and rare-earth oxides. Research can help to identify which among these have health impacts for miners and may be able to initiate research to develop controls to prevent those health impacts.

3.1.10 Study the Impact of Nonmine-Related Disease Coupled with Known Mine-Related Disease Risk on The Health of a Miner.

The recent pandemic raises multiple questions about protection of miners from more than one disease at a time; this is often called comorbidity.

Relevant Publications:

[Attfield et al. 2007; Petsonk and Parker 2008; Jalloul and Banks 2007]

3.1.10a Infectious Disease Control and Prevention Protocols for Safe Operating Conditions in Mining.

Prevention techniques appropriate to mining need to be developed for infectious diseases with high transmission rates: social distancing, face masks, cleaning surfaces, sanitizers, etc. For example, because exhalations are trapped in an underground ventilation stream, social distancing guidelines specific to mining are needed. At the same time, outbreaks need to be identified and traced to their source, which requires good identification of work-place, in-mine contacts and contacts external to the mine. The nationwide movement of miners while transferring jobs, which is common, should be investigated, including a method to track new miners who may originate from other industries or geographic regions. This sub-objective relates to the surveillance issues in 8.3 Trends and Data Gaps in Miners' Health.

3.1.10b Comorbidity of Other Diseases.

A study of the impact of CWP on other lung diseases will help to identify prevention protocols for workers with COPD, tuberculosis, or early-stage cancers. Similarly, the risk of CWP for those with other lung diseases will help to set appropriate exposure levels for these workers.

3.1.11 Consider the Ambient in-Mine Conditions as a Whole.

Study the benefit of a complete environmental assessment in a mine to identify all causal factors that might be in the mine atmosphere.

Autonomous airborne vehicles, drones, for use in surface operations are well developed. More research for use in underground or GPS-denied environments should be conducted. If drones can be fitted with atmospheric monitors, they may be able to produce ambient surveys rapidly.

Relevant Publications:

[Fan and Liu 2021; Kurth and Casey 2020; Kurth et al. 2020; Laney and Weissman 2014; Pan et al. 2021; Shumate et al. 2017; Yucesoy et al. 2015; Zhang et al. 2021]

3.2 Reduce Noise-Induced Hearing Loss in the Mining Workplace

Noise exposure is prevalent throughout the mining industry. It is a significant topic as one out of every four mine workers has a severe hearing loss (https://www.cdc.gov/niosh/mining/topics/HearingLossPreventionOverview.html). This statistic progresses to four out of five mine workers having a hearing impairment by the time they reach their mid-60s retirement age. The following are topic areas for hearing-loss research in the mining industry.

Relevant Publications:

[Azman et al. 2010; Byrne 2000; NIOSH 2021b]

3.2.1 Identify and Determine Methods for Reducing Noise Exposures from Existing and Emerging Technologies And Processes.

A review of the current incidences of noncompliance with 30 CFR Part 62.140 for those exposures that have been determined to be technologically infeasible (P-code given by MSHA) should lead to research and/or development of new noise-control technology methods.

3.2.2 Determine the Benefit of Reducing the Threshold of Noise Exposures for Action from 85 to 80 Dba.

The medical opinion in the Mining Sector Council is that nothing may be done to reduce the loss of hearing until the threshold for action is reduced from 85 to 80 dBA. Research is needed into the consequences of this action including the likelihood of compliance.

3.2.3 If the Threshold for Action is Reduced from 85 to 80 Dba, Conduct Research to Redesign or Repower Much of The Underground Mining Machinery.

Since achieving this reduced standard implies a quantum reduction in sound-pressure levels, research will be needed to redesign or repower much of the underground mining machinery. Substitutes for pneumatic machinery is particularly relevant to the protection of hearing.

3.2.4 Ensure Sufficient Visual and Aural Feedback for Safe Operation of Equipment With Improved Cabins or Other Forms of Tele-Operation.

In creating technologies that remove miners from noisy environments, such as using isolation cabins, research will be needed to ensure sufficient visual and aural feedback for safe operation. This is particularly true if the cabins are armored to protect operators from falling objects or from roll-over accidents.

3.2.5 Develop Personal Hearing Protectors That Inherently Work Well No Matter How They Are Donned.

Individual hearing protectors can be effective if they are fitted and used properly. Research may be needed to obtain personal hearing protectors that work well inherently no matter how casually or carefully donned.

Develop in concert hearing protection that works well with eyeglasses. Donning an earmuff over eyeglasses can leave a gap that reduces the effectiveness of the hearing protection. A better design of muff could prevent this loss of effectiveness.

3.3 Reduce Toxic Exposures of a Nonrespiratory Nature (Dermal and Ingestion)

Past experience has shown that a variety of skin-related diseases stem from direct and indirect contact (through saturated clothing) of chemical contaminants, naturally occurring minerals, and mine water.

3.3.1 Determine Whether There Are Unknown Substances in The Mine Environment That Can Cause Diseases and, If So, Devise Preventive Measures.

Investigatory research is needed to see if there are other substances in the mine environment that can cause diseases and, if there are, to devise methods of prevention.

3.3.2 Determine the Hazards That May Be Associated with The Bacteria Used In Biological Reactors.

The development of biological processes to pretreat ores for leaching and biological reactors to treat acid-rock drainage means that workers will be exposed to the various strains of bacteria that oxidize iron or sulfur. Research should be undertaken to determine the hazards that may be associated with these bacteria.

3.3.3 Investigate Prolonged Exposure to the Chemicals Used in Mineral Beneficiation Plants to Determine If There Are Exposures Not Discussed In The SDS.

Any number of exotic and common chemicals are used in solvent-extraction/electro-winning (SX/EW) mills. While Safety Data Sheets (SDS) exist for them, research into prolonged exposure is needed to see if there is a threshold for disease not discussed in the data sheets. Comparison could be made with the European Union REACH program (Registration, Evaluation, Authorisation, and Restriction of Chemical substances).

3.3.4 Identify Methods to Safely Use and Dispose Of Cyanide.

Cyanide used in gold mills is a topic of major concern for both environmental and occupational health. Additional research into the environmental and occupational effects of cyanide and its safe and responsible use and disposal should be conducted to identify any new risk management issues associated with cyanide use.

Relevant Publications:

[Petrov and Petrov 2012; Petrov 2012]

3.3.5 Investigate the Impact of Cold Temperature on Mining Chemicals to Extend the Range of SDS Information to Polar and Sub-Polar Regions.

In arctic cold temperatures, diesel fuels and hydraulic fluids can be harmful to the skin. Research on the impact of cold temperatures on mining chemicals is needed to extend the range of SDS information to polar and sub-polar regions.

3.4 Reduce Stress-based Diseases

Much of the occupational stress-related research underway today is extremely significant in mining.

3.4.1 Investigate the Implications of an Aging Workforce on the Likelihood of Developing MSD.

One concern in this domain is for the impact of MSD on an aging workforce. Moving the social security retirement age to 70 may have a great impact on the incidence of this disease if prevention methods are not found. Repetitive stresses from activities such as roof bolting, cleaning belt lines, etc. are likely to lead to MSD, and these activities should be studied for a means to reduce MSD.

3.4.2 Investigate Thermal Effects in Mining: Heat in Deep Mines; Cold in Arctic Mines.

In the realm of physical stressors such as heat and cold, much research needs to be done. Mining is moving to more extreme environments and methods of cooling or warming miners, and as the case may be, these thermal effects need to be evaluated against potential health and safety hazards. This subobjective is related to 6.10 Improve the Health and Safety of Mining in Arctic, Very Hot, and other High-Stress Regions.

3.4.2a Determine the Extent of Miner Exposures and Related Accidents/Illnesses in Arctic and Other Cold-Area (Polar and Sub-Polar) Mines.

A study to determine the extent of miner exposures and related accidents/illnesses in arctic and other cold-area (polar and sub-polar) mines would be useful. The study could also delineate best practices in dealing with cold weather.

3.4.2b Determine the Extent of Miner Exposures and Related Accidents/Illnesses Caused by Heat in Large Southwest Open-Pit Mines and in Deep Underground Mines.

Heat exposure issues exist in large open-pit mines in the southwestern U.S. A study is needed to determine whether heat poses an exposure problem, and, if so, what controls are used to protect workers from heat exposure. Although, there are very few deep mines in the U.S., heat stress is still a topic deserving of research. The mines in the Silver Valley (Idaho), approximately 5,000- to 6,000-ft deep, appear to have adequate ventilation at present. As they go deeper, issues of heat and its remediation will need to be researched. Rock and water temperatures at the bottom of Resolution Copper's No. 10 Shaft (6,943 ft. depth) in Arizona reach 180 degrees F.

From studies completed on heat and its impact on the human body, researchers need to provide recommendations for permissible work periods in zones of higher temperatures.

Relevant Publications:

[Ashley et al. 2020; Hardcastle and Allen 2010; Kocsis and Sunkpal 2017]

3.4.2c Develop Methods of Cooling or Warming Miners to Prevent Thermal Stress In The Workplace.

For exposures to cold, extra-thick clothing is used to keep a worker warm, but it also reduces mobility. For exposures to heat, low-cost and environmentally friendly methods to cool ventilating air are needed. The isolation of workers in atmospherically controlled cabins may be needed, but then the workers will need to have aural and visual sensors provided as substitutes for their own ears and eyes. (see 3.1.6g Develop Improved Mobile Equipment Cabins to Protect Operators from Airborne Particulates and Gases., 3.2.4 Ensure Sufficient Visual and Aural Feedback for Safe Operation of Equipment With Improved Cabins or Other Forms of Tele-Operation., and 6.5.5 Develop Improved Mobile Equipment Cabins to Protect Operators from Airborne Particulates and Gases.). Research should be conducted to develop durable and comfortable cooling suits that can be worn for an entire shift for workers, such as in maintenance and surveying, who need to enter a very hot mine atmosphere.

3.4.3 Investigate the Human Willingness to Take Risks to Create Effective Training Programs That Reduce Risky Behavior.

Mental stress arising from the nature of potentially hazardous tasks performed in mining—roof control, blasting, moving machinery through confined spaces, etc.—has the potential to dull alertness or to cause miners to take risks. Further research into the human willingness to take these risks may be an important step in the creation of effective training programs to prevent these behaviors.

3.4.3a Do Miners Indulge in Risky Behavior?

There is a sense that both newly hired miners and those approaching their career's end engage in risky behavior. There have been suppositions made that new miners may engage in unsafe behavior due to their lack of experience, and that long-tenured experienced miners may engage in unsafe behavior due to their overconfidence with mining situations. Studies should be conducted to determine the causes of these unsafe behaviors. Also, current new miner training and annual retraining programs should be examined to see if they effectively address workers' sense of invulnerability to risky behavior. isk aversion should be integral to a mine's overall health program for miners.

3.4.3b Risk Assessment Has Been Studied in Other Applications.

The broad science of risk assessment should be reviewed to see if elements of it can apply to mining.

3.4.4 Redesign the Workplace or the Work Tasks to Minimize Risk Taking.

Repetitive performance of tasks dulls alertness. Research into the psychological factors of human attention span and willingness to assume risk may help in the redesign of the workplace or of the work tasks to minimize risk taking. This topic is explored further in 5.1 Improve Safety Culture in the Mining Industry..

3.4.5 Study the Impact of Longer Shifts or Variable-Length Work Weeks.

The safety and health impacts that arise in variations of the working shift or of the work week are uncertain, and therefore, research should be undertaken on these issues. These issues include longer workdays, for example, four days of ten hours each or three days of twelve hours each, as a substitute for the traditional eight-hour, five-day work week. We do not know if there are mental stresses, fatigue, and task overload associated with longer workdays nor do we know if there are disease impacts associated with longer exposures and shorter recovery periods.

Fatigue monitoring systems have improved greatly in the recent past. Their efficacy should be studied to determine how well they identify a tired miner and to determine whether such a miner shows symptoms of fatigue.

Extended work shifts also extend a miner’s exposure to respirable dusts and other chronic hazards (e.g., diesel particulate matter) over a short period of time, particularly if they work consecutive days, reducing the time available to clear retained particulate matter. Existing threshold limit values all assume an eight-hour shift. With longer shifts, exposure limits need to be examined in light of extended exposure and shorter recovery periods.

Relevant Publications:

[NIOSH 2004a; Mabbott and Lloyd 2005]

3.4.6 Study the Implications of Fly-In/Fly-Out Arrangements.

In fly-in, fly-out arrangements, workers go for extended work periods followed by a number of days away from work. The implications of these arrangements for both safety and health need to be studied.

Relevant Publications:

[Kirsch et al. 2013]

3.5 Improve Behavior That Impacts Health

Behavioral traits demonstrated on and off the job and not necessarily under the direct supervision of management may have substantial impacts on worker safety and health. In this section, we discuss the health impacts of harmful behavioral traits; in Objective 5 we discuss similar concerns for safety. Research is needed to translate national healthiness campaigns for miners.

Relevant Publications:

[Kirsch et al. 2013; Shandro et al. 2011]

3.5.1 Promote Wellness.

3.5.1a Tailor Anti-Smoking Campaigns To Miners.

The number one problem associated with wellness is smoking. Anti-smoking campaigns need to be tailored to miners to help them to understand that smoking, even if only done outside of the workplace, substantially alters the threshold for the onset of respiratory diseases.

3.5.1b Investigate the Impact of Effective Educational Programs on Chronic Diseasein the Mining Communities.

. Chronic diseases such as diabetes, cardiovascular problems, stroke, and heart attack can be particularly troublesome to workers undergoing the physical stress of mining. Research into effective educational programs is needed.

3.5.1c Investigate Distracting Elements of Behavior: Fatigue, Anxiety, Anticipation of a Vacation or Break, or Return from an Extended Lay-Off.

The issues of worker attitudes and ways to reduce risky behavior while enhancing safe work practices should be examined. Personal safety can be affected by fatigue, anxiety, anticipation of a vacation or break, or return from an extended lay-off, and it is suggested that research into this element of behavior be undertaken.

3.5.2 Reduce Substance Use Disorders.

Whether of controlled (illicit drugs) or of noncontrolled substances such as alcohol or prescription drugs, the presence of a worker under their influence is a risk to themselvesand to surrounding workers. There is documented evidence that that substance use disorders are a potential problem in some mining regions.

Relevant Publications:

[Bush and Lipari 2015]

3.5.2a Develop Education Programs to Reduce Substance Use Disorders.

Research is needed into the education methods and materials needed to reduce substance use/misuse in the mining demography.

3.5.2b With Respect to Substance Use disorders, Research From Other VenuesMay Need To Be Transferred Into Mining.

Since some of these substances are addictive, research from other venues may need to be transferred into the mining sector so as to provide support to mine workers for treatment and recovery.

3.5.2c Assess the Performance of Newly Developed Educational Programs.

Rsearch is also needed to assess the outcomes of these educational programs.

3.5.2d Develop Rapid Tests forImpairment.

Mine managers will need to make rapid decisions about workers' fitness for work, particularly in light of the increasing legality of cannabis use. Rapid, noninvasive tests will be needed. The development of such tests for other purposes, such as the fitness to drive a vehicle, should be studied.

3.6 Correlate Dust-Exposure Levels with Dust-Control Techniques

Conduct research to correlate modern mine-specific dust control techniques and operating parameters with dust-exposure levels during production using the CPDM. Exposures could then be extrapolated based on shift production and operating parameters. Focus on accurate predictive models going forward rather than reconstructing the past.

3.6.1 Correlate Respiratory Disease to Personal Dust Exposures.

Continue research on the correlation of respiratory disease to personal exposures to dust or toxic substances. Develop dose-response models for predicting occurrences of respiratory illness based upon personal exposure data.

3.6.2 Predictive Models.

Continue research to develop improved predictive models. Examine earlier predictive models for respiratory disease to evaluate their accuracy.

3.7 Diesel Particulates

These additional subobjectives, while related to 3.1.4 Reduce Diesel Particulate Matter (DPM) Exposure in Mines., recommend evaluating diesel particulate impact on wholistic miner health and safety.

3.7.1 Diesel and Disease.

Researchers should compare the incidence of respiratory diseases, including cancer, against reports of diesel particulate levels in individual mines.

3.7.2 Alternative Fuels.

Research should be undertaken to evaluate the implications of alternative fuels on miner safety and health.

3.7.3 Standards Used in Other Countries

Researchers working with diesel particulates should review the current diesel particulate standard in the U.S. against values used in other countries and investigate the effectiveness of those other diesel particulate standards in preventing respiratory illness/cancer or other such occupational diseases.

3.8 Total Worker Health

Consider research strategies that provide methods for improvements in total worker health.

3.9 Timber-cutting and grubbing safety.

The cutting (trimming) of timbers for underground roof support and grubbing activities at surface mines can involve the use of powered saws as well as larger timber-handling equipment. Because the use of this equipment requires skills best obtained through good training, safety records should be examined to determine the extent, if any, of injuries caused by wood-cutting and handling equipment. If the incidence is significant, then training protocols should be examined, amended, or created to prevent injuries. Further information on timber-cutting and grubbing-safety research topics can be found in the "NIOSH National Agriculture, Forestry, and Fishing Agenda," particularly strategic goals 6 and 7 and Appendix 1. The Agenda can be found at:
http://www.cdc.gov/niosh/nora/comment/agendas/AgForFish/.

3.10 Battery Charging Stations

With the increased use of battery-powered equipment and newer types of batteries, such as lithium-ion, in both underground coal and noncoal mines, there is a need to investigate potential health and safety risks associated with battery charging and maintenance. These risks could include accidents from moving heavy items, chemical exposures, unwanted electric discharges, fires and explosions, and disease caused by gases released during charging.

OBJECTIVE 4: IMPROVE VENTILATION SYSTEMS AND ATMOSPHERIC CONTROL IN MINES

4.1 Improve Air Quality and Quantity in Mines: The Threshold Values for Safe and Healthy Mining

MSHA's standards on air quality and quantity are explicit for most mine gases and aerosols, regardless of mine type and commodity. Standards for exposure thresholds for respirable asbestos, crystalline silica (alpha quartz), coal dust, and other constituents can be found in the Code of Federal Regulations published by the U.S. Government Printing Office. This sub-objective complements OBJECTIVE 3: PREVENT ILLNESS FROM OCCUPATIONAL HEALTH HAZARDS.

4.1.1 Determine the Best Mix of Cost-Effective and Efficient Ventilation Control Technologies for Each Regulated Pollutant to Comply With Standards.

It is clear that revised standards on permissible exposure levels (PEL) would impact both the quality and quantity of air in mines. In general, supplying more air will reduce the concentration of air pollutants; increasing air quantity, however, may not be the most effective choice for reducing concentrations. Thus, research on the best control technologies for a given pollutant is needed to achieve compliance in a cost-effective and efficient way.

4.1.2 Review Mine Ventilation Plans to Determine Fan Applications, Single Versus Multiple, the Level of Air Leakage Found in The Different Fan Applications, and the Impact of Various Practices on Maintaining Effective Mine Ventilation.

There seems to be fewer shafts, but with larger-diameter boreholes, used for mine ventilation today as compared to past practices. This practice leads to longer escape routes to mine exits during an emergency and larger amounts of air leakage throughout the mine. It is not uncommon now to have main ventilation fans three or more miles from active workings. The extent of the use of multiple fans versus one fan, the level of air leakage in the different applications, the use of variable frequency drives with fans, and the impact of various practices on maintaining effective mine ventilation need some study. A review to determine what the current state of fan usage and what are the most cost-effective (capital and operating costs over the mine life) practices would be useful. These practices will likely vary by size of company, mine areal extent, seam thickness, and other factors. For example, more frequent use of multiple fans is likely to be more common in large companies, while there is more likely to be only one fan used in small mines; the practice in medium to somewhat large mines is less certain.

4.2 Reduce Hazards Associated with Explosive Gases and Atmospheres

In the recent coal mine disaster at Upper Big Branch in West Virginia (2010), a possible methane inundation from a lower reservoir was a concern in early phases of the investigation. Also, in 2001, a large emission of gas from a stratum above the coal seam released through a roof fall was involved in a disaster at Jim Walters Resources Number 5 Mine in Alabama. Consequently, we are recommending research into sudden gas releases.

Relevant Publications:

[Danko 2021; Danko et al. 2019; Hope and Rico 2019; Moridi et al. 2018; Pinedo and Espinoza 2019]

4.2.1 Study Available Histories of Large Gas Liberations Coming from Strata Above or Below The Production Seam to Determine the Potential Extent of The Problem.

Histories of large gas liberations may be studied to reveal the potential extent of the problem in future mining, particularly as mines become deeper.

Relevant Publications:

[Karacan and Diamond 2006; Krog et al. 2006; Ulery 2006]

4.2.2 Investigate the Potential for De-Gasification Systems to Control Large Methane Liberations.

Because deeper and more complex mines are likely to have higher gas concentrations, research is needed on improved de-gasification systems. The goal of this research would be application guidance on when and to what extent de-gasification systems should be used to control strata gas.

Relevant Publication:

[Thakur 2006]

4.2.3 Determine When Nitrogen or CO_2 Inertization Systems Could Be Most Effectively Implemented in Gassy, Abandoned Areas of a Mine.

Because sudden barometric changes can result in the emission of large volumes of methane-containing air from mined-out sections of an underground mine, there is increased interest in the use of nitrogen inertization in sealed gob areas in Eastern underground mines. It is recommended that this practice be studied for automation, costs-benefits analysis, and to determine if it will maintain long-term effectiveness.

Relevant Publications:

[Brune 2013; Brune et al. 2016; Marts et al. 2013; Saki et al. 2016]

4.2.4 Study Positive-Pressure Chambers as an Alternative to Inert Atmospheres for Controlling Methane Liberations.

An alternative to nitrogen inertization of entire sealed areas would be the use of positive-pressure chambers to eliminate in-gassing and out-gassing; a study is needed on which system would best control the problem and be the most cost effective.

4.2.5 Investigate the Effective Use of a Tube-Bundle System for Monitoring Nitrogen Inertization.

A complementary study on the most effective use of a tube-bundle system in association with a nitrogen-inertization system would be useful. Tube bundles provide a means to sample air in zones that are sealed to prevent entry by mine personnel. These tube bundle systems are used when the application of other AMS is not practical.

Relevant Publications:

[Forrester 2017; Watkinson 2015, 2016; Zipf Jr et al. 2013]

4.2.6 Investigate Ground Control Methods for Reducing the Likelihood of Spontaneous Combustion Events in Bleederless Systems Due to Exposure of Fresh Surfaces in The Roof, Rib, and Floor.

Movement of the roof, rib, and floor can result in cracking and fracturing of material that exposes fresh surfaces to oxygen. Exposing more fresh surfaces allows oxidation and could increase the likelihood of spontaneous combustion events. A study on methods of preventing exposure of fresh surfaces and outgassing with ground control techniques and their potential relation to spontaneous combustion would be useful. Literature reviews should be conducted on the possible connection between ground control and spontaneous combustion. Research is needed to determine if ground control techniques could be used to help prevent spontaneous combustion events in bleederless systems.

Relevant Publication:

[Smith et al. 1994]

4.3 Real-Time and Intelligent Monitoring and Control of Mine Operating Systems and Ventilation

AMS have become a significant area of interest in underground coal mining. While the regulations under the Code of Federal Regulations require that automatic fire sensor and warning device systems that use CO monitoring systems be installed along belt conveyors [30 CFR § 75.1103-4] , AMS systems are not required [30 CFR § 75.351]. An AMS is defined as a system that 1) continuously monitors methane at the section return [30 CFR § 75.323(d)(1)(ii)], 2) monitors intake air of battery charging stations for CO or smoke [30 CFR § 75.340(a)(1)(ii)], 3) monitors air in the belt entry when belt air is used to ventilate a section where mechanized equipment is to be used [30 CFR § 75.350(b)] , or monitors the air in each return for on-shift examination of CH_4 in each working section where coal production occurs [30 CFR § 75.362(f)] . Obtaining data from 235 underground coal mines, a survey was completed in 2018 by

NIOSH. It reported that there are 204 CO sensor systems for automatic fire detection systems along belt conveyors installed in underground mines, while there are only 33 AMS installed [Rowland et al. 2018] . Members of the mining sector council have recommended an expanded use of mine-wide monitoring systems or AMS that are based on the results of mine-specific risk assessments.

4.3.1 Study the Cost-Benefit Analysis of the Expanded Use of Mine-Wide AMS.

Prior research on mine-wide AMS and tube-bundle systems for monitoring air quality behind sealed areas under conditions of high risk (see 4.2.5 Investigate the Effective Use of a Tube-Bundle System for Monitoring Nitrogen Inertization.) should be assembled into a cost-benefit program for determining their applicability. The threshold of risk should also be determined by this effort.

4.3.2 Investigate the Survivability of Mine-Wide AMS, Including the Survival of Existing Components and Improving the Durability of New and Proposed Systems.

This subobjective has commonalities with Section 2.1 Improve Communications and Tracking Systems in Mines. The survivability of existing mine-wide AMS and the development of new, more durable and permissible systems are very important goals for monitoring the mine atmosphere, post-fire or post-explosion. Research is needed to estimate the period of survival for existing mine-wide monitoring systems during fires and explosions. This research can also be directed toward defining the vulnerabilities that reduce survival times. From this research, further work to develop permissible systems with improved survival characteristics can be undertaken.

4.3.3 Study the Rapid Adjustment of Ventilation in Response to Real-Time Monitoring.

With greater implementation of mine-wide AMS, real-time changes to mine ventilation become possible, so long as the regulatory limitations are followed. A study on what scenarios and conditions are appropriate for AMS-driven, real-time change of ventilation, i.e., ventilation on demand (VOD) is needed for all underground mines. A similar study for underground coal mines, however, would need to consider existing regulations for ventilation system stability. Such studies could benefit from cost-benefit analyses.

Relevant Publications:

[Tran-Valade and Allen 2013]

4.3.4 Investigate the Further Expansion of Mine-Wide Communications and Tracking Systems and AMS. Additionally, Other Mine System Components That Can Be Monitored Simultaneously Should Be Investigated.

Related to Objective 2.1.2 Develop Integrated Communication Systems and AMS Capable of Sensing and Relaying Information in Real Time About the Conditions Existing in The Mine, further expansion of mine-wide systems and AMS to include real-time monitoring of air velocity at strategic locations, dust concentrations at workplaces, and other ventilation-related parameters should be explored. The use of such strategic sensors could minimize risk to miners from potential harmful exposures to airborne hazards if the appropriate displays and read-outs are developed. The integration of AMS with overall mine-operation systems (communications and tracking) is important and should be studied. The goal is to have reliable information for real-time application and control.

Relevant Publications:

[Allen and Tran 2011]

4.3.5 Determine How Wireless-Based Sensor Technologies Can Be Implemented.

Wireless-based sensor technologies have many attractions for AMS in routine and emergency use. Research into the use of wireless sensors should parallel the development of wireless communication systems in underground mines.

Relevant Publications:

[NIOSH 2007b; Patri and Nimaje 2015; Buchan 2018]

4.4 Improve the Control of Chemicals and Reagents that May Enter the Working Atmosphere of a Mill or Preparation Plant

Research is needed into best practices for ventilating mills and preparation plants. These best practices should be based on achieving air quality that is below the thresholds for the different chemicals used in preparation. A survey of current practices for ventilating mills would provide a good basis for this research.

Relevant Publications:

[Natarajan and Sabari Prakasan 2013]

4.5 Improve the Performance of Stoppings, Seals, and Bulkheads

The Mine Safety Technology and Training Commission (http://www.nma.org/pdf/miner_workshops/msttc_presentation.pdf; website accessed on Dec. 1, 2021) recognized that worked-out areas were a persistent issue, especially concerning the detection of methane levels in and near sealed areas. An additional conclusion was to conduct research on improving the integrity of stoppings used to isolate emergency escapeways. This issue remains one that should be pursued with additional research.

4.5.1 Investigate and Develop Ways to Improve the Integrity of Stoppings Used to Isolate Emergency Escapeways.

A study is needed to delineate the best practices in constructing stoppings for the best possible integrity, particularly during a mine fire. At issue is the survivability of stoppings against fire and over-pressure (explosion). A survey to obtain good information on best practices for stopping construction may provide the basis for further research.

Relevant Publications:

[NIOSH 2002a, 2009]

4.5.2 Study the Extent and Conditions Under Which Monitoring of The Atmosphere Behind Sealed and Other Abandoned Areas Should Be Undertaken.

As noted earlier in this objective, there should be a study of the extent and conditions under which monitoring of the atmosphere behind sealed areas is needed. Improvements into the requirements of the Code of Federal Regulations, particularly Title 30, Chapter I, Subchapter O, Part 75, Subpart D, 75.336 on monitoring, should be studied. The recommended way to monitor the atmosphere behind sealed areas should be addressed. The extent to which monitoring is undertaken of the atmosphere at strategic locations in coal mine bleeder entries and other abandoned but unsealed areas should be studied as well.

Relevant Publications:

[30 CFR § 75.334; 30 CFR § 75.335; 30 CFR § 75.336; Juganda et al. 2017; Schatzel et al. 2019; NIOSH 2002a]

4.5.3 Determine the Variation of Methane Levels with Distance from The Longwall Face.

Research is needed to determine the variation of methane levels behind longwall shields at various distances into the gob. The extent to which changes in barometric pressure impact the movement of methane into and out of the active longwall gob should be determined as well. A similar study should be done on active gobs in continuous-mining, pillar-retreat sections.

Relevant Publications:

[Díaz et al. 2022; Strebinger et al. 2019; NIOSH 2008]

4.5.4 Study Bulkhead Construction Practices Considering Long-Term Stability and Influence of Impounded Mine Water on Surrounding Natural Materials.

Bulkheads (i.e., underground dams) are constructed in mines to impound groundwater or mine tailings from the processing plant. These structures are often built in sedimentary rock strata that can weaken in the presence of water. Grouting is typically proposed as a mitigative measure, but grout likely only fills cracks and does not change the potential for dispersive behavior of these rocks when they become saturated. Mitigating the potential failure modes of piping (i.e., internal erosion) and hydraulic fracturing need further research as well as methods to assess if the strata are at risk of these types of failures. A methodology to evaluate the size of pillars needed to prevent punching into soft/saturated floor and any mitigation strategies to prevent punching should be investigated.

4.5.5 Study and Develop Design Recommendations for Lower-Strength Cementitious Foam Materials Seal aAnd Bulkhead Construction.Cementious foam materials are known to be advantageous for their light weight, but they are low strength and easily subject to compression. Research is needed to investigate different strength tests to best predict their behavior under load.

4.6 Improve the Performance of Face Ventilation and Scrubbers

Recent NIOSH research specified best practices to control respirable dust generated during deep cuts in continuous mining sections. ; However, a follow-up research effort is needed to continue the work and to disseminate the research results broadly.

Relevant Publications:

[NIOSH 2011c, 2013, 2021a]

4.6.1 Investigate and Develop Methods to Back-Flush Scrubber Filters.

Research and development of methods to back-flush scrubber filters would be useful. One inquiry to NIOSH sought the integration into scrubbers of an ultrasonic anemometer that would monitor scrubber airflow. This innovation may form a research and development initiative that could be useful. The air-delivery capability of scrubbers has been compromised at times. Recent NIOSH research gives guidelines on best practices to maintain the air delivery of scrubbers; however, the information needs to be disseminated broadly through a translation project.

Relevant Publications:

[Cecala et al. 2016; Organiscak et al. 2016]

4.6.2 Delineate the Optimal Ventilation Parameters for Controlling Methane Migration from Longwall Gob Areas onto The Face.

If methane levels immediately behind longwall shields are elevated, then there is a partial pressure that could drive methane back onto the face. Research is needed to delineate the optimal ventilation parameters for control of methane migration to the face area.

Relevant Publication:

[Zheng and Tien 2009]

4.6.3 Identify the Optimal Ventilation Parameters to Maintain Compliance with the MINER Act.

Another significant research issue relative to face ventilation is the identification of optimal ventilation parameters for compliance with the MINER Act respirable dust standards. Questions that may need to be resolved are how do these parameters vary by type of mining, seam thickness, percent quartz in dust, etc.?

4.6.4 Study the Design of Face Ventilation and Filtration Systems for Ease of Filter Exchange and Maintenance.

NIOSH research has found that continuous miner operators can experience high silica levels, depending on the amount and type of rock cut, but bolter operators can often be exposed to higher levels. NIOSH looked at the use of disposable dust bags, a canopy air curtain, and mist drilling to control dust levels. This problem appears to be a maintenance issue, i.e. maintaining the vacuum system: dust box cleaned, filter checked and seated properly, pre-dump use, etc. Research into the design of systems for ease of maintenance should be continued.

Relevant Publications:

[Gupta et al. 2021; Kumar et al. 2020; Reed et al. 2022; Reed et al. 2020]

4.6.5 Disseminate Best Face-Ventilation Practices by Developing a Best Management Practices (BMP) Manual For Face Ventilation.

A comprehensive study to compare the dust control practices of highly compliant mines with those of troubled mines would help provide a broader dissemination of best practices. A corollary benefit of such a study would be to use MSHA data to target mines that need help to improve their dust control.

Relevant Publications:

[Brune 2016; Oching and Ghomshei 2019; Wu and Gillies 2017; Verma and Brune 2016]

4.7 Improve Deep Coal Mine Ventilation

4.7.1 Define Health Issues Related to Deep, Coal Mine Ventilation in Alabama, Utah, Southwestern Virginia, and Southern West Virginia.

Besides possible improvements on de-gasification, additional health issues need to be defined relative to deep coal mine ventilation in Alabama, Utah, southwestern Virginia, and southern West Virginia. The issues defined should be related to those identified in Objective 3: Prevent Illness from Occupational Health Hazards. However, there could be additional unforeseen health issues involved with deep coal mining. Additional research would be conducted to determine ventilation controls specific to deep coal mines that could mitigate the health issues defined.

4.8 Deep Open-Pit Mines

Very deep open-pit mines may not have sufficient atmospheric circulation to dilute inimical gases and dusts in the mine atmosphere. Studies should be undertaken of total ambient air quality in deep pits and, if some are found to be noncompliant with MSHA regulations, research on efficient air mixing and ventilation should be undertaken.

Relevant Publications:

[Choudhury and Bandopadhyay 2016; Collingwood et al. 2012; Raj and Bandopadhyay 2014, 2017]

OBJECTIVE 5: IMPROVE HEALTH AND SAFETY THROUGH BEHAVIORAL RESEARCH

The Mining Sector Council identifies research into miners' behavior as a critical factor in reducing accidents. What elements of the workplace or of the work organization create increased awareness of miners' responsibility for safety and health, and what is it that encourages some to take risks?

5.1 Improve Safety Culture in the Mining Industry

Understanding that safety culture is vital to every aspect of mining, the Mining Sector Council realizes the role and responsibility of management to encourage and instill a positive approach to safety in the workforce. A positive safety culture is one in which every member of the workforce strives and is encouraged to promote safe operation in the mine; a negative safety culture would encourage risk taking and inappropriate short cuts. Anecdotally, many examples were shared among Council members during discussions of large companies showing leadership in developing a safety culture. Equally, anecdotes were given of poor behavior in small-company operations.

Relevant Publications:

[Haas 2019; Laser 2018; Haas and Yorio 2021; Ritz 2009]

5.1.1 Conduct a Comprehensive Survey into Best Practices That Encourages a Positive Safety Culture, Including a Statistical Examination of The Benefits Of These Practices.

The Mining Sector Council members agree among themselves that no mining, or even other industrial sectors, has monopoly on a positive safety culture and recommends research into best practices along with a statistical examination of the benefits of these practices. Effective dissemination of best practices to mines and miners is a topic of study in and of itself. Research into the impact of pre-mining activities and non-work environments on the worker's willingness to take risks should be undertaken. This research could include both a literature search and surveys of workers, particularly those who have had an accident.

5.1.2 Determine If There Is a Correlation of Best Safety Culture with Size and Type of Mine and the Size of The Company Owning/Operating The Mine.

Research into mine and corporate size versus safety culture would help to understand how best to maintain a safety culture and to determine if there is a correlation to size of mine, type of mine, and size of the owning entity. The type of mine can begeneric such as coal or noncoal, but may also include dominant extraction systems and degree of advanced mechanization. Advances in application of safety practices and culture developed at large mines and mining entities should be translated for use to smaller operations. Examples of best practices should be gathered.

5.1.3 Compare Training Methods for Best Safety Culture Practices and Develop Standardized Outcome Assessments.

The best education and training exercises designed to encourage a safety culture should be gathered. The best training would demonstrate educational effectiveness as measured by standardized outcome assessments. Assessments can include the incidence of accidents at the mine unit, . or the retention by miners of the lessons learned in the training sessions. Independent observation of operations and worker behavior is another form of assessment. The research into operations and worker training could result in a best practices manual for outcome assessments of safety culture training.

Relevant Publications:

[Ross 2011; NIOSH 1998, 2004b; Cullen 2008].

5.1.4 Compare mines that use a safety and health management system (SHMS) with those that do not..

There have been strong suggestions that a safety and health management system (SHMS) would help to build a safety culture. These predictions need to be examined and, if true, verified. Independently, the National Mining Association has developed and released "CoreSafety," a prototype mining SHMS (http://www.coresafety.org/; website accessed on Dec. 1, 2021). These systems parallel environmental management systems and are based on a "Plan-Do-Check-Act" cycle of continuous improvement. Significantly, they place responsibility on all members of the system for successful implementation of the system. Individual miners would be charged with a sense of "if you see something, say something." Research into SHMS for mining should include comparisons of the safety records of mines in the United States and abroad that use a SHMS with those that do not. Successful systems should be identified and best practices defined for use by operating companies.

Relevant Publications:

[Rogers et al. 2017; Yorio and Willmer 2015]

5.1.5 Inclusion of Miners in the Development of SMS.

Miners must be part of the development team for SMS, and methods of encouraging their inclusion should be developed.

5.2 Optimize Work Behavior and Scheduling of Work to Improve Worker Health and Safety.

Longer shifts are becoming commonplace at mining operations. For example, at some surface operations using truck-shovel operations, a 12-hour shift is used instead of the normal 8-hour shift. Time lost with driver changes, the acceptance by workers of 12-hour shifts, and the supervisory benefits of two shifts instead of three per day have led many surface mines to employ the 12-hour shift. To maintain some sense of equivalence with a 40-hour work week, work schedules are augmented with appropriate times away from work. Having large blocks of time offis a reason for worker acceptance of these lengthy shift schedules. Longer shifts are also employed when workers are transported to very remote locations.

The Mining Sector Council recognizes that shift scheduling and duration could have health impacts as well as safety and managerial impacts. Sections 3.4.5 Study the Impact of Longer Shifts or Variable-Length Work Weeks. and 3.4.6 Study the Implications of Fly-In/Fly-Out Arrangements. are related to this section 5.2. In the sub-objectives that follow, elements of behavioral traits that can cause safety impacts are highlighted.

Relevant Publication:

Duchon, J.C. 2010.

5.2.1 Safe Worker Behavior.

5.2.1a Study The Roles of Management to Determine What Encourages Safe Behavior.

If management's role for encouraging a positive safety culture is broader than installation of a SMS, then research is needed in all facets of management that encourage safe behavior. Potential examples of management roles include: empowerment of the workers to take responsibility for the workplace, reinforcement and reward from management, delineation of effective workplace policies and standards including corporate core values, and the formal incorporation of these elements into a SMS. The health and safety impact of management, front-line and above, being actively engaged in miner training to reinforce the importance of the training should be studied.

Relevant Publication:

[Haas 2019; Camm 2015a]

5.2.1b Evaluate the Effectiveness of Rewards for Safe Behavior.

Research into the effectiveness of rewards for safe behavior is needed. How sizable must an award be to be effective? Are there differences in how the reward is given or administered? What are the best methods to implement a reward system?

Relevant Publications:

[Camm 2015b; Swinderman 2017]Camm, T.W., 2016.

Swinderman, R.T. 2017.

5.2.2 Promote a Positive Safety Culture.

5.2.2a Determine How to Formulate Managerial Attitudes and Approaches That Foster the Continuous Search For Safety Improvements.

If the work defined in 5.1 Improve Safety Culture in the Mining Industry leads to observations about the impact of the management system on a positive safety culture, then research can help formulate managerial attitudes, approaches, and involvement that support the continuous search for safety improvements.

5.2.2b Formulate Safety Culture Training for Different Kinds and sizes of Mines.

If the work suggested in 5.1 Improve Safety Culture in the Mining Industry leads to finding a significant difference in safety culture between small and large mines as well as types (mineral extracted and extraction system) of mine, then research can help to formulate safety-culture systems appropriate for a given type of operation.

5.2.3 Quantify the Impacts of Variations in Shift Length, Shift Rotation, and Days Worked Versus Days of Rest on Safety and Health.

There are safety-and-health issues with both shift length and shift rotation. These issues include possible fatigue-induced unsafe behavior and longer-term issues associated with stress. Research is needed to quantify these impacts and to determine if there are optimal costs and benefits associated with shifts longer than eight hours, fewer shifts per week, or with the rotation of shifts through day and night assignments. Longer shifts result in longer exposures to noise and dust with shorter recovery periods before the return to the work environment (see 3.4.6 Study the Implications of Fly-In/Fly-Out Arrangements.). The concept of “day of rest” is ambiguous and may need to be defined better; worker surveys may help to understand what types of stress are experienced by mine workers during their days of rest.

Relevant Publication:

[Duchon et al. 1994]

5.2.3a Identify and Quantify the Potential Impacts on Worker Health and Safety for Various Aspects of Shift Work, Including Shift Duration and Work Schedule.

The Mining Sector Council denotes a host of problems that could develop with these variations in shift timing and scheduling and suggests a research program to identify the magnitude of the problem and potential solutions.

5.2.3b Identify Changes in Fatigue and Alertness That Come with Longer Shifts, More Shifts Between Rest Days, and Larger Numbers Of Rest Days.

Problems with attentiveness and alertness are high on the list of potential problems associated with novel shift assignments. One line of inquiry would be a correlation of reportable accidents against elapsed shift time.

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5.2.3c Longer Shifts Lead to an Increase in Repetition of Tasks, and Research Should Identify If This Repetition Has a Impact on Alertness.

Repetition of tasks over a 12-hour shift, such as might be experienced by the driver of a large haul truck in a surface mine, can lead to a dangerous loss of attention and an injury-causing accident. Keeping limbs in a fixed and tensed position, such as might occur with hands on a joystick used to control bucket functions on an excavator, may lead to muscle and tendon injury. Research could help to correlate these types of accidents and injuries to elapsed shift time in 12-hr shifts.

5.2.3d Improve Operator Control Configurations and Develop Relaxation Exercises If a Correlation Between Shift Length and Alertness Is Established.

Research into improvements in control configurations plus development of relaxation exercises may be appropriate if the reviews and studies demonstrate a link between shift duration and scheduling and accidents and injuries.

5.2.3e Develop Appropriate Rest Period and Work Rotation Schedules and Work Responsibility Guidelines to Enhance Alertness.

The development of appropriate rest periods and rotation of work responsibilities might improve alertness. Research into the entire topic of work schedules and alertness could lead to a manual of best management practices for alertness.

5.2.3f Determine Whether Respiratory Recovery Associated with Longer Shifts and Shorter Rest Periods Is Sufficient for The Maintenance of Respiratory Health.

Another wellness issue is respiratory recovery associated with longer shifts and shorter rest periods. The threshold for exposure to potentially harmful dusts and gases is based on an eight-hour shift followed by a 16- hour recovery period. Research is needed to know if that threshold value is still valid for 12-hour working shifts.

5.2.3g Conduct Research to Determine If the Rotation of Shifts, Day to Afternoon to Night, Etc., Has an Impact on Safety.

The Mining Sector Council recognizes there are questions about shift rotation: a week or two of day shifts followed by the same length of afternoon shifts followed by the same of night shifts. Conjecture suggested that this practice was developed to accommodate the workers' interest in one shift and dislike of the other. Fairness, therefore, developed the rotation. Differential pay and its effects on how it might stimulate an interest in rotation was considered in discussions of this topic. Research is needed on the impact of shift rotation on safety. Are there more accidents after the weekend on which rotation occurs? If so, does the risk of accidents outweigh the benefits provided by the rotation?

5.2.4 The Potential for an Aging Work Force Exists for Which New Safety And Health Practices May Be Needed.

As identified in 3.4.1 Investigate the Implications of an Aging Workforce on the Likelihood of Developing MSD., the the average age of miners may increase due to changes in social security retirement rules and from a shrinking workforce in mining. Studies are needed on the effects of an aging workforce on potential accidents and occupational illnesses.

5.3 Improve Training and Education

The Mining Sector Council recognizes that a tremendous amount of research is underway in the United States on how to effectively teach Science, Technology, Engineering, and Mathematics (STEM), and encourages following efforts reported by the American Society for Engineering Education (ASEE), the National Science Foundation (NSF), the Higher Education Research Institute (HERI) at UCLA, and others engaged in research on learning effectiveness.. The ASEE has both a Council and a Division dedicated to Engineering Technology, and their publications and conferences are relevant to research in training. The American Society for Training and Development (ASTD) brings together experts and practitioners in the realm of training.

Despite this volume of published research, the Mining Sector Council recognizes that education and training dedicated to mining are essential to the development of a safe mine, and therefore discussed areas applicable to mining that could benefit from additional research.

Relevant Publications:

[Hebblewhite et al. 2013]

https://www.wiley.com/learn/jossey-bass/

5.3.1 Investigate Different Styles of Effective Safety Training and Evaluate Their Effectiveness.

A critical issue for a continued reduction in the incidence of accidents and workplace occupational diseases is effective training. The Mining Sector Council understands that training must engage the participants and create a sense of responsibility among these individuals for their on-going job performance. This engagement may be strengthened by active participation of management in the training. Research into effective safety training presentation; such as active learning, virtual reality (VR) simulators, responses to varying attention spans, use of alternative and distance-education modes are needed. This research should includeinvestigation of effective means of assessing the impact of these educational means, and is an integral part of an on-going research agenda into safety training. Investigations should include evaluating education for hazard recognition, critical responses to emergencies, and the development of assessment tools for emergency responses (see Objective 2.2).

5.3.2 Identify Best On-Line and Distance Learning Practices for Training Miners on Critical Topics Related to Safety and Wellness.

With many mining communities located in remote areas, the use of distance-education techniques seems a natural progression for training in mine safety. If these lessons are transmitted into a mine-based facility, such as a training room, attendance and participation can be controlled. Conversely, if the distance education subject matter is not carefully prepared and validated by beta-test groups, then its effectiveness may be diminished.

The Mining Sector Council feels that it is important to identify the best distance-educational practices and assemble them into packages that could be distributed to mines and miners.

5.3.3 Improve Educational Methods Along with Assessment Methodology for Mandated and Suggested Training.

There are currently on-going efforts to improve the teaching of subjects mandated by Part 48 requirements, such as miners' rights, first aid, electrical safety, the donning of self-contained self rescuers (SCSRs), etc. Because these and many other topics taught to miners are critical to their well-being, continuing research is needed on improved educational methods along with assessment methodology. Best practices, as described in 5.1.1, may also be introduced in mandated training.

5.3.4 Develop Methods of Presenting Innovation During Training That Lead Miners To Embrace New Technology.

The Mining Sector Council advocates that mine workers should be engaged in their own training. Stimuli for engagement, such as active and proactive training methods, are needed. A sense of empowerment needs to be provided to the mine workers. If they are held responsible for safety, they need to have the authority to improve the system. Such authority is integral to a SHMS (see 5.1.4 Compare mines that use a safety and health management system (SHMS) with those that do not..). Innovations in methods and technologies have been responsible for great advances in safety improvements, yet there are clear examples of where an innovation has led to a reduction in safety. Research into methods of presenting innovation that lead to a responsible embrace of innovation is necessary.

5.3.5 Develop Methods of Reinforcing Lessons That Are Engaging and Assessable.

Research into methods that reinforce key lessons that are engaging and assessable are necessary to keep the message of safety relevant to the participants. Refresher training can be boring if it is presented routinely. Refresher training should be advanced to match the level of experience of the miners being trained. Research should be conducted to evaluate the effectiveness of training catered to the different experience levels of miners. For example, newly hired miners may not have experience with farm or heavy equipment operation and will need enhanced instruction in safety around heavy equipment. As part of a well-designed SMS that rewards workers for improvements in safety practices and statistics, training should be fun, stimulating, and productive. This is particularly true if refresher training includes active participation from upper management.

5.3.6 Improve Educational Methods Used by Contract Trainers and Develop Assessment Methodology.

Safety training is provided today both by the mining companies' staff (in-house) and specialty consultants and companies (contract). Research is needed on improved educational methods along with assessment methodology that might be used by both contract trainers and in-house staff. Training and safety records for randomly selected mines should be examined to see if there are observable variations in incidences of accidents and injuries between in-house trained and contract-trained workers.

5.3.7 Integrate Safety Analyses into Skills Training, Develop Improved Job Simulation Methods, and Develop the Means to Assess the Effectiveness of Virtual-Reality (VR Training.

Much has been written about classroom safety training and how it applies to job and skills training. The use of VR simulators to raise skill levels in a safe and cost-effective manner is an important development in job training. Integration of safety analyses into this training, including hazard recognition, development of improved simulation methods, and means to assess training effectiveness are all part of inputting a research agenda into training.

5.3.8 Develop Game-Like Simulations to Enhance Learning Among New Miners.

Given the popularity of on-line and mobile video games, their use for safety training should be examined. Additionally, consider the possibility of creating a video game where the impacts of changing the operational parameters of an underground mine can be demonstrated.

5.3.9 Study the Benefits of Collaborative Learning Groups for Health And Safety Training.

Research into methods that enhance learning, such as collaborative learning groups, should be undertaken. Collaborative learning may also help individual miners to understand the safety needs of workers who act in teams. The impact of collaborative training on team safety is a potential area of study.

5.3.10 Develop Methods to Reinforce Safety-Training Lessons Held While Personnel Are at Work.

Researchers should look for simple but effective ways to reinforce safety-training lessons while personnel are in the work environment. Mentoring of newly hired miners by experienced workers is a tradition in mining; organized mentoring programs should be developed to ensure that mentoring is effective. As miners gain experience, adding geology and those geologic conditions that lead to highwall and roof and rib failures could help to reduce accidents from falls of ground. Reinforcing safety training taught in the classroom helps to assure miners of the lesson's validity. As in healthcare and aviation, the use of checklists that help to avoid mistakes and omissions should be studied.

5.3.11 Assess the Effectiveness of Health and Safety Training Requirements and Methods That Are Found in The Mining Industry.

Researchers should examine ways to assess the benefit of health and safety training. This examination may include a longitudinal look at incidence rates for accidents associated with a particular training scheme. These assessments should lead naturally to improvements in the training regime. In this regard, an investigation should be undertaken into the content and quality of training given to recent hires at mines who were experienced miners at other mining operations. Studies Butani [1988] and Muzaffar et al. [2013] have shown recently hired miners have a higher risk of fatal injuries regardless of their experience level.

5.3.12 Assess the Benefits of MSHA Fatal Alerts and Safety Shares for Improving the Safety Culture of Miners.

From experience in the mines, members of the Mining Sector Council asked if today's research teams knew the benefit of several practical techniques used in today's mines to encourage safe behavior. The first was the use of Fatal Alerts to illustrate recent accidents, with the hope that such reviews would prevent a similar accident at the site. The second was the use of a "safety share," where each member of the group would provide one anecdote or idea that illustrated good and safe behavior. Research is needed to assess the benefits of Fatal Alerts and safety shares and to improve them if necessary.

5.3.13 Assess On-Line Professional Refresher Learning Systems for Their Effectiveness in The Mining Industry.

Extending this research agenda into improvements in higher education, whether for credit hours ornoncredit hours, for professionals may be beyond the scope of this research agenda. Nonetheless, mining will be enhanced by educational delivery systems that are responsive to work schedules and locations of mining personnel. On-line learning systems should be assessed for their effectiveness in the mine environment.

5.3.14 Evaluate Hazard Training for Contractors and Visitors, Identifying Best Practices for Hazard Training, Model Training Programs, and Methods Of Assessment.

The Mining Sector Council recognizes the increased incidence of contractors, suppliers, and other temporary workers who go onto or into the mine site and who do not have the same attitude toward safety as the permanent employees. Research into easily deployed safety training for visitors is necessary. This implies an examination into current methods of hazard training for visitors, identification of best practices, development of model programs, and assessment of their use.

5.4 Promote Risk Management in the Mining Industry

Risk management involves independent assessments of the potential hazards facing miners. This could include the design of machines and physical systems (objects) or actions that they must take to operate these machines and systems. An inventory of objects and actions is made for any particular system or sub-system, and each component is assigned a value for the harm that could result from it. The greater the predicted harm, the greater the value or risk factor. A higher risk factor requires a more urgent need to reduce or, even, remove this hazard. Risks can be organized by a hierarchy of potential harm. Risk management includes an assessment of benefits that arise from redesign of the object or from re-education in operating it.

In quantifying these benefits, risk managers assign a higher benefit to self-actuating or autonomous controls and a lower benefit to those that require operator/human intervention and control. A hierarchy of desired reactions and responses to risks becomes the desired control structure within risk management.

Relevant Publications:

[Van der Merwe et al. 2017; Yorio and Willmer 2015; Younis and Dagit 2012]

5.4.1 Research Standards of Competence and Determine What Level of Skill Competence and Expertise Is Needed to Make Risk Assessments.

If there is no self-actuating control available and human intervention will be required in case of a sudden appearance of risk, then one very real concern of the Mining Sector Council is how can it be known that the person who intervenes is competent to do so? Does the operator have situational awareness? Research into standards of competence needs to be undertaken so that there are national standards for expertise, as well as standards of expectation of knowledge of the mine system or sub-system that is to be controlled by the competent person. Intervention should be undertaken only by someone who is completely aware of the mine system and of the consequences of altering it.

As an example, the Mining Sector Council is concerned that design decisions are being made about ventilation systems by people whose level of experience and expertise is less than optimal. Ventilation designs may be assigned to junior engineers whose experience level is modest; a new respect for the role of ventilation design needs to be instilled in mining. While consultants can provide the needed level of expertise, they are not always available to revise and update designs as the mine develops. A review of submitted and approved ventilation plans has found substantial errors that could prove to be misleading in a risk-management assessment. This observation reinforces the need for standards on competence.

5.4.2 Identify and Quantify Risk Factors Used in A Risk Assessment.

A broad research objective is to identify and quantify risk factors in such a way that independent analyses will produce similar results concerning the same identified risks. This means assigning statistically valid values for the probability of failure that are based on observations in mines that are similar in structure, geology, or modes of operation. Risk management needs to be predicated on experience and to share the lessons learned. For example, many design algorithms, such as for slope stability, depend upon a predicted factor of safety.

5.4.3 Investigate the Substitution of Probability Factors for Safety Factors When Making Risk Assessments.

Research into the substitution of probability factors for safety factors (F/S or factors of safety) should be undertaken with the goal of improving model reliability. The probability factors should be given by experts and only placed on a Likert Scale (a scale of 1 to 5, where 1 is sure failure and 5 is sure stability) if they are not quantifiable. This approach to observational systems has been used in rock mechanics to predict the stability of openings and tunnels: rock-mass classifications and rock-mass ratings. It can be used more broadly to predict the probability of failure in many mining systems.

5.4.4 Research the Consequences of Changing a System to Prevent Failure So As to Prevent Unintended Consequences.

Research should be undertaken to evaluate the consequences of changing a system to prevent failure. The consequences of any change should be predictable so as to avoid the so-called "unintended consequence." As an example, fatal accidents have been caused by continuous-miner operators in an underground coal mine running themselves over with tele-operated machines. The tele-operation (either by umbilical tether or by radio) was designed to remove the operator from the risk of roof failure and, instead, increases the risk of harm from the machine. The balance, in risk management, between determining the likelihood of an event and the cost of the consequences of this event should always be considered so that research achieves a reduction in the product of the two values, not in just one or the other.

5.4.5 Develop Effective Training Programs for Risk Assessment.

The Mining Sector Council began with the premise that risk management was the approach needed to reduce risky behavior and was uncertain how this differed from the topics discussed above. It rapidly became clear, however, that risk management implied a statistically driven means to improve safety. If workers can be trained to recognize risk while managers are shown how to identify risks from statistical data on safety, then risky behavior can be reduced. Research into effective training programs needed for risk assessment would be beneficial.

5.4.6 Study the Mine Safety and Health Enforcement System to Determine If There Are Alternatives That Might Deliver Better Health and Safety Performance in Mines.

While not discussed at any great length, the Mining Sector Council also considered an enforcement regime that was risk based. If the enforcement system were able to identify operations and behaviors that lead to a higher incidence of accidents, then the mine could concentrate on their reduction. Coupled with a Health and Safety Management System, workers would be engaged in safety rather than treating it as something belonging to an external enforcer. The Mining Sector Council believes that research is needed to study the enforcement system and see if there are alternatives that might deliver better performance in the mine.

5.4.7 Develop Risk-Based Safety Systems That Provide Goal-Oriented Versus Means-Oriented Approaches to Safety.

The concept of risk appears in several of the major objectives in this Agenda. The Mining Sector Council is very concerned that the current system of regulation does not focus its priorities on a data-driven risk assessment or risk analysis. At one time, mine-safety regulation was very goal oriented and merely suggested that safe behavior was a virtuous objective and left industry to determine what this meant. An insufficient reduction in accidents led to a substantial increase in means-oriented regulations, i.e., specific guidance on machinery and methods. Today, we have a substantial body of data on accidents and a system for continuous updating of this data. Research may be able to show us if accidents can be correlated to the risk of their occurrence, thereby giving guidance on the need for regulation and the assignment of responsibilities for compliance. The research might continue into the realm of the safety culture mentioned previously inasmuch as a clear definition of risks and responsibilities could stimulate active compliance.

5.4.8 Evaluate the effectiveness of risk management programs in reducing injuries and illnesses.

Risk-management programs were implemented in Australia following changes in their federal regulations.. Further research is necessary to determine the effectiveness of risk-management approaches in the U.S. mining industry. Mining rules or guidelines in other countries may also foster risk-based safety systems. Further research is necessary to determine the potential effectiveness for reducing accidents and injuries by the use of risk-management approaches in the U.S. mining industry. Of value will be an investigation into the application of risk-based safety systems practices from other industries and the use of International Electrotechnical Commission (IEC) functional safety standards in establishing goal-oriented approaches to safety in U.S. mines. This research should include the mechanisms used to move from a regulatory to a risk-based system

5.5 Employee Assistance Programs: Substance Use Disorder and Counseling

Employee assistance programs (EAP) may be offered by employers. These programs offer counseling services and can help employees confidentially resolve problems, such as mental health, personal issues, substance abuse, grief, etc. These services are offered free to the employee, as the cost is borne by the employer. Benefits of EAPs to the employer include lower medical costs, reduced employee turnover, higher employee productivity, etc. Their effectiveness may be questioned as there seems to be little research on EAP effectiveness in the mining industry. This section concerns EAPs in the mining industry

Relevant Publications:

[Fantauzzo and Smith 1987; MacMaster 1988; Harris and Harris 1997]

5.5.1 Identify Best Practices In Employee Assistance Programs (EAP) For Identification And Treatment Of Substance Use Disorder.

The Mining Sector Council recognizes the existence of EAPs which are voluntarily joined by employees who have behavioral problems, such as addiction, that they would like to overcome. It should be noted that NIOSH has established the "Workplace Supported Recovery Program" (https://www.cdc.gov/niosh/topics/opioids/wsrp/default.html) that provides information related to this subobjective. What the Mining Sector Council could not identify is whether or not EAPs are effective. Similarly, members of the Mining Sector Council (see 3.5.2 Reduce Substance Use Disorders.) recognized that substance use disorder is a tremendous problem in some mining regions. Research is needed to review the ways that the mining industry handles these problems and identify best practices for substance-use disorder identification and treatment . Whether or not an EAP represents best practice is something that should be examined.

5.5.2 Determine the Best Forms of Managerial Intervention to Reduce the Incidence of Substance Use Disorder in Mine Workers.

Misuse of alcohol, controlled drugs, such as opioids, cannabis, and tobacco, has known impacts on the quality and cost of work performed by mine personnel. Research is needed on the best forms of managerial intervention to reduce impairment in the workplace. Considering the cost of replacing workers, research might be able to demonstrate preferred forms of employee assistance programs in lieu of strict enforcement of sanctions and terminations.

5.5.3 Conduct an Independent Examination of The Use of Sanctions for Appearing at Work Impaired.

Many companies have implemented mandatory drug and alcohol testing, and the Mining Sector Council was uncertain as to the fairness of the practice since failure of a drug test can lead to a non-appealable termination. The question is whether or not this is the best approach toward maintaining a safe workplace. On the whole, the Mining Sector Council thought that it was, but suggested that an independent examination of the problem was worthwhile.

5.5.4 Develop Protocols to Assess Workers' Fitness for Duty

Many legal substances that may be used by mine workers may reduce their fitness for duty. Objective and legal protocols for determining a worker's fitness for duty need to be developed for marijuana, painkillers, opioids, etc. in addition to alcohol.

5.6 Develop Training Programs That Address Wellness in Haul Truck Operators

A wellness issue identified by the Mining Sector Council focuses on the workers engaged in truck driving, which is essentially a sedentary job (see 3.5.1b Investigate the Impact of Effective Educational Programs on Chronic Diseasein the Mining Communities.). Research should be conducted to determine what health and environmental factors cause the degradation of health in haul truck operators and provide programs to improve truck-driver health.

5.7 Survey Safe Workers' Attitudes to Safety and Health

Consistent with the recommendation in Objective 8, Surveillance, to identify long-term workers who have not had a reportable accident, research should be performed to develop and administer, consistent with human-research protocols, a survey on their attitudes toward health and safety.

5.8 Attitudes of Above-Average Companies

Similarly, companies with better-than-average safety records should be identified and their corporate attitudes to health and safety examined for best-practice benchmarks. (see 5.1 Improve Safety Culture in the Mining Industry).

5.8.1 Public Record of Above-Average Companies.

For companies with a better-than-average safety record, researchers should review their public statements for suggestions on best-practice benchmarks.

OBJECTIVE 6: IMPROVE MINE DESIGN, SYSTEMS OPERATIONS, AND MANAGEMENT PERFORMANCE TO ENHANCE MINE HEALTH AND SAFETY

6.1 Systematic Safety Management

Similar in design to an Environmental Management System, a SHMS, inventories aspects and impacts within the system, lists objectives for improvement that are based on the inventory, lists all directives and regulations that affect the system, creates a policy that guides the system, defines management's role in guiding the system, and sets up an archive for all documents created within the system. It makes all members of the system both responsible and empowered to propel the system toward its objectives.

6.1.1 Develop SMS for Mining.

SMS, now expanded to be SHMS, have been formalized through various standards by, for example, the United Kingdom, Australia/New Zealand, International Labor Organization (ILO), and International Standards Organization (ISO), and have been used for 15 to 25 years. Significantly, these systems require active participation from all members of a system, especially operators and workers. They have not yet been adopted broadly in the U.S. Research is needed to guide the adoption and modification of such standards for the U.S. and to determine their potential effectiveness in consideration of the U.S. regulatory approach to mine safety. The program in CoreSafety, recently developed by the National Mining Association presents an opportunity to study the effectiveness of SHMS intended for mining. This sub-objective is an extension of 5.1.4 Compare mines that use a safety and health management system (SHMS) with those that do not...

Relevant Publications:

[Rogers et al. 2017; Yorio and Willmer 2015]

6.1.2 Evaluate the ISO 45001:2018 for its Applicability for Mining.

The ISO 45001:2018 standard. Since research is needed to determine if it will fit into U.S. mining with ease.

Relevant Publications:

[Nagyova et al. 2017; Uhrenholdt Madsen et al. 2020; ISO 2021]

6.2 Regulation

The United States, and its respective mining-oriented individual states, have a strict approach to mine safety. Yet, although relatively effective, the statistics on total mine safety, i.e. all injury-causing accidents, have not continued to decline in recent years. While a decade or more ago, the prominent disasters (including Sago:2006, Crandall Canyon:2007, Upper Big Branch:2010, etc.) that occurred despite the strict safety laws have demonstrated that the regulatory mode may need reexamination to maintain or increase effectiveness. It is noted that the recent decade has seen no disasters and a continuing decline in fatalities. No recent searches of the One-Mine database (https://www.onemine.org/) for Relevant Publications have found any publications on this subject.

6.2.1 Conduct Impartial Research to Improve Our Regulatory System in Mining.

Disinterested and impartial research may help to improve our regulatory system in mining. Mining law has been amended and enhanced over four times since the first federal Coal Mine Safety Act in 1952 (MSHA 2022). Data analysis should be used to determine if these amendments have led to definable positive impacts on miners' health and safety. These acts have also led to substantial numbers of rule changes, and they may have, also, made a positive impact on miners' health and safety. This research may guide the development of future regulatory changes.

6.2.2 Demonstrate That Effective Regulatory Requirements Are Scientifically Sound and That Future Requirements Are Science Based.

What approach to regulation and enforcement works best? At present, there is a mixed system that is predominantly guided by a strict operating code and a system of inspection and penalties. Research is needed to show that the current requirements are scientifically sound and that future requirements, including quantified risk-assessment techniques, are compatible with good science.

6.2.3 Determine Whether a Specification-By-Permit System, Such As Exists in Mine Reclamation, Can Increase the Involvement of All Personnel in a Mine Unit.

Research is also needed to see if a specification-by-permit system, such as those that exist in mine reclamation, can increase the involvement of all personnel in a mine unit. SMS need to be examined in terms of their utility for regulation and inspection. Other major mining countries rely on codes of practice and descriptions of Best Management Practices, BMP.

6.2.4 Compare the Effect of Alternative Codes of Practice and BMP to Determine Their Effect on Mine Safety Experiences.

Research is needed to see if the adoption of codes of practice or management practices, such as in Western Australia (Australian codes of practice for mining are issued by the individual states; this reference is from Western Australia and was accessed on Dec. 1, 2021https://www.dmp.wa.gov.au/Safety/Codes-of-practice-16145.aspx) and the United Kingdom, (although now called "Regulations" include a lot of guidance, https://www.hse.gov.uk/pubns/books/l149.htm, accessed on Dec. 1, 2021), into U.S. mining would enhance or degrade our mine safety experiences.

6.2.5 Compare the Effect of Alternative Systems of Regulation on Mine Personnel Attitudes Toward Safety.

Research is also needed to see if the adoption of alternate systems of regulation in the U.S. would improve or degrade mine personnel attitudes toward safety. The psychology of compliance may be determined by the nature of the regulatory system. Mine workers should be working toward a common goal of safety rather than focusing primarily on regulatory compliance.

6.2.6 Conduct Research to Determine If Managerial Systems Affect Workers' Attitudes Toward Safety.

Many mine management systems work in a hierarchical, authoritarian fashion. Research is needed to see if managerial systems affect workers' attitudes toward safety. If there is a culture of acceptance of unsafe behaviors, rather than one of safety, then there may be ingredients for an increased incidence of accidents. Research into management systems, including safety and health management, may help to create an environment of collaboration instead of intimidation or lack of managerial support.

6.3 Integrate Operational Management into Advances in Engineering Design to Improve Health and Safety

The near future has the potential for substantially different technologies to be implemented in mining: autonomous vehicles, mine-monitoring and control systems, advanced mechanization in extraction systems such as longwalls and continuous miners, and so forth. The implementation of any one of these advances should be accompanied by managerial methods that specifically consider the impact of these systems on miners' safety and health. The rate of introduction of new technology should be studied along with their effect on management systems. Managerial improvements will need to accompany the technical ones.

6.4 Develop Working Prototypes for Inserting Exploration Data into Geological Models and Mine Designs

It is anticipated that, as the technologies of exploration continue to be developed, data gathered during deposit exploration may be integrated into mine designs as rapidly as the data are collected, i.e., in real time. Also, exploration data may be able to guide mining equipment. The data may come from pre-mining or ongoing exploration programs, in which case they may aid initial mine design as well as be pre-loaded into machine guidance systems. Alternatively, as they are gathered from exploration equipment, the data would be used to refine these guidance systems.

The science and technology of seismic tomography should be developed to obtain a better picture of mineral deposits and the surrounding rock lithology from readily available geophysical tools. Exploration data can utilize global and regional models that help to locate and delineate target deposits within their place in the earth's crust; they can specifically be used in local models to help refine mine plans and to guide machinery. Research is needed to convert these concepts into real prototypes.

6.5 Improve the Safety of Automated and Mechanized Mining Equipment

The Mining Sector Council considered the broad topic of automation as applying to both production efficiency and safety improvements. It was agreed that NIOSH's charge was confined more to safety, but that productivity and safety were linked. Moreover, the NORA Agenda was to be national, not just for NIOSH. Consequently, it was agreed that safety and health would be the first considerations but that relevant operational ideas would not be excluded because they appeared to enhance production.

Relevant Publication:

[Cheng et al. 2013]

6.5.1 Develop Reliability Software for Locating and Tracking Face Workers on Automated Longwalls.

Automation of shield advance based on shearer location needs to have more reliable software. The system also needs to be able to locate all personnel and determine their risk for harm before moving shields. Software aberrations—glitches—have caused unwarned and unprepared movement of heavy equipment to the potential harm of face workers. Research is needed into software reliability as well as continuous identification of face workers and their location.

Relevant Publications:

[Fink and Beikirch 2011, 2015]

6.5.2 Develop Reliable Self-Diagnosis Systems to Protect Maintenance Workers While Working on Automated Face Equipment.

The failure of autonomous equipment has its own risks to maintenance workers. If electricians and mechanics enter a section after the equipment fails or shuts down to prevent further damage, then they were not present to hear or otherwise sense the symptoms of failure. Consequently, they may have difficulty in diagnosing the problem. During the repair, the equipment may be restarted to diagnose the problem. Injuries can occur if the maintenance workers are not properly shielded from the malfunctioning equipment. If the failure was due to a software glitch, the machine may well malfunction again during operation or during the period of repair. Research into reliable self-diagnosis and predictive maintenance systems would help to protect maintenance workers.

Relevant Publication:

[Marek et al. 2012]

6.5.3 Improve Proximity Detection Around Equipment in Mines.

6.5.3a. Develop a Reliable, Intelligent Proximity System for Detecting Workers Around Any Piece of Automated Equipment.

MSHA approval of proximity warning systems does not guarantee functionality, only that they are explosion protected (intrinsic safety) against ignition of methane gas and coal dust. One good research target is an intelligent proximity system that would create a hazard zone that is responsive to the shape and functions of various automated equipment. It would also identify people entering into the hazard zone and distinguish between those who should be there and those who should not. This recommendation is coupled to one first found in 1.3.1.

Relevant Publications:

[Bissert et al. 2017; Carr et al. 2010; Cooke and Horberry 2011; Godwin and Schwabe 2016; Jobes et al. 2011; Sifferlinger and Rath 2016; Swanson and Bellanca 2019]

6.5.3b. Develop Reliable Proximity-Detection Systems for Continuous Miners.

Continuous miners, with their multiple degrees of freedom, are good targets for further development of reliable proximity-detection systems.

Relevant Publications:

[Bissert, Carr, et al. 2016; Bissert, DuCarme, et al. 2016; Zhou and Carr 2019; Zhou et al. 2019]

6.5.3c. Avoid Interference Among Monitoring Systems.

As sensors and monitoring systems are added to autonomous equipment, the potential for interference among them rises. Studies are needed on ways to isolate signals and avoid interference among them.

6.5.3d Avoid Accidents Between Autonomous and Human-Guided Vehicles.

Accidents between autonomous and human-guided vehicles are avoidable if there is sufficient rigor in the overall guidance systems. Studies are needed on these, presumably digital, master guidance programs to ensure that they can identify and guide every vehicle or machine in a mine.

Relevant Publication:

[Jobes and Carr 2018]

6.5.4 Coupled with the Development of Proximity-Detection Systems, Develop Guidance Systems That Protect the Operator from Inadvertent Harm.

Related to proximity-detection systems are autonomous guidance systems. As we consider the increased use of remotely operated continuous miners, either through an umbilical tether or by a radio system, we note that there have been cases of operators being run over by their own machines. Deep-cut remote control has led to a new class of accidents. In cooperation with the research on proximity systems, there should be research into guidance systems that protect the operator or that allow the operator to be sufficiently far from the machine to avoid being run over. An intelligent guidance system will know where all personnel are located at all times.

Relevant Publication:

[Bhattacherya et al. 2006]

6.5.5 Develop Improved Mobile Equipment Cabins to Protect Operators from Airborne Particulates and Gases.

In keeping with the recommendation from 3.1.6g Develop Improved Mobile Equipment Cabins to Protect Operators from Airborne Particulates and Gases., research should be undertaken to improve operator cabins that increase the protection from airborne particulates and gases. A connected objective for these cabins should be increased comfort levels leading to increases of alertness and awareness of safe equipment operation.

Relevant Publications:

[Cecala et al. 2016; Cecala et al. 2014; Noll et al. 2014; Organiscak et al. 2014; Patts et al. 2018; Patts et al. 2017; NIOSH 2012]

6.5.6 Study Sensor Reliability.

As sensors are added to autonomous equipment for guidance, proximity detection, machinery health, predictive maintenance, etc., the potential exists for conflicting signals to be sent to controllers, whether digital or human. Studies are needed on optimal levels of redundancy and the untangling of conflicting signals from redundant sensors. Also, studies are needed on isolation of sensors and their signal carriers to prevent interference among signals.

6.5.7 Technology Forecasting for New Technologies.

The development of new and innovative equipment and technologies can have unforeseen circumstances for the health and safety of miners. Independent technology assessments and forecasts are needed in an effort to predict system failures and accidents that may result from the introduction of innovative equipment and, thus, reduce their occurrence.

6.6 Improve Ground Control in Mines

Ground failure of roof/back and pillar in underground mines and of slopes in surface mines is a substantial cause of injuries and fatalities.

Relevant Publications:

[Bock et al. 2018; Peng 2015]

6.6.1 Continue to Develop Numerical Models That Exceed the Current Empirical Systems in Efficacy.

Research in the area of ground control should continue to search for numerical models that exceed the current empirical systems in efficacy. These models should be based on universal design considerations rather than trial-and-error methodology. Exploration data should be input into the model before the simulation is initiated, and then the model should self-modify, or "learn," based on in-mine monitoring or other additional data. To be practical and to guide the ongoing research, the modeling should start with localized ground-control models that can later be inserted into a larger framework. In coal mining of thin seams and multiple seams, this ground-control modeling research may be of great use in reducing roof failures.

6.6.2 Improve Methods for Determining the Rock Mass Characteristics That Form One of The Critical Independent Data Sets for A Numerical Model.

Numerical models based on commercially available finite-element and boundary-element codes have had some success in accurately modeling ground-control conditions. Research is needed in the key material characteristics that become one of the sets of independent data for a model; geometry of the openings is the other. These are well-studied elements in the laboratory but are less reliably measured *in situ*. Independent parameters of rock strength and yield function need to be developed for semi-infinite rock masses. Rock-mass characterization is an observational technique that attempts to give accurate values to *in situ* rock strength and stability and should be developed further. Geostatistics should be applied to rock-mass characterization to increase its predictive value. We should be able to identify weak ground in advance of its appearance at the mine face. Moreover, quantification of the term "weak" may help to improve the validity of ground-control models.

6.6.3 Develop "Smart" Roof-Control Drills for Continuous Detection of Roof Stability Data.

Research should develop "smart" roof-control drills that gather information about rock strength and roof stability as they drill holes for the emplacement of roof bolts. The data should go directly in real time into the ground-control models.

Relevant Publication:

[Anderson and Prosser 2007]

6.6.4 Develop Methods for Rib Reinforcement and Reliable Rib-Roll Warning Devices.

Rib failures are already responsible for many of the recent ground-control fatalities in underground coal mines. As coal mines go deeper (see 1.3 Integrate Engineering (Technical) Controls into Mine Design to Reduce Risk) into the underground environment, this condition will only worsen. Research should resume into rib reinforcements and rib-roll warning devices.

Relevant Publications:

[Sinha and Walton 2017; Zingano 2006]

6.6.5 Conduct Investigations to Discover Relevant Predictive Seismic Signals.

Coal-mine bumps and rock bursts in hardrock mines will become more prevalent as mines go deeper. Research should concentrate on finding relevant predictive seismic signals to be used as real-time warnings. Earlier research into this topic was stymied by the large volume of signals that were produced by stressed ground. Improved data analyses and artificial intelligence models make resumption of this work beneficial.

Relevant Publication:

[Yang et al. 2019]

6.6.6 Search for Rib-Control Technologies That Reduce the Incidence and Impact of Bumps and Bursts.

In addition, rib-control technologies and pillar design that reduce the occurrence and impact of bumps and bursts should be investigated. Recent advances in the Analysis of Retreat Mining Pillar Stability – Laminated Overburden Models, ARMPS-LAM, need to be maintained and improved as more information is gained from seismic and ground control monitoring systems.

6.6.7 Improve Seismic Monitoring Systems for Mine Safety and to Guide Mine Design.

Given the rapid advance of underground coal mines with the concomitant change in ground-stress conditions, seismic surveying has not been very successful in identifying impending bumps. The pace of coal mining outruns the ability of a seismic network to provide meaningful data. The slower pace of mining in hardrock mines means that we have had some success in using seismic surveys to identify impending rock bursts. Research into improved seismic monitoring systems is essential. These include mobile three-dimensional seismic arrays. Seismic information, even if it arrives too late to predict an imminent failure, can still be used to improve mine design. Trials of various geometries can be observed by their seismic activity and can be an indicator of potential risk of failure.

Relevant Publications:

[Lynch 2016; Swanson et al. 2008]

6.6.8 Develop Easy-To-Use Intelligent Surface-Mine Drilling Systems That Include Automated Guidance to Drill Parallel Holes in a Single Plane.

In surface mines, the use of controlled (smooth-wall) blasting to reduce highwall failures and falls of rock from untrimmed highwalls is a promising area of research. Drilling parameters can be applied to mapping detailed geology to be used in best utilization of explosives. The research should be directed toward easy-to-use systems that include automated guidance to drill parallel holes in a single plane or that use multiple drills on a track to achieve the same result. Expert systems might be applied to blast design such that design occurs in real time. These systems should be designed to prevent overbreak and flyrock. They should also predict the appropriate amounts of explosive to be used to achieve optimal fragmentation. All of these measures will reduce instability of the highwall.

Relevant Publications:

[Appelgren et al. 2012; Gering et al. 2017; Gerst 2017]

6.6.9 Study the Safety Impacts of Working Under Underground Backfilled Stopes.

Many mechanized underground, hardrock mines use an underhand method of mining, whereby they operate under previously mined and, subsequently, backfilled stopes. The fill is usually strengthened by a cementing agent. Questions, which should be resolved, arise over the early strength of the fill, subsequent improvements of strength with time, and loss of strength over time. Answers to these questions will assist in developing safe working plans for these mines.

6.6.10 Develop aA Risk-Based Slope/Bench Design Methodology.

Research on slope/bench design methodologies and exploration of risk-based approaches may improve failure predictions of these structures. This research could include additional testing with more realistic wall conditions (roughness, benches, etc.).

Relevant Publications:

[Pierson et al. 2001; Ritchie 1963]

6.7 Transportation Systems

Many elements of mine transportation have been studied extensively for their impact on safety and health and, thus, the potential to reduce incidence of accidents. Nonetheless, the potential for improvement remains.

Relevant Publications:

[Parreira and Meech 2010; Sun et al. 2017; Swinderman 2015, 2018]

6.7.1 Revise Surface-Mine Haul Road Design Practices to Accommodate Autonomous Vehicles.

As autonomous vehicles become more prevalent, haul roads will need to be constructed using different design procedures. The current design practices may need to be revised to include features that allow for smooth operation of these vehicles. Additionally, if either wire guidance or wireless broadcast is part of the autonomous system, there will need to be design protocols and installation instructions for the guidance systems.

6.7.2 Develop Effective Methods of Detecting the Proximity of Personnel Around Conveying Systems.

Slips and falls of personnel around and under conveyor belts is still a major source of accidents. Research into effective methods of detecting personnel proximity should be undertaken. These are meant to be more effective and reliable than the current pull-cord system of emergency stopping. If mine design can find ways to separate personnel from conveyances, it would also be highly desirable.

6.7.3 Develop Better Systems for Locating Personnel in Complex Underground Mines.

Tracking and location of personnel is an issue raised in several of the objectives, where research on better location systems is necessary. At present, resolution details in the various tracking systems are not fine enough for those systems to be used as a proximity detector. The Mining Sector Council thought that radio-frequency identifiers (RFID) would work but were uncertain about their acceptance by mine personnel. Research into better location systems should include social elements of worker acceptance.

6.7.4 Trolley Systems

Surface mine operators, in a move to reduce their carbon footprint, are moving toward electric haul trucks powered through trolleys. The installation and maintenance of trolley wires throughout the mine, including movement to meet the needs of changing and expanding geometry, will place personnel on or alongside haul roads. Assessment of the potential safety impacts and, thus, the research needed to mitigate these impacts, will first need an estimate of the number of personnel at risk and then a listing of potential accidents. Then, research needed to minimize these impacts can be defined.

6.8 Improve Power Systems Safety

Accident data reveal that mines still experience injuries associated with arc flash and burns (https://www.cdc.gov/niosh/mining//works/coversheet1839.html). In addition, shock injuries and electrocutions are also still prevalent.

6.8.1 Investigate Proper Grounding Design, as well as Educational Materials and Training to Reduce Risky Behavior When Working With Power Systems.

More research is needed on proper grounding design as well as education and training material to reduce risky behavior.

6.8.2 Develop Fail-Safe Lockout Mechanisms.

The failure to lockout electrical supply boxes or cables when work is being done by electricians is still a leading cause of electrical accidents. Fail-safe lockout mechanisms should also be considered for research.

6.8.3 Research Should Be Considered on Self-Actuated Diagnostic Devices In Power Systems.

As suggested in 6.5.2 Develop Reliable Self-Diagnosis Systems to Protect Maintenance Workers While Working on Automated Face Equipment., electricians may be called on in the future to repair systems that failed when there was no human observation. Consideration should be given to research on self-actuated diagnostic devices. In addition to providing support for maintenance, tracking power consumption can be used to work optimally and safely. Protocols for maintenance and repair of autonomous equipment should be developed.

6.8.4 Research on New Battery Technologies and their Impact on the Health and Safety of Miners.

For a variety of reasons including avoidance of diesel particulate matter, flexibility of use, and increased energy efficiency, there is increased interest in the development of battery-powered mobile equipment. Newer battery technologies, such as lithium-ion, are improvements over the older Ni-Cd (nickel-cadmium) batteries. Studies, however, are needed to identify risks from these newer batteries, such as spontaneous fires and gases produced during charging. Equally, studies are needed on the physical efforts that might lead to musculoskeletal disorders (MSD) when changing or handling batteries. See, also 3.10 Battery Charging Stations.

Relevant Publication:

[Rowland et al. 2018]

6.9 Improve Blasting and Explosives Safety by Investigating the Risks Inherent in Electronic Initiation Systems

The introduction of electronic blasting systems adds a new source of risk into blasting. The Mining Sector Council is certain that much work has been done to ensure that new systems are safe but encourages independent research into the risks inherent in electronic systems. Studies are needed to ensure that there is no interference to blasting circuits from all other digital signals in an automated mine.

Relevant Publications:

[Dozolme and Bernard 2006; Lownds and Steiner 2010; Reisz and Trousselle 2012]

6.10 Improve the Health and Safety of Mining in Arctic, Very Hot, and other High-Stress Regions

Recent exploration projects in the arctic regions, high-altitude mountains, and hot, arid desert regions suggest that mine workers will be working regularly in those regions. Research is suggested on the health and safety impacts of these stressors: extremes of temperature, altitude, and isolation. This is connected to 3.4.2 Investigate Thermal Effects in Mining: Heat in Deep Mines; Cold in Arctic Mines.

Relevant Publications:

[Masloboev et al. 2016; Meyer 1995; Bandopadhyay et al. 2016]

6.10.1 Develop Compromise Approaches That Optimize Conflicting Applications of Infrastructure in Arctic-Condition Mines Without Jeopardizing Mine Safety and Health.

The Mining Sector Council discussed concerns related to underground mining, particularly of placer materials, in permafrost arising from the use of conventional mining systems. Research should be undertaken to develop compromise approaches that seek alternative applications of infrastructure without jeopardizing mine safety and health. For example, ventilation air will be frigid. Heating it to provide comfort to underground workers will cause thawing and softening of underground pillars that provide roof support. If the roof is also a gravel layer, thawing will cause its collapse.

6.10.2 Develop Dust Control Methods That Work in Underground Placer Mines at Temperatures Below Freezing.

The creation and control of dust is also very different in these placer mines. Since the indurating agent for the silts and fine sands is water, in the form of ice, heating at the face will melt the ice and cause fine particles to enter into the ventilation stream. As long as air temperatures remain at freezing or below, water sprays for the control of dust will be ineffective; they will produce ice crystals or artificial snow. Research is needed into forms of dust control that work in underground placer minesat temperatures below freezing.

6.10.3 Develop Effective Social-Support Systems and Methods to Increase Familial Contact Through Electronic Media for Fly-In/Fly-Out Mining Operations.

The stress of long shifts and fly-in/fly-out operations are a concern in arctic conditions. Alcohol and substance abuse is common. Family stresses are high, as is the incidence of divorce. Prolonged absences of workers from their home residences exacerbate these stresses. Research into means for increasing familial contact through electronic media should be undertaken. Also, research into effective social-support systems is needed.

6.10.4 Develop Cold-Resistant Metals.

Cold embrittlement of metals leading to abrupt fracture is a problem. Sudden fracture can directly hurt a worker or, by failure of a structure, indirectly. Research into cold-resistant metals along with the development of internal heating devices would help to create machinery that can survive this environment.

6.10.5 Develop Cold-Weather Lubricants.

Equally, lubricants should be effective in intense cold, or else lubricated surfaces should be heated effectively and inexpensively. Research is needed in these lubrication issues as well.

6.10.6 Improve the Health and Safety of Mining in High-Altitude Regions

Strenuous work in the rarefied atmosphere of high altitudes may have health impacts. Research should be undertaken to assess risks from working in thinner atmospheres. If risks exist, then mitigation efforts should be examined.

6.10.7 Research is Needed to Improve Working Conditions in Deep, Hot Mines.

As described in 3.4.2b Determine the Extent of Miner Exposures and Related Accidents/Illnesses Caused by Heat in Large Southwest Open-Pit Mines and in Deep Underground Mines., newly developed deep mines will cause heat stress among workers if cooling is not provided. Research is needed into cost effective cooling systems, including light-weight cooling suits.

Relevant Publications:

[Van den Berg and Bluhm 2015; Fourie and Sheer 2005]

6.11 Assign Wireless Frequency Bands to Respective Device Types to Prevent Safety Hazards

It was noted during some of the early discussions about the use of wireless systems in mining that there was little control of the assignment of frequencies to particular uses. The Mining Sector Council believes that recommendations, based on valid research, be made for the assignment of frequency bands to particular categories of use in mining.

6.12 Improve Health and Safety for Small-Mine Operations

A continuing challenge to mine safety is the higher incidence of accidents found in units operated by small enterprises. These enterprises may use older used equipment that may not incorporate current safety technology. With mine planning, they may have minimal to no mine planning. If they have a mine plan, they may rely on designs done by others, outside consultants, or they replicate designs of nearby mines. This can result in a potential disconnect between mine design and operation. Because of their small size, the share of overhead cost assigned to permitting and mine design is inherently greater than for larger units.

6.12.1 Determine How Intrinsically Safe Designs Can Be Shared Among Small Mining Enterprises in Cooperative Collaborations.

Research is needed to see how intrinsically safe designs can be shared in cooperative collaborations.

6.12.2 Improve Methods of Technology Transfer into Small Mining Enterprises.

Research is also needed to improve our methods of technology transfer to ensure that small mine units take advantage of the lessons already learned. Publications, whether in print or on-line, are a “push” methodology when what we need is for these mine units to want to “pull” the information into their operations.

6.13 Near Hits and Misses

Researchers should work with the developers of mine safety management programs to see if a valid system of data collection can be devised for “near hits and misses.” Evaluate “near hit” and “near miss” data for improvements to worker safety.

6.14 Leading Indicators

An examination of the ways in which the “impacts/aspects” elements of a mine SMS program can identify categories of leading indicators, i.e., precursors, for accidents may lead to the development of a protocol for measuring the incidence of occurrences of leading indicators.

6.15 Explore the Use of Robotic Devices in Monitoring Large Open Stopes and In Rehabilitating Mines After Emergencies, Fires, Disasters, and Re-Opening of Mines After Long-Term Closures.

Ground and air-based unmanned vehicles (drones) may be useful in monitoring large open stopes in underground mines and in initial re-entry to mines after emergencies, fires, disasters, and in re-opening of previously sealed or closed mines for the purpose of rehabilitation. Experience suggests that re-entry can be dangerous; robots and drones can be used to map open entries, check air quality, and test rock and ground stability. They may be used also to re-establish communication nodes. Research is needed to establish needs, objectives, protocols, and methodologies for their use. This research may include the use of repeaters carried in by drones. If the research clearly identifies a need that a robot can fulfill, then prototype systems should be evaluated.

Relevant Publications:

[Australiandroid 2022; RESPEC 2022; Mitchell and Marshall 2017]

6.16 Integration of Monitoring and Control Systems.

As monitoring grows and improves, there will be a need to integrate all systems into an integrated master program. Studies on this integration need to also include issues of interference and reliability. The question of needed sensor redundancy has been addressed elsewhere and leads to issues on resolving conflicting messages.

6.17 Underwater Mining.

As underwater mining, i.e., ultra-deep dredging, develops, research should be undertaken into potential worker hazards in this technology.

OBJECTIVE 7: APPLY HUMAN FACTORS ENGINEERING IN MINING TO INCREASE HEALTH AND SAFETY

The Mining Sector Council recognized that future mining systems will be substantially more reliant on automation and robotics. While it is believed that automation will be installed as a measure that alleviates the risk of harm or exposure to workers, it is recognized that harm to workers can come as an unintended side effect. The deliberations of the Mining Sector Council are aimed at identifying potential hazards in the minin system of the future and recommending research to reduce these hazards. In general, the Mining Sector Council also found that physical ergonomics and prevention of cumulative, trauma-type injuries will continue to be an area of research needed in the future.

7.1 Enhance the Safety oOf Mine Workers, Especially Those Who Maintain Equipment

Unlike mine workers who operate mine equipment and can be expected to be with that equipment for the entire shift, maintenance workers and laborers job duties are transitory. Their work locations can vary many times during a shift. There can be difficulty in determining injury or hazardous exposure source within these job classifications. This section pertains to all mine workers, but most specifically for those transitory mine workers.

Relevant Publication:

[Parks et al. 2019]

7.1.1 Develop Design Protocols as well as Training Programs for Electricians and Mechanics to Understand and Use Software-Based Diagnostic Tools.

After functionality, maintainability should be a primary consideration in equipment and system design, particularly as it pertains to minimizing worker exposure to hazards and injury. This is particularly true with regards to equipment blocking and disassembly, part replacement, and access. Replacement parts should be designed so as to be free from sharp edges and inaccessible fasteners. Furthermore, well-maintained equipment is safe equipment; where poor machine design inhibits both routine and repair maintenance and can potentially lead to the use of unsafe equipment. Maintenance systems require the ability to accurately diagnose mechanical problems and establish correct procedures for repair. Thoughtful equipment design will integrate self-diagnostics into the machine allowing for swift diagnosis and repair. Research that leads to design protocols as well as training programs for electricians and mechanics to understand and use these diagnostic tools will help in maintaining safe equipment.

7.1.2 Develop Predictive Maintenance Procedures for New Models and New Types of Equipment.

A long-desired goal is to have equipment that will signal, in advance, an impending failure. Maintenance can then be done at a convenient time with a minimum of downtime and at optimum cost; such a process is known as predictive maintenance. As new forms of equipment are developed, research should continue into predictive maintenance procedures for them. The safety advantages are obvious; catastrophic failures, such as of braking systems while on a hill, are avoided; maintenance can be performed safely and at times with the least interference with other operations. Hastily performed jobs intended to bring failed equipment back online quickly, but which increase the potential for injury, can be avoided.

Relevant Publications:

[Faitakis et al. 2004; Willingham and Marchant 2016; Willingham and Xie 2017]

7.1.3 Apply the Lessons Learned from Research on the Maintainability of Preparation Plants to Other Mining Systems.

Coal preparation plants have on-going research into maintainability. Lessons learned from this research should be applied to other systems. Equally, work done on maintainability in other industrial sectors should be transferred to mining.

7.1.4 Investigate the Implications of an Aging Workforce on the Safety of Miners and Maintenance Workers.

As the retirement age trends upward, consideration should be given to an aging mining and maintenance workforce: capacity losses, longer recovery times, etc.

Relevant Publications:

[Fotta and Bockosh 2000; NIOSH 2004b; Myers 2011]

7.2 Improve Worker-Machine Interfaces

7.2.1 Continue to Apply Human Factors Engineering with Worker-Machine Interfaces, Particularly When New Machines Are Introduced, to Mining Equipment.

As machinery becomes increasingly automated, it is essential that there remains a cognitive mesh between the operator and the machine, even if the operator is in a remote location. The process of automation means that the operator becomes dulled and, potentially, cedes thought to the machine. We know from disasters, such as the failure of the cooling system at the Three Mile Island nuclear power plant, that operators frequently ignore warning signs when their main control unit fails to signal. There is a parallel here to the initial introduction of computers. Users would give answerssaying that "the computer says…" without checking if the computational results were verifiable. A portion of the concern for alertness factors (7.3 Alertness Factors: Shift Duration, Multiple Assignments and Tasks, and Fatigue) should include the loss of mental engagement When responsible for an autonomous machine. Research should continue on human factors engineering, particularly when new machines are introduced.

Elsewhere (6.5.3 Improve Proximity Detection Around Equipment in Mines.), proximity detection was identified as a significant part of the human-machine interface, as is the atmosphere in which the operator is found. Heat and humidity are significant sources of alertness deterioration. A social issue is offsite behavior of workers. If they come to work fatigued or recovering from substance use disorder, they will certainly not be as alert as if they arrived fresh.

Relevant Publications:

[Eger et al. 2013; Danko 2013]

7.2.2 Develop Training Programs for Contractors.

Similar problems may be found with contractors, whose employees may not be subject to training requirements. The supervisory line for contractors may be unclear. Training programs for contractors should be developed as well as model organizational structures for the use of them.

Relevant Publication:

[Calizaya et al. 2008]

7.2.3 Link Human-Factor Behavior with Psychology.

Continuing research effort is needed to link human-factor behavior with psychology. We need to better understand how equipment operators make decisions. What drives their decision making: ease of behavior, regulatory compliance, or some other factors? Studies may be able to determine if behavior-intervention teams can be effective in reducing unsafe behavior.

7.2.4 Find Ways to Stimulate and Enforce Good Behavior Through Safety Culture Modification.

Research should be encouraged among all mining research entities to find ways to stimulate and enforce good behavior. Protocols should be developed for concerted, continuous education that is based on outcome assessments.

7.3 Alertness Factors: Shift Duration, Multiple Assignments and Tasks, and Fatigue

There is an overlap among human factors research and that of health (see 3.4.5 Study the Impact of Longer Shifts or Variable-Length Work Weeks.sub-objective 3.4.5) and worker behavior (see 5.2 Optimize Work Behavior and Scheduling of Work to Improve Worker Health and Safety.). The Council agreed that the topics in this section were important and benefitted from reinforcement.

Relevant Publications:

[Vasquez-Coronado and Tenorio 2016]

7.3.1 Create a Guidance Manual on Best Practices for Shift Rotations and Extended Shifts.

Coupled to the issues of worker-machine interfaces are those of operator alertness. The impact on safety of shift rotation has been studied elsewhere. Research is needed that assembles the known research into a report or monograph and produces a guidance manual on best practices for shift rotations and for extended shifts.

7.3.2 Develop Safety Guidelines for Extended Work Schedules.

We do not know the impact of long shifts on alertness. If workers are working for an extended period in difficult environments, e.g., cramped, hot, or humid areas, operators may become fatigued and, thus, less alert. Since there is a move to longer shifts, i.e., greater than eight hours, research into the safety elements of these schedules should be undertaken. Mention has been made of the health concerns for longer exposures to dusts and noise during long shifts. Off-site behavior leading to fatigue or of post-alcohol impacts (“hangover”) certainly affects worker alertness.

7.3.3 Determine Whether Education and Safety-Culture Reinforcements Reduce the Incidence of Unsafe Behavior Away from The Work Site.

Studies should be undertaken, within the education protocols dedicated to safety culture, that determine whether education and safety-culture reinforcements reduce the incidence of unsafe off-site behavior.

7.4 Investigate the Effects of Vibration on Operators and Develop Duration and Intensity Thresholds

There is a sense that the impact of whole-body vibration on workers’ balance and stability is under-studied. Data suggest that the vibratory effect on drivers in light vehicles may be negligible, but this may not be so for large and ultra-class vehicles. Research into the effects of vibration on operators should include the development of duration and intensity thresholds. The parameters would include frequency and amplitude of the vibration, its duration, and the benefit or, conversely, risk of intermittent operation. These studies would be companions to those on the impact of longer shift durations for truck drivers.

Relevant Publications:

[Dickey et al. 2006; Svinkin 2006; Yantek et al. 2005]

7.5 Study the Safety Characteristics of Alternative Lighting Systems and Develop Technology to Make Them Explosion Protected (i.e., Intrinsically Safe)

Many technologies, such as Light-Emitting Diodes, LEDs, are available for use in mining. LED lighting provides an improved view of the underground workplace. Research or, more realistically, development of the safety characteristics of these alternatives and steps needed to make them explosion protected as required for MSHA Permissibility should be undertaken. On-board lighting systems are being developed by the manufacturers, and research personnel should undertake cooperative development work with them.

Relevant Publications:

[Reyes et al. 2013; Sammarco, Reyes, et al. 2009; Sammarco, Mayton, et al. 2009]

7.6 Prevent Slips and Falls

Improved lighting should reduce the incidence of slips and falls in underground mines and in the night shifts of surface mines. Housekeeping and cleanliness of ladders and walkways are important factors in the reduction of slip-and-fall accidents. These are a matter for the observance of a positive safety culture by workers. Research into the safety culture should include housekeeping factors.

7.7 Investigate the Safety and Health Impacts of Changing Materials Handling Technologies

The concern with the development of improved materials handling equipment parallels the concerns written above for the safety impacts of automation in general. A continuous line of research will search for the safety and health impacts of changing technology, particularly for materials handling. Lifting heavy objects, such as rock-dust bags, roof bolts, and timbers in confined spaces, leads to MSD. Equipment modifications should be studied to reduce this disorder. Improvements are needed in monitoring instrumentation, and as written before, proximity detection coupled with safe shutdown in the event of a worker straying too close to the conveyance.

Relevant Publications:

[Kittusamy 2006; Dai and Ning 2013; Seo et al. 2013]

7.8 Increase the Use of Guards on Equipment

Guarding is a well-studied topic; however, educational programs are needed to encourage workers to maintain guards and not to use equipment with faulty or missing guards. It is important to understand why workers would knowingly work without guarding or, worse, would remove it during operation.

7.9 Improve the Efficacy, the Fit, and the Ease of Donning of Personal Protective Equipment

Personal protective equipment (PPE), particularly respirators designed to protect workers from dusts and protectors for hearing conservation, needs to be worn correctly. Lessons in donning these two items have significantly aided in reducing the introduction of respiratory dust and hearing damage. Continued research is needed in the ease of donning, comfort, and, particularly, the ability to communicate while wearing respirators (see sub-objectives 2.2.5 Determine If Electronic Telephony Can Be Used Effectively in Breathing Apparatuses, 3.1.8 Refine Recommendations for Personal Protective Equipment Related to Atmospheric Control: Respirators, Powered Air Purifying Respirator (PAPR), Etc., and 3.2.5 Develop Personal Hearing Protectors That Inherently Work Well No Matter How They Are Donned.). The weight of this equipment has a consideration for worker comfort when it is worn over an entire working shift.

OBJECTIVE 8: SURVEILLANCE

8.1 Improved Accident Reporting

Research should be performed to analyze MSHA accident reporting methods for consistency of format and completeness among the various categories: fatal (FATAL), non-fatal days lost (NFDL), and no days lost (NDL). This research could suggest improvements that could be made to these reports that could help identify causes of accidents.

8.1.1 Scoring Matrix.

Determine if a scoring matrix, such as used in various forms of assessment, will increase replicability of reports. Look for other improvements that can enhance the usefulness of these reports.

8.1.2 Style Manual.

Similarly, the benefits of a style manual for the writing of reports should be examined.

8.1.3 Multiple Injury Reporting.

Reports on accidents should be modified so that when a miner sustains multiple injuries, it shows at least the top three individual injuries by category and body part.

8.1.4 Backward Compatibility.

Ensure that all new data are backward compatible for cross-sectional studies.

8.2 Trends and Data Gaps in Miners' Safety

Attempt a systematic analysis of all accident and injury reports to look for trends and data gaps. The objective is to report on the most common work-related injuries and medical costs associated with each. Researchers will need to select time periods that match legal or technical developments in mining. An outcome of this research could be the development of models that show how interventions can save money by reducing medical costs and, eventually, insurance and workers' compensation costs.

8.2.1 MSHA Reports.

In the first instance, the research project should conduct a comprehensive review of MSHA reports.

Relevant Publications:

[Seymour et al. 2013; Tarshizi et al. 2018]

8.2.2 Other Databases.

There are other national databases in OSHA, the National Safety Council, etc. that should be consulted as part of this research.

8.2.3 Healthcare Delivery System.

Parts of the healthcare delivery system, including private insurance carriers and healthcare providers, may also have databases of value and these should be examined for injury information. Also, to improve the ability to obtain occupationally associated injury data from the healthcare delivery system in the future, there should be a pursuit of improvements to the occupational data that are included in electronic health records.

8.2.4 Research Individual U.S. State's Health and Safety Databases.

State databases in their mine safety agencies or in the files of Workers' Compensation programs may also yield information of value to these research projects (Eastern Research Group 2014). In the search for best practices, it may be useful to identify those agencies and programs with the most useful information and suggest those as benchmark best practices for others to follow.

8.2.5 Transform Existing Data Sets into Usable Formats.

Research should be undertaken to determine, using a good statistical approach, the steps needed to process existing accident and injury data sets into usable formats. This can mean translation of written phrases into standardized language, provision for parallel hierarchies of data, or the conversion of qualitative language into quantitative, i.e., digital forms.

8.2.6 Archive the Data.

The research program that undertakes to transform data sets should also examine mine safety and health statutes and regulations to identify preferred places for archiving the processed data sets. Data that have been arranged into forms amenable to analysis are worthy of sharing with other researchers; this recommendation suggests that an open archive be considered for these data sets.

8.3 Trends and Data Gaps in Miners' Health

A research program should be undertaken to organize information on miners' occupational diseases so as to identify trends and data gaps. The objective is to report on the most common work-related diseases, underlying risk factors, and medical costs associated with each. An outcome of this research could be the development of models that show how interventions can save money by reducing medical costs and, eventually, insurance and workers' compensation costs.

The identification of "hot spots" for coal workers' pneumoconiosis (CWP) across the eastern coal fields strengthens substantially the need for valid data across companies and political jurisdictions

Relevant Publications:

[Pollock et al. 2010] .

8.3.1 Distinguishing Mine-Related Diseases.

Surveillance for miners' occupational diseases is very challenging. For diseases with work- and nonwork-related causes, such as degenerative osteoarthritis, researchers should assemble data to assess whether there is excess disease burden across the mining population. For diseases of long latency, such as pneumoconiosis, researchers should assemble data sets that include long-tenure and former miners.

Uniform assessment techniques could be developed so as to reduce data variability arising from the inconsistency inherent in self-reported data.

8.3.2 Healthcare Delivery Datasets.

Similarly, to the recommendation above on injury data, research should look at parts of the healthcare delivery system, including private insurers' and healthcare providers' data sets for health and occupational disease information. Also, it should seek improvements to electronic health records to facilitate using the healthcare delivery system as a source of information about miners' work-related diseases.

8.3.3 Workers' Compensation Programs.

Also, research into information available in the healthcare delivery system should look at Workers' Compensation databases for occupational disease information. Coal miners are covered under the separate black lung program, but substantial information may be available on hearing loss, musculoskeletal diseases, and noncoal respirable diseases.

8.3.4 Patient Confidentiality Issues.

A research review of the incidence of occupational diseases may entail the examination of health information in confidential databases. This review may open the issue of client/subject confidentiality with respect to analyses of these health databases. Research methodology may be needed on how to perform analyses while remaining compliant with data-protection protocols. A look at procedures used by medical researchers, when they analyze large data sets, may give acceptable paradigms for managing confidentiality.

8.3.5 Nuclear Industry Data

The nuclear-generation industry has developed a comprehensive health-data system that should be examined for its transfer to mining.

8.4 Causation for Degraded Health and Safety Variables

Research to identify the independent variables that appear to have a causal influence on degraded miner health and safety in the coal and metal/nonmetal industries should be undertaken. Variables to investigate include, but are not limited to, size of mine, demographic characteristics of the miners, corporate structure, and deposit characteristics.

8.4.1 Task Identification.

The research task is very important but substantial. An initial step in any research undertaken to identify causal influences would be an examination of the benefit of division of the task by industry and by major category: health or safety.

8.4.2 Additions to the Data.

Based on the review of these variables, the researcher should suggest improvements and additions to data gathered that improve post-analysis conclusions.

8.4.3 Define a Small Mine.

As part of the identification of independent variables, it may be necessary for researchers to examine the definition of "small mine" with the objective of creating a consistent and commonly accepted one. MSHA defines small mines as those with 19 employees or fewer (MSHA, 2007). The NIOSH ECWHSP (Enhanced Coal Workers' Health Surveillance Program) defines a small mine as an underground mine with 50 employees or fewer. A review of NIOSH publications finds the definition of a small mine as variable—anything from 5 employees up to 50 employees.

8.5 Dust Data in Metal/Nonmetal Mines

A significant line of research is to examine ambient air quality data for metal/nonmetal mines to see if the data provide insight into air quality in these mines.

8.5.1 Correlate Dust Exposure Data to Reports of Respiratory Diseases.

This research should look for correlations with reports of respiratory diseases in noncoal miners. The disease of interest is primarily silicosis but may expand to include other specific mineral-induced diseases.

8.5.2 Improve Data Collection.

Researchers should investigate potential improvements to federal and state requirements in metal/nonmetal commodities for collecting dust-concentration and/or toxic substance data.

8.5.3 Reporting Standards in Metal/Nonmetal Mines.

An investigation into metal/nonmetal, dust-concentration and/or toxic-substance reporting standards should be undertaken. Evaluate potential recommendations to these reporting standards. Provide a cost-benefit analysis for the recommended changes.

8.5.4 Compliance Sampling.

An important issue is the adequacy of compliance sampling in protecting workers from disease. Research should be undertaken to compare the data collected in metal/nonmetal mines for compliance sampling to reports of work-related respiratory illness to evaluate the relationship of compliance sampling to occupational respiratory illnesses.

8.6 Improve Health Surveillance in Mining

Data on the health of miners have been collected through the various programs such as voluntary x-rays or audiograms for hearing conservation. Unfortunately, these databases are held at individual clinics and health facilities and, therefore, are not unified nor in a consistent format. Even if they were uniform, privacy issues have intervened to prevent their use by researchers.

8.6.1 Determine Whether the Move by The Healthcare Industry to Digital Data Records Can Be Used to Create Privacy-Protected Databases That Can Improve Health Surveillance in the Mining Industry.

If we are to make substantial advances in protecting the health of miners, we will need statistically valid data on disease incidences and associated working conditions. Risk-based standards such as are used in Australia have the potential to reduce the incidence of disease below what prevails today. Research is needed to see if the move by the healthcare industry to digital data records can be used by mining researchers to create privacy-protected databases that can be queried to find answers to the questions posed above.

Eventually, we will need to know as much about the health of miners as we do about their accident histories. Comprehensive databases that can be accessed by the public and by researchers will help move mining into healthier realms.

8.6.2 Remote Health Monitoring

There have been substantial advances in remote health monitoring, from nearby, such as fever monitors, to distant, such as wearable blood pressure and pulse monitors with links to data networks. Research into integrated monitoring systems may identify incipient health problems before they become acute. Suitably anonymized, these monitors may help to provide valid surveillance data.

Appendix A: NORA Mining Sector Council Membership

Randy Reed Co-Chair, Program Coordinator	NIOSH
Lee Saperstein Co-Chair	Missouri University of Science&Technology
George Luxbacher *Program Manager*	NIOSH
Vaibhav Raj Program Assistant Coordinator	NIOSH
Adele Abrams	The Law Office of Adele L. Abrams PC
Dan Alexander	NIOSH - Retired
Kwame Awuah-Offei	Missouri University of Science and Technology
David Blackley	NIOSH
Andrea Brinkey	South Dakota School of Mines
Jürgen Brune	Colorado School of Mines
Jeff Burgess	University of Arizona
Alberto Cabán-Martinez	University of Miami
Jay Canada	Pine Bluff Sand and Gravel Co.
Snehamoy Chatterjee	Michigan Tech
John Cowie	Industrial Minerals Association – North America
George Danko	University of Nevada Reno
Mark Ellis	Industrial Minerals Association – North America
Arthur Frank	Drexel University – Retired
Bill Gleason	Society for Mining, Metallurgy, and Exploration
Chris Greissing	Industrial Minerals Association – North America
Stephanie Griffin	University of Arizona
Ken Groves	Cementation USA, Inc.

Lori Guasta	Colorado School of Mines
Joel Haight	University of Pittsburgh
Cara Halldin	NIOSH
Steve Harrison	Innovative Wireless Technologies, Inc.
Jim Haughey	Komatsu
Keith A. Heasley	West Virginia University
Thomas A. Hethmon	Hethmon Associates LLC
Ariel Hill-Davis	Industrial Minerals Association – North America
Joseph Hirschi	Southern Illinois University
Phil Joggerst	Small Mine Development, LLC
Douglas Johns	NIOSH
David Kanagy	Society for Mining, Metallurgy, and Exploration
Jessica Kogel	NIOSH
Stacey Kramer	Freeport McMoRan Inc.
Nikky LaBranche	University of Queensland
Scott Laney	NIOSH
Ali Lashgari	Clean Air
Paloma Lazaro	University of Arizona
Eric Lutz	University of Arizona
Matthew H. Main	Freeport McMoRan Inc.
Maral Malekian	University of Arizona
Hugh Miller	Colorado School of Mines
Michael Murphy	Caterpillar
Tom Novak	University of Kentucky
Julie Pier	Imerys Group PLC
Gerald Poplin	NIOSH
Mary Poulton	University of Arizona

Libby Pritchard	NSSGA
Raja V. Ramani	Penn State University
Laura Reynolds	NIOSH
Josh Roberts	United Mine Workers of America
Pratt Rogers	University of Utah
Pedram Roghanchi	New Mexico Tech
Michael Runner	Intrepid Potash
Breanna Sanders	Rio Tinto Mining
Javad Sattarvand	University of Nevada-Reno
Mark Savit	Predictive Compliance
Steven Schafrik	University of Kentucky
Joseph Sottile	University of Kentucky
Monique Spruill	Mine Safety and Health Administration
Corey Stevens	Freeport-McMoRan Inc.
Jason Stoltz	Mine Safety and Health Administration
Stanley Suboleski	Evan Energy Investments
Marcus Thomas	SafeBox
Michael Wegleitner	Hecla Mining
Joe Zelanko	Rosebud Mining Company

Appendix B: Comparison of MSHRAC and the NORA Mining Sector Council

	MSHRAC	NORA Mining Sector Council
Authority	• Federal Advisory Committee Act – Public Law 92-463, as amended (5 U.S.C. App. 2)	• Internally created by NIOSH – cannot provide advice to NIOSH.
Mission	• Advises the Secretary, HHS; the Director, CDC; and the Director, NIOSH on the conduct of mine health and safety research including offering grants and entering into contracts for such research.	• Develops and maintains a mining-specific research strategic plan for the nation to address the most important mining safety and health problems. • Maximizes impact through partnerships by promoting widespread adoption of improved workplace practices based on research results.
Function/Guiding Principles	• Evaluates the degree to which mine research conforms to standards of scientific excellence appropriate to federal scientific instruction in accomplishing objectives in mine safety and health. • Evaluates mine research activities, along or in conjunction with other known activities inside and outside of NIOSH • Addresses currently relevant needs in the field of mine safety and health. • Evaluates the results produced by the research in addressing important research questions in mine safety and health, both in terms of applicability and translation of the research findings.	• Seeks broad participation in identifying the most important problems, developing the goals, conducting research, and translating/sharing results. • Practices transparency by displaying its inputs and results of its decision-making publicly. • Establishes and periodically updates sector-specific research goals. • Promotes high-quality research. • Promotes effective partnerships. • Hosts reviews and tracks progress on goals.
Structure	• Consists of 10 appointed members, including the Chair. • Consists of individuals from the following federal agencies: Assistant Secretary of Labor, Mine Safety and Health Administration; Director, National Science Foundation; and Director of the National Institutes of Health; individuals knowledgeable in mine safety and health research and dissemination of scientific research findings and currently practicing in their profession; individuals	• Co-chaired by the NIOSH Sector Program Manager or a designee and by a council member representative. • Membership guidelines encourage broad and diverse participation with such categories as trade associations, labor groups, government agencies, and professional organizations. • Consists of researchers, and safety and health professionals.

	representing mining labor organizations; and individuals representing the mining industry.	- Membership consists of full members and corresponding members.

Appendix C: Major Subcommittees/Working Groups of the NORA Mining Sector Council

Major Subcommittees of the NORA Mining Sector Council (2010-2012)

During 2010-2012, subcommittees were formed to work on the National Research Agenda. These subcommittees were identified by the Agenda Objective. In the following table, the major objectives and Sector Council members who are linked to these objectives are identified.

Major Objectives	Sector Council Members
Health	Bise, Burgess, Frank, Miller, Storey, NIOSH Corresponding Members.Colinet, Haight, Kovalchick
Behavioral Research	Hustrulid, Poulton
Disaster Prevention	Patton NIOSH Corr. Mbr. Varley
Disaster Response	O'Dell, Suboleski NIOSH Corr. Mbrs. Alexander, Bauer, Harteis, Varley, and Weiss
Mine Design and System Improvements for Normal Operations	Bandopadhyay, Sottile, Sweigard NIOSH Corr. Mbr. Barczak
Ergonomics (Human Factors Engineering)	Frimpong, Kogel, Sharpe NIOSH Corr. Mbr. Haight
Atmospheric Control and Ventilation	Grayson, Luxbacher NIOSH Corr. Mbrs. Goodman and Martikainen
Operations and Management	Ellis NIOSH Corr. Mbrs. Brnich, Peters, and Welsh
Data Adequacy and Data Analysis: Surveillance	Bise, Burgess, Caban-Martinez, Casper, Ellis, Frimpong, Heasley, Kravitz, Lutz, M. Main, Moore, Patton, Potts, Reed, Saperstein, Snyder, Sottile, Storey, Suboleski, Torma-Krajewski, Zelanko NIOSH Corr. Mbrs. Jenkins, Luxbacher, Peters, Potts, Stein, and Stolarczyk

Working Groups (May through July 2020)

Working Group I: Health, Ventilation, and Surveillance: Objectives 3, 4, and 8.	Working Group II: Behavioral Research; Mine Design, Systems, and Management; and Ergonomics: Objectives 5, 6, and 7.
Eric Lutz, Chair	Hugh Miller, Chair
Barczak, Tom	Arnold, Tim
Brune, Jürgen	Chatterjee, Snehamoy
Butterfield Pat	Danko, George
Drysdale, Dale	Goodman, Gerrit
Ellis, Mark	Grubb, John
Frank, Arthur	Haarala, Peter
Guasta, Lori	Haughey, Jim
Haas, Emily	Joggerst, Phil
Halldin, Cara	Kramer, Stacy
Lashgari, Ali	Main, Matt
Poplin, Gerry	McCaslin, Mick
Poulton, Mary	Reiher, Michelle
Reed, Rustin	Runner, Mike
Roberts, Josh	Sottile, Joe
Rogers, W. Pratt	Sturgis, George
Savit, Mark	Trackemas, Jack
Stolarczyk, Larry	Wegleitner, Michael
Yeoman, Kristin	Zelanko, Joe

Relevant Publications

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CFR [2022c]. 30, in Chapter I, Subchapter O, Part 75, Subpart L, ed. by Department of Labor MSaHA.

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