NIOSH Mining (MIN) Program:

Response to MIN Expert Review Panel's Report

April 2020

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Introduction

The National Institute for Occupational Safety and Health (NIOSH) Mining Program (MP), managed by the Office of Mine Safety and Health Research (OMSHR), focuses on miner health, mine safety, and disaster prevention and response. Mining is a high-risk occupation that involves a wide range of activities and work environments including underground mines, surface mines, and mineral processing facilities. Miners may be exposed to a broad spectrum of hazards including unstable ground conditions; dust that contains toxic substances such as crystalline silica, asbestos, and diesel particulate matter; mobile equipment; electrical hazards; noise; and underground fires or explosions. Through its intramural and extramural research activities, the MP develops new knowledge and practical solutions including guidelines, best practices, training materials, communication materials, engineering controls, monitoring devices, and other interventions to address these issues.

In 2018, NIOSH convened an expert panel to assess the relevance and impact of the MP from 2008 through 2018. The panel was comprised of six experts in disaster response, ground control, respiratory medicine, translation science, and program evaluation. The evaluation was based on a contribution analysis framework, which examines the association between program activities, outputs, and outcomes to establish a theory of change that explains the contribution of the program to a given outcome. The MP provided a detailed evidence package to the panel that described program activities, outputs, and how the outputs have been used by stakeholders to improve mine worker health and safety in three select programmatic areas: (1) disaster prevention and response, (2) ground control, and (3) respiratory hazards. The panel based its review on information provided in the evidence package and during a face-to-face meeting with NIOSH subject matter experts and leadership.

After considering all the information presented to them by the Program, panel members provided individual scores, using a five-point scale, for relevance and impact. The individual scores were then averaged to arrive at a single score for each category. The panel gave the Mining Program a score of 5 for relevance and a score of 4.5 for impact for a total score of 9.5 out of 10. In addition to the scores, the panel also provided a comprehensive report that includes the rationale for the scores and specific recommendations to help strengthen the Program. The report also included responses to six questions that NIOSH posed to the panel to help focus the panel's recommendations around specific topics for which the Program was interested in receiving feedback.

The panel felt that NIOSH MP research "has made substantial, unique, and vital contributions to the field," and the panel commended NIOSH for "its sustained and effective research-to-practice efforts." Some of the most significant contributions cited by the panel include work on rock dust to prevent propagation of explosions in underground mines, development of industry standards for ground control software, developing the wearable, real-time continuous personal dust monitor (CPDM), and the Helmet-CAM program, which was cited as "an excellent example of effective multidisciplinary, multi-method research that encompasses how humans respond to new safety technologies."

NIOSH appreciates the careful review and thoughtful recommendations provided to the MP. This document provides the MP's responses to the expert panel's recommendations and addresses how the panel's recommendation will inform the future directions of the Program.

Mining Panel's Summary Recommendations for Future Considerations

Recommendation 1: Disaster management research

Further human factors research is needed to assist mine rescue teams in the management of a disaster. The tension surrounding one of these events requires a unified approach as to how teams are managed

and deployed. As of now, the Mine Safety and Health Administration (MSHA) has the authority over any recovery action, but clear lines of command with an understanding of the responsibilities for all elements of the operation are imperative. Properly handling these complex interactions can mean the difference between success and failure in disaster response.

NIOSH addressing at this time: No

Rationale: NIOSH acknowledges the panel's recommendation that further human factors research is needed to support management of a mine disasters. NIOSH conducted both intramural and extramural research in this area from 2007 through 2009 [Alexander et al. 2010]. As the panel points out, MSHA has authority over the recovery action and approves response and recovery management plans proposed by mine operators at the disaster scene. The management of mine rescue teams at the scene of an event is *one element* of a complex mine emergency management system, requiring close coordination with MSHA and the involvement of multiple private mine rescue teams. Although the NIOSH Mining Program has experience with mine rescue team training and preparation (e.g., virtual reality, mine rescue contests, mine emergency response drills), the MP has carefully assessed its resources and determined that it will not actively pursue this intensive human factors research at this time. However, NIOSH will remain open to pursuing this specific topic in the future should there be an appropriate opportunity.

Recommendation 2: Automation research

Recommendation 2a. The Panel does not recommend that NIOSH research focus on developing new automation methods, but instead track trends in the industry and assess the H&S effects of these changes. More information is needed on the extent of, and emerging trends in, automation in the industry.

NIOSH addressing at this time: Yes

Rationale: We agree with this recommendation and in fact, in 2016, NIOSH brought together a panel of internal and external subject matter experts to develop a plan for establishing a research program to examine the impact of automation on mine worker health and safety within the NIOSH MP. The plan was implemented and led to a number of activities including the establishment of the Metal Mining Automation and Advanced Technologies Workgroup under the Mine Safety and Health Research Advisory Committee to organize a two-day workshop on this topic [NIOSH 2020], the publication of a Request for Information [NIOSH 2019], and the establishment of an Automation Team at the Spokane Mining Research Division. Based on these activities, NIOSH has engaged in two efforts to track trends related to the health and safety impacts of automated mining equipment: (1) NIOSH has established the Mine Automation and Emerging Technologies Health & Safety Partnership to provide an opportunity for industry, manufacturers, academia, labor, trade groups, federal agencies, and others who are working on autonomous mobile equipment and associated technologies to discuss the state of the technology, research findings, health and safety concerns, and regulatory considerations. The first meeting of this partnership is scheduled for summer 2020; (2) NIOSH is collaborating with researchers in Australia and the U.S. to assess and disseminate the global experience and lessons learned in implementing automated equipment in surface and underground mines.

Recommendation 2b. There is also a need to examine and better understand work organization factors that may occur with increased automation. For example, a recent strike at Lucky Friday Mine was triggered, in part, by the question of who would control the automated equipment that is transported underground—the underground miners or the surface miners? NIOSH could have an important role in

examining the effects of automated systems on work organization and miner health (e.g., stress levels, autonomy).

NIOSH addressing at this time: Yes

Rationale: The MP concurs with this comment and has already begun exploring the effects of automated systems on work organization. Research needs regarding work organization and change management are currently being defined by the MP's automation health and safety initiative as described above. When studying aspects of increased automation in the mining environment, it will be important to assess how work organization and the overall management system in the workplace is affected. Specifically, results of previous NIOSH research demonstrated that an organization must have leadership commitment and support, mechanisms to promote worker involvement in these areas, and also open lines of communication [Haas et al. 2019a; Haas et al. 2018]. General interventions around these factors can be developed and studied to better understand the workforce and how it may be affected by automation as well as how worker skills could evolve over time. Additionally, most research to date has found that technology affects job tasks and not jobs per se [Haas et al. 2019b; Haas and Colinet 2018; Haas 2018]; thus, a better understanding of how specific tasks may be impacted as well as how these changes affect individual job roles will be important as automation continues to occur within the industry. This research will help to ensure the mining industry is ready for changes to how work is organized and is managed in a way that reduces stress and uncertainty for the workforce.

Recommendation 2c. Moving equipment accounts for a substantial number of the accidents and fatalities that occur in coal and metal/nonmetal mines. Proximity detection systems, to help protect miners from contact with moving machinery, are currently required on continuous mining machines used in the face areas of underground coal mines. More research is needed to refine these proximity detection systems and to explore expanding these protective devices to all mobile face equipment.

NIOSH addressing at this time: Yes

Rationale: NIOSH appreciates this feedback and will continue our research efforts into refining existing proximity detection systems. Since proximity detection was not included in the topics selected for the MP review, some details related to work in this area may be helpful. Our initial research on proximity detection systems for continuous mining machines was conducted from FY 2011 through 2016. NIOSH has also conducted research on the application of this technology to mobile face equipment at underground coal mines—initially through a one-year pilot project in FY 2015 and then with an FY 2016–2018 project. Under these latest two projects, researchers evaluated proximity detection system performance in the laboratory and field as installed on mobile face equipment [Bellanca et al. 2019b], created numerical models of signal propagation in proximity detection systems [Zhou et al. 2018], explored alternative technologies to improve system performance [Bissert et al. 2017], evaluated safe stopping distances through dynamic simulations of mobile face equipment [Bellanca et al. 2019b; Jobes and Carr 2018], investigated the effects of metallic objects in the mine environment on system performance [Li et al. 2018, Zhou et al. 2019], investigated the effects of electromagnetic interference on system performance and strategies to mitigate those effects [Li et al. 2019b; Noll et al. 2018], built and evaluated a control system to stabilize system performance [Li et al. 2019a], and investigated the human factors associated with mineworkers' perception of the technology and task-technology fit [Bellanca 2019a; Swanson and Bellanca 2019].

We currently have an ongoing research task directed toward electromagnetic interference and electromagnetic compatibility considerations in underground mines based on issues found through our

completed research activities. After a thoughtful assessment of our resources, expertise, access to partners, and stakeholder interest, we are not expanding research to these protective devices for all mobile face equipment at this time, although the MP will remain open to pursuing this specific topic in the future should there be an appropriate opportunity. While our prior research was conducted specifically for underground coal mining equipment, many of the lessons learned apply to metal/nonmetal mines as well.

Recommendation 3: Self-escape research

The Panel suggests ongoing research focused on the human factors aspect of self-escape. When under stress, how do people react when mobilizing for and facilitating escape? The Panel feels that NIOSH may need to focus more on social science/behavioral research, while acknowledging the difficulty in determining how to prioritize research for low-probability events. The Panel suggests that it might be helpful to first summarize relevant self-escape research from firefighters and the military to inform priorities and next steps for NIOSH research in this area.

NIOSH addressing at this time: Yes

Rationale: The MP thanks the panel for this important input and we, too, believe that research focused on the human factors aspect of self-escape is critical. Most recent MP efforts to characterize the self-escape system have focused on what is required and what is lacking in terms of individual (rank-and-file miner) self-escape competence and the development of a framework to better prepare all underground miners to effectively respond to a mine emergency [The Group for Organizational Effectiveness & Aptima Inc. 2016a,b; Hoebbel et al. 2018; Ryan et al. 2018]. A competency framework "Self-Escape Core Competency Profile: Guidance for Improving Rank-and-File Miners' Self-Escape Competency" has recently been developed for dissemination to the industry, while research continues with a focus on the interactions between and among all human components of the escape system (e.g., mine management, other formal self-escape leadership positions, and rank-and-file miners) and the relevant technical and nontechnical skills required during initial response to a mine emergency.

In addition, a self-escape cognitive task analysis [The Group for Organizational Effectiveness & Aptima Inc. 2017; Keeney et al. 2018] and extensive review of the literature surrounding decision-making in the military and other high-risk occupations [The Group for Organizational Effectiveness Inc., 2017b] has been recently conducted under a NIOSH contract. Among other things, this review suggests that the focus of training should be nonroutine technical skills whenever possible, thereby freeing up the cognitive capacity required for performing critical nontechnical skills while under duress. This foundation provides the basis for training guidance and other materials being developed by NIOSH (e.g., "The Self-Escape Core Competency Profiles for Rank-and-File Miners"), which emphasizes frequent realistic, hands-on exercises, assessment, and reinforcement. In addition, "Emergency Decision-making: Underground Coal Mine Escape Scenarios"(publication pending), is a cognitive simulation that encourages users to practice naturalistic decision making in real-world scenarios.

NIOSH agrees with the panel that further exploration of human response to unanticipated and nonroutine events in high-risk industries other than mining will be critical for prioritizing related research to address self-escape in low-frequency and potentially high-severity mining events. NIOSH also agrees that a holistic approach to characterizing and evaluating the mine emergency response system (prevention, preparation, response, and recovery) is needed. At this time, NIOSH is conducting research that includes a thorough characterization of a highly effective "initial response" (self-escape) system and the development of strategies to continuously assess the state of this system. If effective,

this ongoing assessment framework can be applied to all aspects of emergency management to include prevention, rescue, and recovery.

Recommendation 4: Rib support research

Recommendation 4a. The Panel noted that it would be helpful to the industry to have a field tool to help predict conditions where rib supports need to be installed, as well as information on the types of support (rib bolts, "pizza pans," welded wire mesh, metal straps, and fiber and plastic mesh) needed to address specific ground conditions.

NIOSH addressing at this time: Yes

Rationale: We concur with the recommendation for the need for a field tool to address rib support. As mining operations move into deeper reserves and reserves are subjected to adverse multiple seam mining stress, coal rib stability will continue to become a greater challenge. Much of the rib support in U.S. coal mines is designed using a trial-and-error approach. There is an urgent need for an engineering-based coal rib design approach to define the minimum design requirements for rib control.

NIOSH is currently engaged in coal mine rib stability research that will produce the following tools for designing safe coal ribs: (1) a Coal Pillar Rib Rating (CPRR) procedure to quantify the competency of the ribs of coal pillars [Mohamed et al. 2015; Mohamed et al. 2018; Mohamed et al. 2020]; (2) understanding of the mechanism of coal rib deformation and the interaction between coal rib and rib support systems, such as mechanic bolts and fully grouted bolts through field monitoring [Mohamed 2020; Mohamed et al. 2020]; and (3) a standalone software application to design and analyze the primary rib supports.

Recommendation 4b. Panel subject matter experts also recommend that NIOSH perform research on rib support needs when the longwall shearer comes to the end of the panel and cuts into the open entry of the recovery room to better understand the supplemental supports needed in recovery rooms.

NIOSH addressing at this time: No

Rationale: While NIOSH acknowledges this feedback, the Institute does not currently have research planned to better understand the supplemental supports needed in recovery rooms. MSHA data on rib-related fatalities show that areas such as rib stability during longwall and room-and-pillar advance and pillar retreat in room-and-pillar panels are greater hazards. Therefore, after careful consideration, we have determined that we will not actively pursue this recommendation at this time. However, we will remain open to pursuing this specific topic in the future should there be an appropriate opportunity.

Recommendation 5: Longwall coal mining research

NIOSH is doing critical work to determine the interactive effects of longwall coal mining adjacent to frack gas wells, assessing the effect of subsidence-induced deformation on well casings. This research will provide MSHA with the data it needs to determine the dimensions of the barrier pillar to leave around pads with multiple frack wells. Further research is recommended, as within the next five years, longwall mining and underground coal reserves will be affected by thousands of frack wells drilled in the Northern Appalachian coalfield.

NIOSH addressing at this time: Yes

Rationale: We agree with this recommendation for further research in this area. Currently a significant research effort is underway to investigate and provide recommendations for preventing unplanned interactions between unconventional gas wells and operating coal mines [Su et al. 2018; Schatzel and Zhang 2019; Su 2017; Schatzel et al. 2019].

Over the next five years, about 500 shale gas wells will be influenced by longwall mining, and these interactions will provide NIOSH an opportunity to perform real-world case studies. Our stakeholders—which include MSHA, the Pennsylvania Department of Environmental Protection (PADEP), the West Virginia Department of Environmental Protection (WVDEP), Ohio Department of Natural Resources (OHDNR), coal operators, and gas operators—expect NIOSH to use scientific information derived from these case studies to assist in modifying the initial guidelines from our previous work to create final engineering guidelines and recommendations for future regulatory consideration.

Recommendation 6: Shotcrete research

NIOSH research has established standardized techniques for the application of shotcrete to rock, the evaluation of shotcrete mixes and provided standardized methods for evaluating results of shotcrete application. The shotcrete research program is an excellent example of research that is directly applicable to mining and tunneling industries, with appropriate involvement of stakeholders. The Panel feels that this area of research is approaching an End Outcome. Although NIOSH needs to maintain testing, it may not need to expand research in this area.

NIOSH addressing at this time: Yes

Rationale: The MP greatly appreciates the panel's input; however, NIOSH plans to maintain research in this area for the foreseeable future. Shotcrete manufacturers typically supply the strength properties of shotcrete. However, mine operators also need to understand the performance characteristics of the entire shotcrete support system which depends on reinforcement, installation techniques, the type of ground, and environmental conditions. Several mining companies have requested NIOSH assistance in addressing ground stability issues concerning time-dependent aspects of support degradation, including methods for determining the long-term integrity of in-place shotcrete and backfill. This research will require the testing of new shotcrete support systems to determine their long-term performance.

NIOSH is uniquely equipped to perform the research needed to provide performance characteristics of shotcrete support systems, particularly under specific loading conditions [Martin et al. 2015]. NIOSH also uses the high-energy high-displacement (HEHD) test machine to identify and compare the support characteristics of different ground support systems that incorporate shotcrete to quantify load capacity, energy absorption, and rupture displacement [Raffaldi et al. 2017; Raffaldi et al. 2018]. As mining methods, ground control systems, and shotcrete characteristics evolve over time, we anticipate that there will be a continued need for the unique research that NIOSH performs in this area.

Recommendation 7: Pillar research

Recommendation 7a. S-Pillar software created a standardized approach based on case histories, and the industry uniformly relies on it. Prior to the development of S-Pillar software, the design of underground stone pillars was not standardized. The dissemination of S-Pillar software was a multi-pronged, successful effort. The Panel recommends that NIOSH continue to add case histories to improve pillar design under dipping limestone beds, in multi-level mines, and with deeper overburden.

NIOSH addressing at this time: Yes

Rationale: NIOSH concurs with this recommendation and believes that it is critical that we continue to improve the S-Pillar software. The ground fall injury rate in underground stone mining has not decreased at the same rate as the ground fall injury rate in coal mining during the past decade and, in fact, it has increased significantly over the past two years. Likewise, the fatality rate in the underground stone sector has increased overall during the past decade, while the underground coal sector fatality rate has declined. These trends are likely to increase as more mines operate under increasingly adverse geological conditions, including deeper cover and more steeply dipping strata.

In addition to adding cases in an empirical database as recommended by the panel, the stability of underground limestone mines located in steeply dipping, deep, and/or multilevel strata is currently being investigated [Gangrade et al. 2019; Murphy et al. 2018; Slaker et al. 2019], and NIOSH is reviewing factors that form the basis of current pillar design guidelines [Sears et al. 2018; Sears et al. 2019], with the intent of using these case study results and parametric studies to establish universal design guidelines for stone mining.

Recommendation 7b. NIOSH should consider the S-Pillar program research applicability for other commodities (e.g., salt, trona), multi-level quarries, and deeper mines that have had catastrophic failures.

NIOSH addressing at this time: No

Rationale: We thank the panel for its thoughtful consideration of how S-Pillar program may be applied in the future. Currently, NIOSH's pillar design efforts in hard rock mines are focused in the stone mining sector because this sector has a relatively higher risk of ground instability. Unfortunately, design approaches are fundamentally different for other ore types such as salt and trona, limiting the applicability of the S-Pillar software. Therefore, building upon S-Pillar's limited applicability to other ore types would require a substantial new research investment. Based on a careful assessment of MP resources and available expertise, NIOSH has determined that it will not actively pursue this recommendation at this time. However, NIOSH will remain open to pursuing this specific topic in the future should there be an appropriate opportunity.

Recommendation 8: Surface mining and quarry highwall stability research

The Panel noted that there was no discussion of surface mine or quarry highwall stability in the Evidence Package, and suggested that these would be important areas for future research in ground control.

NIOSH addressing at this time: Yes

Rationale: The MP agrees with this recommendation, as we recognize that our research into ground control issues at surface mining operations has been limited to date. Although the MP recognizes the need for research to improve highwall safety at surface mines, there is only very limited research in this area. This includes contacts established with a surface mine collaborator, which have resulted in an initial field project and preparation of a conference presentation. In addition, work is currently being initiated to examine catch bench design and nonstandard applications of slope stability radar.

NIOSH also funded a contract with the University of Nevada Reno (UNR) on "Developing a New Tension Crack Analysis System to Increase the Safety of Open Pit Slopes" (Contract 200-2017-85360). This work utilized innovative data analytical techniques coupled with drone imagery of the pit benches and slopes

to provide an early warning system of potential failures. UNR is considering further development of this system.

Recommendation 9: Seismic monitoring research

Coal and metal mine seismicity monitoring requires a great deal of specialized expertise unique to NIOSH. The primary application of this research is in characterizing coal bump and rock burst potential in metal/nonmetal mines. Additional research is recommended for the application of seismic networks in coal and deep metal mines.

Similarly, for deep metal mines, seismic monitoring research on ground control issues may be relevant to address specific bounce/burst/collapse problems. NIOSH could consider lessons learned from the Brazilian dam collapse, as this event involved issues related to soil/mine waste liquefaction, seismicity, and ground control.

NIOSH addressing at this time: Yes

Rationale: NIOSH appreciates this feedback and will continue to seek opportunities to promote the use of seismic monitoring. Additional seismic research will continue with a new "Unconventional Monitoring" project, which will also examine other monitoring technologies as applied to surface and underground coal, metal, and nonmetal mining. New technologies and data processing techniques will likely improve the management of medium- to large-scale stability issues such as bursts and collapses [Boltz et al. 2019; Chambers et al. 2019; Pankow et al. 2018]. Key aspects of the planned work involve the use of distributed acoustic sensing (DAS) in underground mines and the development of better processing and interpretation algorithms [Chamberlain et al. 2018; Chambers 2018; Megies et al. 2018]. Continued work on improving mine-induced seismicity monitoring [Kim and Larson 2019] will leverage the existing in-house expertise. With existing projects and projects proposed in the Mining Program Strategic Plan, research on application of seismic monitoring in deep metal and coal mines will continue.

Recommendation 10: Respirable crystalline silica research

Recommendation 10a. NIOSH recognizes the need to continue its efforts on miniaturizing RCS monitoring technology and developing a real-time monitoring device. The Panel questioned whether there may be different, more optimal dust suppression methods that should be explored now that the evidence points to RCS as a major relevant exposure in underground coal mines. The Panel also suggested that NIOSH explore interactions between RCS and diesel particulates.

NIOSH addressing at this time: Yes

Rationale: We concur with the panel's recommendations and in fact, the MP is developing enhanced engineering controls to reduce respirable dust exposures in coal mines with a focus on respirable crystalline silica (RCS). This research will evaluate different strategies for reduction including using water spray additives and aqueous foams and the use of flooded bed scrubber systems.

Regarding the interaction between RCS and diesel particulate matter (DPM), NIOSH's efforts are focused on addressing various research issues pertinent to control strategy and technology and monitoring of RCS and diesel aerosols in underground mines. However, the MP concurs with the panel that additional research is needed to assess the health effects of simultaneous exposures to these aerosols. Underground miners and other workers [Maximilien et al. 2017; Galea et al. 2017; OSHA-NIOSH 2012]

are often exposed to both of these carcinogens in the workplace. Although the literature offers very extensive evidence of the effects of both RCS and diesel exhaust on various health endpoints, very limited information exists on the synergistic effects of the simultaneous exposures of underground miners and other occupations to those health endpoints. A study conducted by NIOSH's Health Effects Laboratory Division (HELD) and West Virginia University [Farris et al. 2017] indicated that noninflammatory doses of DPM had the capacity to increase silica-induced lung injury, inflammation, and onset/incidence of fibrosis in rats. An ongoing study by the same researchers is examining the impact of load and clearance on the combined exposures.

Recommendation 10b. Several Panel members feel that current use of the CPDM does not enable optimal sampling and monitoring to enhance dust control programs, in part due to regulatory constraints. NIOSH could play an important role as the honest broker in identifying ways to optimize the use of the CPDM as part of a holistic approach to reducing mining exposures.

NIOSH addressing at this time: Yes

Rationale: The MP appreciates this feedback and will continue to seek opportunities to promote the adoption of the CPDM to optimize its use for reducing miner's exposure to dust. For example, NIOSH recently completed a longitudinal study to identify what individual miners learned about their respirable coal mine dust (RCMD) exposure based on CPDM use, corrective actions taken, and miners' behavioral changes to reduce personal exposures [Haas et al. 2016; Haas and Helton 2017; Haas and Colinet 2018]. Results show that it is critical for the organization and management to provide a medium for miners to learn how the CPDM works and what the dust data output means for their personal health. After workers learned that dust exposure information could be used immediately to reduce their RCMD exposure, their perceptions of the CPDM improved as well as their protective health behaviors—showing that increased communication and supportive communication can positively impact behavior.

While this research is directed at factors that influence proactive secondary and primary prevention behaviors with and without dust monitoring technology, the MP can also develop new communication interventions and recommendations that can be implemented to increase prevention behaviors and further support mine management and workers' efforts to minimize dust exposure.

The MP has also made the development of a low-cost noncompliance-based respirable dust monitor part of our annual Broad Agency Announcement (BAA) solicitation for the last several years and is funding several contracts in this area. Our goal is to be able to equip all underground miners with a device to indicate their exposure to respirable mine dust, enabling them to take appropriate actions as part of a holistic approach to reducing mining exposures—as suggested by the panel.

Recommendation 10c. Panel members also expressed concerns about whether compliance sampling of designated occupations is representative of non-sampled miner exposures.

NIOSH Addressing at this time: No

Rationale: NIOSH acknowledges this feedback and understands the concern raised by the panel regarding whether or not compliance sampling of designated occupations adequately represents the exposure of workers who are not sampled. However, we believe that, when implemented appropriately within the context of an appropriate dust control program, using the designated occupation (DO) approach for compliance sampling to protect miner's respiratory health is well supported by both MSHA and NIOSH data as described below. Although we are not currently conducting additional research in

this area by sampling other occupations, the MP will remain open to pursuing this specific topic in the future should further data or analysis suggest otherwise.

MSHA's approach to controlling worker exposure to respirable coal mine dust has historically relied on two main components: designated occupation sampling and mine ventilation plans [Tomb 1990]. During MSHA's quarterly dust surveys prior to the passage of its dust rule in 2014, inspectors would sample a minimum of five occupations at each mechanized mining unit (MMU). The inspectors would also ensure that the dust control parameters specified in the ventilation plan approved by the District Manager were being utilized during sampling. If all results from the inspector-collected samples were below the dust standard, the dust control parameters in the plan were assessed as effective. The occupation that had the highest dust exposure would become the DO. A second occupation with the potential for high exposure would become the designated area (DA) sample. Mine operators would then be required to maintain the plan parameters on a routine basis and, also, to conduct bimonthly sampling of the DO and DA to demonstrate ongoing compliance with the dust standard.

The premise is that if the implemented plan parameters controlled the dust exposures of the highest exposed workers (DO and DA) below the applicable dust standard, then all other occupations on the MMU would also be protected. Data show that longwall occupations typically have higher respirable dust exposures and continuous miner occupations typically have higher silica exposures [NIOSH 1995; Tomb et al. 1995]. Continuous miner and roof bolter operators have also been diagnosed with lung disease [Wade et al. 2011; Reynolds et al. 2018], indicating elevated dust exposures for these occupations.

After promulgation of the new dust rule in 2014, MSHA still relies on designated occupation sampling and the ventilation plan, but with some modifications. Although MSHA continues to conduct quarterly dust surveys, the DO is specifically defined in the new rule for each type of mining (continuous, conventional, or longwall) with the DA occupation now identified as the other designated occupation (ODO). Based upon historic sampling results, MSHA has designated the continuous miner operator (continuous), cutting machine operator (conventional), and tailgate-side shearer operator (longwall) as the DOs that must be sampled by mine operators on a quarterly basis with the CPDM. In the new rule, roof bolter operators and jacksetters are identified as the ODOs as well as face haulage operators on super-sections and MMUs utilizing blowing face ventilation. When considered necessary, the District Manager also has the authority to specify an additional ODO or ODOs in the ventilation plan.

If NIOSH were to prioritize this research in the future, our focus might be to (1) verify that individuals identified as DO and ODO utilize the experience gained while wearing the CPDM to modify their exposure to RCMD even when not wearing the CPDM, and (2) conduct exposure studies to verify that the other mining occupations not included in the DO or ODO have no excessive exposures. That said, a challenge to collecting data representative of the mines where risk of pneumoconiosis is greatest is that mines with the very unsafe work practices that were described to NIOSH by miners with progressive massive fibrosis [Reynolds et al. 2018] are not likely to participate in NIOSH research.

Recommendation 11: Diesel particulate research

Further exploration of the effects of diesel particle size and number in addition to measurements based on mass concentration will enhance the applicability of NIOSH DPM research. Ongoing research on the development of science-based technology, and its dissemination, is vital to protect miners from the effects of diesel particulate exposures, including partnerships with toxicologists and enhanced cross-sector collaborations.

NIOSH addressing at this time: Yes

Rationale: We thank the panel for this recommendation and will continue our efforts to routinely characterize size distributions, concentrations, and chemical properties of sub-1 µm and sub-10 µm aerosols using mass, number, and surface area metrologies through state-of-art instrumentation, devices, and equipment. These include the fast mobility particle sizer (FMPS), scanning mobility particle sizer (SMPS), electrical low-pressure impactor (ELPI), NanoScan, optical particle sizer (OPS), electrical particle sensor, and thermal-optical transmittance-evolved gas analysis (TOT-EGA). This instrumentation is used in field studies conducted at a longwall section of a trona mine, the continuous miner section of an underground coal mine, in various sections of a molybdenum mine, and in the Pittsburgh Mining Research Division (PMRD) laboratories. The use of various metrologies is particularly important during evaluations of control technologies and strategies based on implementation of advanced diesel engine and exhaust aftertreatment technologies (EPA Tier 4 final and Euro Stage V). The MP is collaborating with NIOSH HELD on the characterization of physical and chemical properties of various aerosols using scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy (EDS). The aforementioned instrumentation and methods are also being used to develop alternative mass-, number-, and surface-area-based methodologies for sampling and measurements of DPM in underground coal mines.

Recommendation 12: Mine dust particle research

The Panel believes that understanding these fundamental characteristics of mine dust particles is vital to controlling exposure hazards and associated health risks, and should be prioritized in future NIOSH research (as recommended in the 2018 National Academies of Sciences, Engineering, and Medicine's publication on Control of Respirable Coal Mine Dust Exposure in Underground Mines) [NIOSH 2018].

NIOSH addressing at this time: Yes

Rationale: The MP agrees with this recommendation and believes that such understanding should be prioritized. NIOSH responded to the NAS report by including characterization as a focus area in the FY 2019 BAA solicitation; in response, four contracts were issued:

- Michigan Technological University, Temporal and Spatial Characterization of Respirable Coal Mine Dust Using Area Monitoring Devices and X-ray CT
- Pennsylvania State University, Characterization of Submicron-/Nano-scale Coal Dusts and Their Effects on Miners' Pneumoconiosis and Lung Cancer for Appalachian Coal Mines
- University of Nevada, Reno, Characterization of Respirable Coal Mine Dust Size Distribution, Chemical Composition, and Source Contributions
- Virginia Tech, Respirable Crystalline Silica Characteristics and Sources in U.S. Underground Coal Mines

In addition, two additional contracts were awarded through the NIOSH capacity-building BAA solicitation that address respirable dust, including characterization:

- NMIM&T, Respirable Coal Mine Dust (RCMD) Research: Characterization, Deposition, Monitoring, and Mitigation of RCMD and Capacity Building for Mine Health and Safety
- Virginia Tech, Respirable Coal Mine Dust: Mineral Content Sources, Monitoring and Control, and Building Capacity to Protect Miner Health

These six contracts directly address both the panel's recommendation as well as the NAS report recommendations. Intramurally, NIOSH field surveys will further seek to characterize source, size,

composition, and associated occupational exposures to airborne particulate under current mining conditions. These in-mine surveys will also benchmark ventilation and dust control practices to identify possible common traits in successfully managing respiratory health hazards.

Recommendation 13: Collaboration with other federal agencies

NIOSH is well-positioned, as part of CDC, to strengthen its communication and collaboration with its parent agency on topics that cross the boundary between workplace/occupational health and environmental/public health exposures. There seems no reason not to formalize efforts on data gap identification and data collection, and the Panel recommends that NIOSH consider how best to do so, going forward. Further, since NIOSH brings expertise and insight on how to integrate research on worker health with public health and the environment, NIOSH should consider how to work more closely with sister agencies (e.g., the Environmental Protection Agency) to assure that foundational principles (e.g., the hierarchy of controls for primary prevention) inform policy decision-making.

NIOSH addressing at this time: Yes

Rationale: NIOSH concurs—maintaining and strengthening engagement and collaboration with both our parent as well as sister agencies is important. The NIOSH MP will continue to regularly interface with our parent organization and sister agencies on mutual topics of interest and those topics of interest to our stakeholders. For example, NIOSH currently participates in the Interagency Working Group on Asbestos in Consumer Products (IWGACP) that was recently formed by the Food and Drug Administration (FDA). The IWGACP consists of 38 subject matter experts representing the following U.S. federal agencies: FDA, NIOSH, National Institutes of Health (NIH), National Institute of Environmental Health Sciences (NIEHS), Occupational Safety and Health Administration (OSHA), Environmental Protection Agency (EPA), Consumer Product Safety Commission (CPSC), National Institute of Standards and Technology (NIST), and Department of Interior's U.S. Geological Survey (USGS). The focus of the IWGACP is to support the development of standardized testing methods for asbestos and other mineral particles of concern that could potentially affect consumer product safety. The IWGACP is specifically addressing terminology and definitions of asbestos and other elongate mineral particles (EMPs) of health concern in talc and talc-containing consumer products, recommend methodological improvements for measuring asbestos in talc and talc-containing consumer products, and recommend laboratory reporting standards for testing talc and talc-containing consumer products. Since 2010, NIOSH has also served on a committee composed of occupational and environmental regulatory and research agencies including OSHA, MSHA, the EPA, NIOSH, and the National Institute for Environmental Health Sciences (NIEHS) (the OMNE Committee) to ensure that our research is integrated into policy decision-making. NIOSH also regularly interacts with MSHA to ensure that rulemaking and policies are based on sound science.

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