National Institute for Occupational Safety and Health

NIOSH

Comments to MSHA

Comments of the National Institute for Occupational Safety and Health on the Mine Safety and Health Administration Request for Information to Improve the Health and Safety of Miners and to Prevent Accidents in Underground Coal Mines

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The National Institute for Occupational Safety and Health (NIOSH) has reviewed the Mine Safety and Health Administration (MSHA) Request for Information (RFI) *Request for Information to Improve the Health and Safety of Miners and to Prevent Accidents in Underground Coal Mines* published in the *Federal Register* (FR) on February 26, 2015 [80 FR 10436]. NIOSH offers the following responses and comments to assist MSHA.

A. Requirements for Developing and Implementing Roof Control and Mine Ventilation Plans

Question IV.A.3: Please comment on the recommendation to increase the minimum quantity of air. What are the advantages, disadvantages, impact on miner health and safety, and costs associated with an increase in the minimum quantity of air for longwall mines? How could this minimum quantity of air be determined and where would it be measured?

Response: Potential increases in respirable dust need to be considered when contemplating an increase in air quantity. An increase in air quantity results in an increase in air velocity. Past longwall research on the impact of increased air quantity/velocity on airborne respirable dust levels found mixed results regarding potential impact on miners' health. Underground dust sampling conducted by MSHA indicated that increases in face air quantity reduced designated occupation dust levels [Haney et al. 1993] or did not adversely impact respirable dust levels [Tomb et al. 1990]. In both studies, the shearer was the primary source of respirable dust generation and water sprays on the machine were used to wet the coal product. However, in laboratory studies simulating shield-liberated dust, the coal product contained less than 1% moisture and increases in air velocity resulted in increased airborne respirable dust [Chekan et al. 2001].

Question IV.A.4: What is the most effective way to control methane, oxygen, and respirable dust levels to assure the health and safety of miners?

Response: NIOSH summarized best practices and technologies for successful dust control in the mining industry [NIOSH 2010a] including the use of water sprays to suppress airborne dust and to prevent generation of airborne dust, barriers and enclosures to contain dust, and use of the flooded-bed dust scrubber to remove dust during mining. NIOSH also outlined technologies and ventilation practices used to control levels of respirable dust, methane gas, and oxygen in underground mines [NIOSH 2006, 2008]. These practices include methane drainage prior to mining, use of gob vent boreholes to remove methane during mining, use of bleeders to maintain proper ventilation flow around gobs, and the use of water sprays and ventilation airflow to control accumulations of methane during mining. Mine operators can examine the various controls identified by NIOSH and select those most appropriate for their specific operation.

B. Atmospheric Monitoring Systems and New Technology for Remote Monitoring Systems

Question IV.B.7: Where should continuous remote monitoring systems be installed in underground coal mines? Please be specific as to locations and provide rationale, including the impact on miner health and safety.

Response: Remote monitoring via atmospheric monitoring systems (AMS) can deploy a large number of sensors within the underground workings to provide extensive coverage of critical areas. One such remote monitoring system is a tube bundle system (TBS) as described by Zipf et al. [2013]. The primary uses of this system are early detection of possible spontaneous combustion products, such as CO and CO_2, and maintaining sealed areas inert, with oxygen levels below 10%. The authors detail the placement of sampling tubes at longwall tailgates and returns, inby gob isolation stoppings, and in the main mine return to detect potentially hazardous gas concentrations and the development of a heating due to spontaneous combustion. Remote monitoring with a TBS might also provide mine atmosphere and gas composition data analyses after a catastrophe occurs in an underground mine, if the sampling tubes are not damaged. However, Zipf et al. noted that TBSs are not an alternative to mandated monitoring of gas and ventilation airflow, but are an option for supplementing an overall mine atmospheric monitoring strategy.

Based upon the work by Zipf et al., NIOSH suggests that MSHA consider the application of remote monitoring systems in critical areas. For a bleederless longwall operation, these include locations outby the longwall tailgate and inby the mix-point regulator in the back return air path to provide mine workers with notice of elevated levels of methane and gob gases, and a location immediately inby the gob isolation stopping to monitor for products of combustion (POCs) from self-heatings. The sampling location inby the mix-point regulator also provides mine workers with notice of expansion of potentially dangerous gob gases into the tailgate during low barometric pressure events. Despite this successful demonstration, NIOSH has not investigated the deployment of such a continuous monitoring system in a bleedered longwall operation.

Question IV.B.8: Under what conditions should additional gas monitoring sensors and sensors that measure air velocity and direction be used to monitor the longwall face and its tailgate corner to minimize accumulations of methane, other gases, and dust? Where should these sensors be located?

Response to first question only: In the United States, longwall gobs are usually ventilated with bleeder systems. These bleeders are designed to dilute, render harmless, and carry away flammable, explosive, noxious, and harmful gases, dusts, smoke, and fumes from the active mining areas. One of the most critical areas for longwall ventilation is the tailgate corner. Krog et al. [2014] showed that positive ventilation may be obstructed if the tailgate entry immediately inby the longwall face cannot be kept open due to caving of the roof and/or floor heaving. Brune and Sapko [2012] used computational fluid dynamics (CFD) simulations with the Fire Dynamics Simulator (FDS) developed by the National Institute of Standards and Technology (NIST) to analyze the ventilation patterns and potential methane accumulations and mixing patterns in the tailgate corner area. Both efforts showed that a total collapse occurring in the supported entry adjacent to the longwall tailgate corner would adversely impact effective ventilation of that corner, allowing methane to accumulate in that area or to flow outby to gather near the tail drum. In addition, Brune and Sapko [2012] concluded that sensors typically located on the shearer body and on the tailgate drive motor may not pick up these methane accumulations, thus creating an explosion hazard. Their work showed that explosive levels of methane could be drawn to the face from areas inby the shield line and accumulate near the tail drum. Based on the results of these studies, NIOSH suggests that MSHA reevaluate the locations of monitoring devices on longwall equipment to more accurately measure dangerous methane accumulations as the shearer cuts into the tailgate. This should include locations to detect movement of methane flowing toward the face from areas behind the shields.

Question IV.B.12: What types of continuous remote monitoring systems can continue to safely operate and function after an explosion, fire, or any other mine accident? How long can such systems operate after an explosion or fire, since power is likely to be deenergized due to the emergency? What can be done to improve the survivability and reliability of continuous remote monitoring systems after an explosion or fire?

Response: Tube bundle and fiber optic monitoring systems are applicable for monitoring post-accident environments because neither requires power underground to be operational. TBSs are used extensively in Australia, although they are not widely deployed in this country. The U.S. Bureau of Mines [1975] described the five-month deployment of sampling tube bundles at an underground mine fire in West Virginia. The TBS was a key tool in the first successful U.S. effort at remote fly ash sealing of a mine fire and re-ventilation prior to recovery of the underground workings. The TBS proved invaluable in assuring a safe mine recovery. Of particular importance was the immediate monitoring of gas concentrations during potentially hazardous activities, with the system providing timely warning of dangerous gas concentrations which developed during surface and underground recovery activities. Zipf et al. [2013] documented the installation and operation of a tube bundle system at an active mining operation, showing that the system could accurately monitor atmospheric conditions in remote workings and sealed areas. Protection of the tubes through shotcreting or placement in buried conduit would improve the likelihood that a tube bundle system would provide mine atmosphere gas composition data after an underground mine catastrophe.

The design and short term deployment of a fiber optic-based monitoring system is described in detail by RSL Fiber Systems [2014]. Such a system could transmit data up to 20,000 feet and could remain operational indefinitely as no power is required underground.

Question IV.B.13: What types of technologies exist to remotely determine methane-air mixtures and other gas, dust, and fume levels in bleeders and bleederless ventilation systems, other than traditional AMS and tube-bundle systems? Please be specific and note if this technology is practical and feasible.

Response: The U.S. Bureau of Mines [1992, 1995] discussed use of fiber optic-based sensors and their application for monitoring of methane and other gases. This technology is gaining acceptability for its ability to transmit data over distances approaching 20,000 feet. NIOSH continues to investigate potential applications of fiber optic-based sensors for monitoring methane and other gases.

Fiber optic systems have been developed and tested in an underground mine environment to measure methane and temperature in a bleeder split, a ventilation split ventilating a sealed area, a bleeder evaluation point, and on idler bearings on a conveyor belt (temperature sensing cable) [RSL Fiber Systems 2014]. While it is not confirmed that this is practical and feasible for underground mines for the purpose of monitoring, it should be studied and evaluated to show its benefits. Therefore, NIOSH continues to examine the suitability and deployment of fiber optic-based sensors in underground coal mines.

Question IV.B.15: If fiber optic technology is capable of operation when electrical power is deenergized underground, how long can such systems remain operable after power is deenergized? What is the maximum distance such technology is capable of transmitting data to the mine surface?

Response: The fiber optic system developed under NIOSH contract [RSL Fiber Systems 2014] can transmit data up to 20,000 feet. Since underground power is not required, such a system could remain operational indefinitely.

Question IV.B.16: Please describe how fiber optic technology can be used in areas of the mine that require the use of permissible or intrinsically safe equipment.

Response: Fiber optic detection of gases is a non-powered, passive technology for detection of hazardous gases. The U.S. Bureau of Mines [1992] explored fiber optic detection of methane gas and stated that the system was an electrically passive and intrinsically safe system using the light-absorbing properties of the gas. A prototype fiber optic system for detection of nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO) was built and tested by the U.S. Bureau of Mines [1995]. The primary advantage of this fiber optic system was its reliability in locations where electrical power was not available. NIOSH continues to investigate potential deployment strategies for fiber optic-based sensors in underground coal mines and proposes that MSHA consider future applications for such technology.

C. Rock Dust

Question IV.C.17: What specific tests should be performed to monitor the quality of rock dust to assure that the rock dust will effectively suppress an explosion in the mine environment?

Response: The optimum rock dust particle size to arrest explosion propagation was reported by the U.S. Bureau of Mines [1933] where at least 70% of the particles were required to have a size less than or equal to 200 mesh, or approximately 75 microns. At that time, practical experience showed that superfine rock dust tended to agglomerate and form cakes without the use of anti-caking additives. Research has also showed that the rock dust behaved as a thermal inhibitor [Sapko et al. 1989a].

Amyotte et al. [1995] found that rock dust particle size had a significant effect on the amount of rock dust required to inert. The increase in inerting effectiveness with a reduction in rock dust particle size can be explained by the corresponding increase in rock dust surface area, which leads to greater radiant heat absorption.

A specific surface area designation improves the uniformity of rock dust particle size distributions in lieu of relying solely upon the percentage finer than 200 mesh. Cybulski [1975] found considerable differences among the percentage of particles passing 75 microns but much less variability in measurements of rock dust surface area. These variabilities, however, produced insignificant differences in inerting potential. He discussed a method to measure surface area of rock dust by measuring the velocity of airflow through a compressed layer of dust. Later, a similar method was standardized in ASTM C204 "Standard Test Methods for Fineness of Hydraulic Cement by Air–Permeability Apparatus." The ASTM C204-11 [2011] test method covers determination of the fineness of hydraulic cement, using the Blaine air-permeability apparatus, expressed as total surface area in square centimeters per gram. The Blaine air-permeability apparatus is initially set up using a standard reference material (SRM 114q) purchased from NIST [2008]. This apparatus includes a Certificate of Analysis with certified values of surface area for calibrating the Blaine air-permeability apparatus. Once calibrated, this reference material is compared to the surface area of a rock dust.

Rock dust should also be tested for dispersibility. The National Coal Board (NCB) of London specification for limestone dust, Amendment No.1 March 1987, describes a specification to establish essential requirements, including methods of testing, for limestone dust used underground as a safety measure against coal dust explosions [NCB 1987]. The following NCB dispersibility test is a simple and straight forward method. It places fifty (50) grams of dust in a 250 milliliter (ml) beaker, shakes gently with 100 ml of distilled water at room temperature added to the beaker. The beaker and its contents should be at room temperature for 24 hours after which time the contents should be decanted from the beaker. The dust should be tested immediately for dispersibility by blowing on the sample by mouth or other appliance and reporting whether the samples disperses. Although decidedly low-tech, this technique can provide an immediate answer on the dispersibility of the sample.

Question IV.C.18: What materials produce the most effective rock dust?

Response: Cybulski [1975] summarized research in Poland and stated "...the clay-slate dust, limestone dust, and also dolomite dust are equally effective as a means of preventing the danger of the propagation of explosions." The U.S. Bureau of Mines [1927] stated "Limestone and dolomite dusts are preferential rock-dusting material, as they are free from silica and are whitish in color."

Question IV.C.19: What are the advantages, disadvantages, impact on miner health and safety, and costs of limiting rock dust to light-colored inert materials, such as limestone and dolomite?

Response: The U.S. Bureau of Mines [1927] stated advantages of light-colored inert materials: "Their light color is in great contrast to the blackness of coal dust, and discloses to the eye when there are dangerous accumulations of coal dust. A further advantage of light color is the aid to illumination."

The color of rock dust is important because: (1) inspectors use the visual assessment to identify and cite excessive accumulations of coal dust [MSHA 2013a,b,c]; (2) the mine fire boss uses visual contrast between coal and rock dust to help schedule and manage the application of additional rock dust; and (3) light color improves visibility for identifying potential tripping hazards [Sammarco et al. 2012].

Question IV.C.20: Please provide information on the types of impurities that could degrade rock dust performance. What tests or methods can be used to detect the presence of impurities?

Response: Impurities such as combustible matter (i.e., organic material such as coal bands) can render rock dust less effective in inerting a coal dust explosion. A low temperature ashing test could be administered to determine the amount of combustible matter contained in the rock dust [NIOSH 2010b].

Question IV.C.21: What particle size distribution for rock dust would most effectively inert coal dust? What should be the maximum particle size? What should be the minimum particle size? Please explain and provide the rationale for your answer.

Response: Research has shown that surface area and particle size distribution are important factors in the ability of a rock dust to effectively inert a coal dust explosion. Man and Harris [2014] indicated that rock dust particles greater than 75 µm do not participate in inerting an explosion. Therefore, the maximum particle size of rock dust should be 75 µm or smaller (100% passing through a 200-mesh sieve). However, a minimum rock dust particle size designation is more difficult to specify based upon the wide variability in particle size distributions found in rock dust supplies currently on the market. Amyotte et al. [1995] acknowledged the inerting effectiveness of smaller rock dust particles due to their larger surface area; very fine particles (<20 µm) offered the most significant contribution to flame quenching and explosion suppression.

Question IV.C.23: How can the potential of rock dust to cake be minimized? Are objective and practical tests available to determine the caking potential of rock dust? If so, please explain and provide documentation.

Response: The caking potential of rock can be minimized through the use of additives mixed with or sprayed on untreated rock dust.

Tests to assess the dispersibility and, hence, the caking potential of rock dust have been discussed by the National Coal Board [NCB 1987] and Powell and Taylor [1964]. The NCB developed a simple test to assess the dispersibility and, hence, the caking potential of rock dust. The rock dust and water are mixed in a container, allowed to sit for 24 hours, after which time the liquid is removed from the container. The rock dust is tested immediately by blowing on the sample to see if it disperses. Powell and Taylor suggested sprinkling the dust onto the surface of water. Untreated dust is wetted, sinks rapidly, and disappears from the surface in about two minutes; a well-waterproofed dust will float for months. These authors also presented a method to determine the degree of waterproofness (resistance to caking) based on the rate of wetting. Water in equilibrium with the atmosphere contains sufficient carbon dioxide in solution to give a pH of 5.0. As the limestone dust on the surface is wetted and sinks, the pH of the solution rises. Bromo-Cresol Purple, which changes from yellow to purple in the range pH 5.2-6.8, is a suitable indicator for measuring the change in pH. The time required to produce a complete change of color throughout the solution is a measure of the rate of wetting, and therefore of the degree of waterproofness of the waterproofed limestone.

Question IV.C.24: Please provide information on how fine particles (less than 10 μm) may increase the likelihood of caking in rock dust.

Response: Christakis et al. [2006] described a numerical model of the caking of granular materials, but NIOSH has not explored the applicability of this model to rock dust. Generally, the processes of powder caking due to moisture migration for granular and soluble materials can be summarized in the following way. When particles wick moisture, their surfaces are wetted and liquid bridges form between the particles. A small amount of calcium carbonate dissolves in water and when the moisture evaporates, recrystallization causes solid bridges to form between the particles during the drying process, which bind the particles together. This irreversible consolidation of bridges results in particle agglomeration and the formation of cakes.
The authors stated that the bridges formed between particles are proportional to the inverse of the particle diameter cubed. Accordingly, a reduction in particle diameter increases bridge thickness by the third power.

Question IV.C.25: Can rock dust be treated with additives that would reduce caking? Would the additive enhance or diminish the ability of the rock dust particles to quench a coal dust explosion and, therefore, impact the effectiveness of the rock dust to inert coal dust? Please provide information on the chemical composition of any suggested additives, the quantities needed, costs, and potential impact on miner health and safety. If available, what areas of an underground coal mine would need to be treated with non-caking rock dust? Please explain and provide the rationale for your answer.

Response: In underground coal mines in Poland, rock dust is treated with additives to reduce caking tendency. Cybulski [1975] described methods to make rock dust waterproofed. To waterproof limestone dust, or any stone dust, small quantities of fatty acids (i.e., stearin) are added to the limestone.

Instead of the natural stearin, other hydrophobic substances, such as synthetic stearin, synthetic pitch, olein, or tallow acids, may be added. To make the limestone dust sufficiently waterproof, Cybulski [1975] detailed the addition of 0.15% - 0.25% of these substances. A thin layer of the hydrophobic substance on rock dust particles prevents the particles from absorbing water for extended periods. The waterproof dust remains dispersible during exposure in humid and even wet conditions and is more dispersible than ordinary limestone dust. Waterproofed rock dust is less cohesive than non-waterproofed dust [Cybulski 1975]. The increased dispersibility of a waterproof dust improves its effectiveness for inerting coal dust explosions. The Coal Industry National Consultative Council (CINCC) [1960] recommended the primary use of waterproofed limestone in wet and humid roadways.

NIOSH investigated the development of an anti-caking rock dust through a contract with IMERYS [IMERYS Carbonates 2014]. This treated rock dust was composed of an IMERYS base rock dust treated with 0.125% calcium stearate. Calcium stearate is a long-chain hydrocarbon carboxylate of calcium that is also found in some lubricants and surfactants. Testing in the 20-liter explosion chamber showed that such small amounts of calcium stearate added to the base rock dust did not impact inerting effectiveness. NIOSH is currently investigating potential health effects of exposure to respirable-sized particles of treated rock dusts, with underground evaluations of treated and untreated rock dusts being discussed with a number of mine operators. NIOSH suggests MSHA continue to explore additives to reduce the caking tendency of rock dusts.

Question IV.C.28: How should MSHA modify the existing requirement for free and combined silica in the definition of rock dust? Please explain and provide documentation.

Response: NIOSH does not suggest modification of the definition of rock dust analysis to measure free silica at this time. The current MSHA definition of "rock dust" at 30 CFR 75.2 specifies that the dust not contain more than 4 percent free and combined silica. This percentage, if completely crystalline silica, might allow exposure to respirable crystalline silica (RCS) exceeding the NIOSH recommended exposure limit (REL) of 0.05 mg/m^3, since 4% of the current MSHA permissible exposure limit (PEL) for airborne respirable coal mine dust of 2.0 mg/m^3 is 0.08 mg/m^3. However, this is a conservative calculation, based on an assumption that all of the free and combined silica is free silica. Analyses of 261 rock dusts provided to NIOSH by MSHA suggest that the percentage of free silica in rock dust is generally lower, with only 7 (<2%) samples exceeding 2% crystalline silica and only one sample exceeding 3%. In addition, a new lower MSHA PEL for respirable coal mine dust of 1.5 mg/m^3 will be implemented in August 2016 and then the highest percentage value in the MSHA rock dust analyses would lead to a concentration below the NIOSH REL for RCS. Thus, in practice, there will be a margin of safety where a site is in compliance with the coal mine dust standard.

D. Surface Moisture and Total Incombustible Content

Question IV.D.30: What are the advantages, disadvantages, and costs of excluding surface moisture from the definition of TIC?

Response: NIOSH does not recommend including surface moisture in the definition of TIC (total incombustible content). The surface moisture content of a mine dust sample can vary greatly with the relative humidity and seasonal mine conditions [Harris and Alexander 2014], leading to variability in measured TIC values. Samples collected during the humid months of the year may show adequate TIC due to the presence of moisture; whereas other samples collected during the dry months may show inadequate TIC due to the lack of moisture. To maintain the incombustible content of rock dust at 80% for explosion suppression, regardless of seasonal variations, the moisture content should not be included in the determination of incombustible content. No additional costs would be incurred with the modification; as TIC analysis using the low temperature ashing procedure would start with a dry sample, rather than a sample with added moisture. See the low temperature ashing procedure in NIOSH [2010b] for incombustible content determination.

F. Active and Passive Explosion Barriers Used to Suppress the Propagation of a Coal Dust Explosion

Question IV.F.39: What types of active or passive explosion barriers could be used and where could they be used in underground coal mines? How does the movement of equipment and personnel affect the effectiveness of explosion barriers to quench a coal dust explosion?

Response: NIOSH suggests further development of active and passive barriers for limiting propagation of coal dust explosions. Such devices would be especially useful in belt entries where accumulations of combustible coal dust are greatest and rock dust may not be completely effective.

The U.S. Bureau of Mines [1984] indicated that rock dusting alone does not completely prevent coal dust explosions, especially along conveyor roadways and at transfer points where float coal dust layering can occur. They summarized the results of barriers installed in two operating coal mines. Water barriers were adaptable to the size and shape of existing cross sections of beltways in U.S. coal mines where the height was seven feet or more. They did not receive any complaints on the presence of barriers by mine personnel. There appeared to be no effect of the barriers on the belt operation or on rock dusting practices and the effect on ventilation appeared insignificant.

In addition, Zou and Panawalage [2001] conducted an extensive review of passive and triggered barriers in underground coal mines. Barrier technologies used around the world for suppressing coal dust explosions were reviewed. This report is a good reference for answering questions about the effectiveness of barrier deployment in underground coal mines.

A South African passive rock dust barrier bag system was shown to effectively suppress propagating coal dust explosions during large-scale explosion tests within the Lake Lynn Experimental Mine (LLEM) [du Plessis et al. 2001]. The barrier bags were designed to isolate rock dust from the humid mine environment and, when ruptured by the explosion pressures, disperse the rock dust. For the barrier system, 12 rock dust-filled bags were suspended from the mine roof using a steel cable; the cables were installed at 2-meter intervals down the entry in either a distributed or concentrated configuration. The distributed system involved four cables between each crosscut and the concentrated system consisted of 16 cables at 2-meter intervals. The suspension of the barrier bags did not pose a problem for vehicular movement since vehicles were not used in these coverage areas of the mine.

Roof- and floor-mounted passive water barrier tubs were also evaluated in experimental mine explosion testing [Meerbach 1975, Zhou and Lu 1987, Michelis et al. 1987, Sapko et al. 1989b; Lebecki et al. 1995, Lebecki et al. 2001, Lebecki 2010; Zou and Panawalage 2001; Cybulski and Dubiński 2010]. The roof-mounted barrier systems were shown to be effective but were limited to conveyor belt entries and similar confined entries due to blockages of vehicular traffic. Water-filled barrier tubs stacked along the ribs were also effective and were not a significant impediment to movement of vehicular traffic.

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