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NIOSH Miner Act Extramural Research for Silica Dust

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ABSTRACT

Mine worker exposure to respirable coal dust and silica dust can result in coal workers' pneumoconiosis and silicosis which are occupational respiratory diseases that have no cure and are ultimately fatal. In 2021 the Mine Safety and Health Administration reported just over 11,000 operating metal/nonmetal mines with the potential for silica dust exposure for just under 200,000 miners. The National Institute for Occupational Safety and Health (NIOSH) conducts respirable coal and silica dust research associated with mining through its Office of Mine Safety and Health Research. NIOSH respirable coal and silica dust research began under the U.S. Bureau of Mines (USBM), which initially examined silica dust, progressing to include coal dust, with a stronger focus after 1969 with the passage of the Federal Coal Mine Health and Safety Act. A review of extramural research to develop real-time respirable silica dust monitor is presented along with a brief history of silica dust regulation.

INTRODUCTION

Silicosis is an occupational respiratory disease that is caused by exposures to high levels of respirable crystalline silica dust. Respirable crystalline silica dust for sampling purposes consists of dust particles with a D_{50} of 4.0 µm for total airborne particles (the D_{50} is 4.25 µm based upon the inhalable convention) as defined by the International Standards Organization [1]. The D_{50} represents the median diameter of a particle size distribution. The definition of D_{50}, being 50% of particles are less than 4.0 µm and 50% are greater than 4.0 µm. Silicosis consists of acute silicosis, accelerated silicosis and chronic silicosis. Acute silicosis develops over months or over several years through exposures to very high levels of respirable crystalline silica dust. Chronic silicosis, most commonly encountered, develops over many years (to decades) of exposure to respirable crystalline silica dust. Accelerated silicosis can result from exposure to high levels with development occurring within 5 to 10 years. Silicosis is irreversible, has no cure, and is ultimately fatal. In addition, silicosis can be associated with tuberculosis, lung cancer, renal disease, and nonmalignant respiratory diseases (emphysema, chronic bronchitis, etc.) [2, 3]. The only way of avoiding silicosis is through prevention of exposure to respirable crystalline silica dust.

REGULATIONS

The current regulations for respirable crystalline silica dust in metal/nonmetal mining are listed in Code of Federal Regulations, Title 30, Chapter I, Subchapter K, Part 56 and 57, Subpart D; with the current limits referenced in the "TLV's Threshold Limit Values for Chemical Substances in Workroom Air Adopted by ACGIH for 1973." As referenced in this document, for respirable crystalline silica dust or quartz[1], the current limit (as of 2023) is: . For total dust (respirable and nonrespirable) the limit is . There is a special category for silicates (<1% quartz) where limits are referenced in the document. If quartz is <1%, then

1. MSHA uses "quartz" for crystalline silica. This convention will be used throughout the rest of the paper.

the respirable dust limit becomes a total dust standard of 10 mg/m^3 for those mineral dusts listed in Appendix E [4]. Currently (in 2023), the Mine Safety and Health Administration is proposing a new respirable quartz dust standard which will change these limits to 50 μg/m^3 with a 25 μg/m^3 action limit [3].

Currently for either coal or metal/nonmetal, operators do not sample for respirable quartz dust. The MSHA inspectors complete all sampling for respirable quartz dust. Coal sector samples for respirable coal mine dust are made on a prescribed schedule as laid out in CFR Title 30, Chapter I, Subchapter O, Part 71. Sampling requirements for dust in metal/nonmetal seem somewhat ambiguous as referenced in Part 57 and Part 56, Subpart D, where Part 56.5002 and Part 57.5002 state "Exposure monitoring. – "Dust, gas, mist, and fume surveys shall be conducted as frequently as necessary to determine the adequacy of control measures."

In July 2023, MSHA proposed a new silica dust rule that will apply to the mining industry. The proposed rulemaking can be found on the Federal Register, Docket No. MSHA-2023-0001 "Lowering Miners' Exposure to Respirable Crystalline Silica and Improving Respiratory Protection" [3]. This proposed rule intends to lower the respirable silica dust limit from 100 μg/m^3 to 50 μg/m^3 with a 25 μg/m^3 action level, require operator sampling, necessitate personal protective equipment (respirators) when silica levels are exceeded, add additional medical surveillance of miner by operators, etc. This rule will amplify the demand for research in real-time respirable dust measurement, particularly for respirable crystalline silica dust in order to allow mine operators to operate within compliance.

To assist mine operators maintain compliance with the regulatory limits for respirable coal mine dust and respirable silica dust, NIOSH has maintained a portfolio of research for developing and improving dust controls used in mine operations, developing new and upgrading existing measurement methods for real-time dust monitoring, developing and analyzing surveillance databases, and investigating dust characteristics to determine the chemical makeup and physical dimensions of respirable dusts. Through this research NIOSH can provide important information and interventions that can reduce exposure to respirable dusts to miners.

NIOSH FOCUS ON RESPIRABLE DUST

The U.S. Bureau of Mines (USBM), and later NIOSH, have funded research for preventing respiratory occupational diseases CWP and silicosis. The Bureau of Mines was established in 1910 and early dust research was conducted for controlling dust from underground drilling operations in metal mines. Beginning in the 1950s research on roof bolting drilling operations in coal mines commenced [5]. The Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173) established respirable dust level limits for the first time. This regulation provided additional impetus for conducting research on respirable dust in the mining industry. In 1996, the mining health and safety research programs of the USBM were transferred to NIOSH. Since that time NIOSH has been funding research on mine safety and health including a focus on respirable dust that emphasizes developing new or improving current control methods to prevent exposure to respirable dusts. Included are research in developing measurement methodologies, particle characterizations, etc. NIOSH funds this research both internally and externally through contracts.

INTERNAL RESEARCH

The research conducted internally within NIOSH is broad and impacts the entire range of the mining industry (coal, metal/nonmetal, stone, sand & gravel) for both surface and underground operations. The research topics are too numerous to include in this summary. Since the publication of the proposed silica rule by MSHA, an area of concern in the rule is the measurement of silica. Therefore, only research on the continuous personal dust monitor (CPDM) and field analysis of silica tool (FAST), two focus areas of interest to respirable dust, are summarized. The CPDM is a respirable coal mine dust monitor that provides near real-time respirable coal mine dust concentrations, in that the concentrations provided are averaged over the previous 30-minute time period [6]. While the FAST method for silica analysis, though not real-time (currently there is no commercially-available device for real-time measurement of respirable silica dust) it is a step forward in advancing technology for real-time measurement of respirable silica dust.

A starting point for the research for both CPDM and FAST began with the USBM. The USBM initiated basic research on different technologies for use as a short-term dust monitor in underground mines (beta attenuation, light scattering, mass). This work was conducted from 1970–1990, reviewing the Tyndallometer –German, SLIMSIN –Britain, RAM-1 –US (precursor to the personal DataRAM pDR-1000AN Monitor (Thermo Scientific), and Sibata P5 –Japan. From the review, the USBM concluded that direct mass measurement was most feasible and accurate for underground mining environment [7].

CPDM

The CPDM development timeline can be considered to begin in 1990–1998, where USBM and MSHA researched use of tapered element oscillating mass microbalance (TEOM) – a direct mass measurement method[2]. This work was conducted through the machine-mounted continuous respirable dust monitor (MMCRDM) and the personal end-of-shift/continuous respirable dust monitor (PESCRDM). Before 1998 PESCRDM was only in the development stages. The majority of the work was on the MMCRDM which was heavily favored by MSHA management. In 1999, NIOSH ended work on the MMCRDM finding it was not mine-worthy and failed to meet NIOSH accuracy criteria [8, 9, 10, 11].

In 1998, NIOSH began work through a contract with Rupprecht and Patashnick Co.[3], to develop and deliver a PESCRDM, now known as the CPDM. From 2000–2004 NIOSH conducted laboratory and field testing of several iterations of the CPDM. In 2004 and 2005, 25 pre-commercial TEOM 3600 CPDM units were purchased and testing at 20% of US mines was initiated evaluating accuracy, precision, durability, wearability, and equivalency to the MRE (Mining Research Establishment)/CMDPSU [6, 12] with a peer-reviewed paper published in 2008 reporting on the underground full shift performance of the PDM compared to the traditional gravimetric coal mine dust personal sampling unit (CMDPSU) [13].

In 2009 a commercial version of the CPDM was made available for purchase. Changes in Part 74 of CFR were finalized in 2010 to define the requirements of a continuous personal dust monitor for use as a certified dust sampler [14] and the CPDM 3600 was certified by MSHA and NIOSH for use in underground coal mines in 2011 [15]. Work continued to modify the CPDM for improvement in performance with the CPDM 3700 being certified in 2014[4]. MSHA issued the final rule revising the existing standards on miners' occupational exposure to respirable coal mine dust [16]. Part of this rule required underground coal operators, after February 1, 2016, to use the CPDM for compliance sampling. NIOSH continues to let contracts to conduct research and/or improvements to existing respirable coal mine dust measurement devices.

2. Note that in 1996 this work was transferred from the USBM to NIOSH. Worked continued under NIOSH after 1996.

3. In 2007, Rupprecht and Patashnick Co., Inc. was purchased by Thermo Electron Corp.

4. NIOSH certified for coal mine dust sample collection: Certif. No. TC-74CPDM-02 [17]

FAST—Research on Real-Time Measurement of Respirable Silica Dust

Currently, there is no commercially-available method to measure respirable crystalline silica dust in real-time. The CPDM measures respirable coal mine dust in near real-time but cannot differentiate the crystalline silica component of the dust. The current method for sampling respirable crystalline silica dust is to use the CMDPSU. The CMDPSU uses a 10 mm Dorr-Oliver cyclone, 37 mm PVC filters with 5 µm pore size in a two-piece cassette holder, and a pump operating at 2.0 lpm if measuring respirable coal dust, 1.7 lpm if measuring metal/nonmetal respirable mine dust. This type of sampler is not a real-time sampler. It only provides a time weighted average concentration after the filter is subject to an analysis using one of three methods for crystalline silica analysis: MSHA P7, NIOSH 7500, and NIOSH 7603 methods.[5] These methods quantify silica either through x-ray diffraction or Fourier transform infrared spectroscopy (FTIR) and require ashing of the filter as part of the sample analysis. NIOSH has been conducting research to develop an end of shift filter-based method for measuring respirable crystalline silica dust.

Research on silica measurement methods is focused on direct on filter (DoF) measurement of silica which initially began with the USBM. For silica quantification on filters, MSHA uses the MSHA P7 method which uses infrared spectrophotometry to determine the mass of silica on the sample [18]. The NIOSH 7603 method is similar to the MSHA P7 method [19]. MSHA has used infrared spectroscopy since the inception of the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173). Infrared spectroscopy does not have the ability to quantify cristobalite and tridymite, but these forms of crystalline silica are not found in respirable coal mine dust [20].

The USBM created a standard method for infrared spectroscopy for the determination of quartz in coal mine dust in 1972 [21]. MSHA partnered with the USBM to improve the infrared spectroscopy method [22]. This report by Huggins et al stressed the importance of calibration of the infrared instruments. A report by Stanford Research Institute, developed under contract by USBM and NIOSH, discussed the interference of kaolinite interference in quartz analysis [23]. Ainsworth discussed the development and improvements to the MSHA P7 method in detail [20].

USBM continued work on infrared analysis conducting a study to evaluate a method to analyze the full face of 37 mm filters without ashing. This study by Tuchman,

5. OSHA uses method ID-142 for crystalline silica quartz and cristobalite [24].

stated that satisfactory results were obtained using a custom-built filter holder. The detection limit was found to be approximately 20 µg quartz. There were drawbacks such as vulnerability to light scattering and random noise associated with the FTIR spectrometer when measuring the sample. Another issue of note was the nonuniform deposition of dust across the filter face. Recommendations were made to use sampling cassettes that deposit the dust uniformly [25].

Work was initiated developing a method to quantify silica on TEOM filters used by the CPDM by Tuchman. This work developed a new filter using polyester and nylon materials for the CPDM that were ashable, with the nylon materials showing the most promising results. However, the nylon filter material and filter body (polypropylene) required longer ashing times than typical PVC filters. Results of testing established that accuracies within 10% with a precision of 5% were possible, demonstrating that this filter was promising for silica quantification for CPDM filters [26].

Miller et al. continued the research to investigate using portable FTIR spectrometers for quantifying the silica content on respirable coal mine dust samples. Issues to overcome were the sensitivity of portable FTIR instruments is less than laboratory instruments and the ability to overcome minerals that interfere with free silica quantification. Coal dust samples were tested with two different instruments (FTIR and variable filter array (VFA)) with their results compared with the MSHA P7 method. Both instruments showed promising results; the FTIR was more suitable for the coal samples, while the VFA was promising for pure silica samples [27]. Further research continued using the FTIR spectrometer. This work included testing the effects of nonuniformity/uniformity of dust deposition, coal versus noncoal dusts, different filter material types, and different calibration techniques [28, 29, 30, 31].

From this research and numerous additional studies not noted here, the Field Analysis of Silica Tool (FAST) was developed. The measurement process uses a Fourier Transform Infrared (FTIR) spectrometer to analyze gravimetric filters. The software imports data from FTIR instruments and translates the data into silica mass concentration for each sample. While FAST can be used for determining end of shift silica results from samples from commodities other than coal, a disclaimer is made that other commodity end of shift silica results should be considered approximations only [32].

For coal samples the results are comparable to MSHA P7. However, it should be noted that the software calculations are based upon using 37 mm 5 µm pore PVC filters in 4-piece conductive cassettes with stainless steel support (instead of using a cellulose backing pad) or a capsule with stainless steel support (also known as the coal sampling cassette). Other recommended parameters for the instrument settings are provided for resolution (4 cm^{-1}), sample scan time (16), background scan time (16), spectral range (4000 cm^{-1} - 400 cm^{-1}), result spectrum (Absorbance), phase correction (Mertz), apodization (Blackman Harris 3), and zero-fill factor (2). Samples evaluated this field-based approach are not considered for regulatory compliance [33], however the filter can be sent off for further analysis.

Field analysis of silica is an important step in monitoring silica levels at the mine site. Being able to provide end of shift silica results is an improvement in reducing potential respirable silica dust exposures to miners. While not real-time, these end of shift results are an improvement to the previous method of sending the samples to a certified lab for analysis which can have long lead times. The shorter lead time obtaining results will enable operators to initiate controls for reducing potential respirable silica dust exposures sooner, when warranted [34]. NIOSH continues to conduct research to improve the field-based method of silica analysis and also continues to work to improve the respirable dust and respirable silica dust measurement methods.

EXTERNAL RESEARCH

The NIOSH mining program maintains a portfolio of extramural contracts and grants awarded to institutions and private entities to encourage the development and manufacture of mine safety equipment, and to education institutions or private laboratories for the performance of product testing or related work with respect to new mine technology or equipment. One of the purposes of these contracts and grants is to enhance the development of new technology and technological applications, and to expedite the commercial availability and implementation of such technology in mining environments [35]. This program was established through the Mine Improvement and New Emergency Response Act of 2006. [36].

In the recent past, contracts have been awarded that are related to the topic of respirable dust characterization, measurement, and control. The following describes active contracts that are related to respirable silica dust in the categories of characterization studies and real-time respirable silica monitors.

Characterization Studies

Characterization studies provide information on the mineral makeup of the sampled dust. The studies also include documentation of particle size distributions and typical particle shapes. Some results from these contracts are the recognition of nanoparticles generated in mining operations, the presence of micro-agglomerated particles, and the occurrence of differing chemical materials in the samples. There are currently 5 active contracts related to respirable dust characterization which are described individually. Additionally, there have been 4 contracts that have been completed, in which a broad overview is provided.

Active Contracts

Reduction or Elimination of Coal Mining Related Respirable Dust Toxicity by Selection and Proper Application of Dust Control Additives - Pennsylvania State University

Researchers are reviewing and studying various chemical dust control additives for reduction or elimination of dust toxicity with a focus on eliminating silica toxicity but have not yet been implemented in mine operations. The different chemical additives will be analyzed with different coal mine material types. Results of toxicity reduction as measured by hydroxyl radical generation will be used in determining the potential application for dust control and/or toxicity reduction of respirable coal mine dust.

Advancing the Understanding of Respirable Silica Occurrence in Coal Mines—Virginia Polytechnic Institute and State University.

An evaluation of the relative abundance of respirable silica containing micro agglomerates and their characteristics (e.g., size, dispersibility) in respirable coal mine dust (RCMD) is being performed. Tests will be conducted to evaluate the capabilities of advanced SEM-EDX tools for classification of respirable silica micro-agglomerates and other micro-agglomerates and characterize respirable silica particles (e.g., size, occlusion, association with other particles) in lung tissue specimens from coal miners with progressive massive fibrosis.

Investigation of Respirable Mine Dust and Crystalline Silica Dust Characteristics and Toxicity in Metal/Nonmetal Mines—New Mexico Institute of Mining and Technology.

This project leverages resources from ongoing interdisciplinary collaborations, including mining engineering, environmental chemistry, and mineral processing, to investigate the characteristics and toxicity of mine dust and RCS in metal/non-metal mines. Characterization studies (i.e., size, shape, surface area, mineralogy, elemental components) on mine dust and RCS samples of metal/non-metal operations are being conducted. Toxicity of metal/non-metal mine dust using simulated lung fluid and in-vitro toxicity comparisons of respirable dust will be investigated.

Size-dependent Metric Analysis of Respirable Coal Mine Dust (RCMD) - Michigan Technological University.

This contract has two objectives. The first objective of this project is to develop a beyond-compliance approach of characterizing size-dependent metrics of RCMD particles, addressing one recommendation by National Academy of Sciences (NAS) committee [37] on particle size information of RCMD particles. The metrics of RCMD particles include particle size information, elemental and mineral compositions at different size fractions. The second objective of this project is to develop a protocol for the characterization of RCMD collected on CPDM filters that are normally discarded after each shift. The impact of this method is to generate a large quantity of dataset on the metrics of RCMD from various operating underground coal mines in the United States.

Characterization of Forms of Silica with Varying Degrees of Crystallinity in Respirable Dust to Assess their Effects on Miners' Pneumoconiosis—Pennsylvania State University.

An evaluation of the presence and forms of silica in the respirable dust from various host rocks through an integrated experimental and field study program will be conducted. The overall goal of this study is to characterize various forms of silica and provide statistically significant silica characteristics for future toxicity analysis. The project aims are to 1) collect representative floor, roof rock samples from different mines to prepare dust samples, 2) characterize rock dust samples to get the physical and compositional properties, including the proportion of crystalline and non-crystalline silica components, and 3) correlate what forms of crystalline of non-crystalline silica are related to different host rocks. The results will lay the foundation for investigating the effect of non-crystalline silica on biological effects on lung cells.

Completed Contracts

Integration of RCMD and RCS Physicochemistry and Toxicity Outcomes in an Occupational Risk Assessment Model—New Mexico Tech

The establishment of a validated model which risk-stratifies miners for coal workers' pneumoconiosis (CWP) based on mine-, dust-, and miner- specific measures that could help identify high-risk miners who may benefit from the early intervention was proposed. Comprehensive characterization studies (i.e., size, shape, mineralogy, elemental content) and toxicity analysis (using a high-throughput, imaging platform) to capture distinct in vitro physiologic and phenotypic data involved in toxicity were completed on dust samples collected from mines selected from geographically representative regions across the United States that have high, medium, and low prevalence of CWP or PMF. The data from these characterizations were to be used in the model. However, while a model was constructed, it was not comprehensive enough to provide valid results due to the insufficient number of samples collected.

Characterization of Submicron-/Nano-scale Coal Dusts and Their Effects on Miners' Pneumoconiosis and Lung Cancer for Underground Coal Mines—The Pennsylvania State University

A characterization of submicron/nano-scale coal dust particles of different grades of coal and analyze the interaction between nano-scale coal dust (NCD) and lung cells was conducted. The toxicity of coal dust and its varying composition could be primary factors for CWP. Recent studies have confirmed that nano-sized particles are potentially more toxic due to their unique physicochemical properties and easier uptake by living organisms. The underlying mechanism of miners' lung diseases due to the exposure of NCDs is not well-understood and their role in CWP is largely unknown. This characterization for NCD was completed using different analysis methods: field emission scanning electron microscopy, x-ray photoelectron spectroscopy (XPS), x-ray diffraction, and free radical analysis. Additionally, testing to evaluate the biological effects of NCD on lung tissue was completed; several different tests were conducted. Results showed that NCD has higher surface area and pore volumes but the oxygen content in NCD are lower than micron sized material. The higher surface area of NCD and lower oxygen, which could be related to weaker wetting behavior, indicates that inhalation of NCD could have potentially higher adverse effects on miners' health by inducing cells to secrete inflammatory factors which produces an inflammatory response in the lung tissue cells.

Temporal and Spatial Characterization of Respirable Coal Mine Dust—Michigan Technological University

Researchers from Michigan Tech conducted tests on coal samples obtained from mines in Utah, Colorado, and Indiana. The goal was to provide more information on the variation of the RCMD during the mining cycle at multiple locations within the mine to reduce cumulative miner exposure to RCMD. The characterization technologies used included scanning electron microscopy with energy dispersive x-ray spectroscopy (SEM/EDX), x-ray (micron and nano) computed tomography, field-flow fractionation, and micro x-ray fluorescence spectroscopy to determine size and composition from individual particles. Results showed that the elemental and mineral compositions of RCMD particles vary with coal geology and mine activities. Nanoparticles were present in both the coal particles as well as the silica particles. While the number of nanoparticles can be high, the weight is low. Results of testing found that the nano-sized fraction made up 3–10% by weight. Generally, the percentage of nano-sized dust particles varies with mine locations and mine activity as well.

Characterization of Respirable Coal Mine Dust Size Distribution, Chemical Composition, and Source Contributions—University of Nevada, Reno

A comprehensive assessment of respirable coal mine dust (RCMD) particle characteristics was underway because different particle characteristics (for example, composition and surface area) can potentially pose different health hazards. An extensive literature review was completed reviewing RCMD measurement methods, particle size characterization, and chemical composition and methods of determination. The collection of RCMD samples at various locations in underground coal mines was also completed. These samples were analyzed from two mines, an eastern coal mine and a western coal mine, to characterize the particle size distribution and determine the chemical composition of the material. Overall, the silica content ranged from 4.9% - 24.6%. The eastern coal mine samples contained more calcium carbonate, thought to be related to rock dusting practices. The western coal mine samples contained more elemental carbon, due to the fact the mine used diesel equipment underground. Analyzing the samples for transition metals (V, Cr, Fe, Ni, Cu, Al (oxide), Zn (oxide), and Pb) showed that all concentrations were below exposure limits (RELs) and limits for Immediately Dangerous to Life and Health (IDLH) [38].

Real-Time Respirable Silica Monitors

NIOSH maintains a portfolio of contracts let to develop real-time respirable dust and respirable silica dust monitors. The goal is to develop an instrument that is low cost and can provide real time results with accuracy and precision. Two of the active contracts do not focus on developing instrumentation, but rather focus on developing filters for the CPDM that can be used for silica analysis. These two contracts are considered an important step towards the goal of developing near real-time respirable silica dust monitors. Currently there are 7 active contract and 1 completed contract. An overview is provided for each.

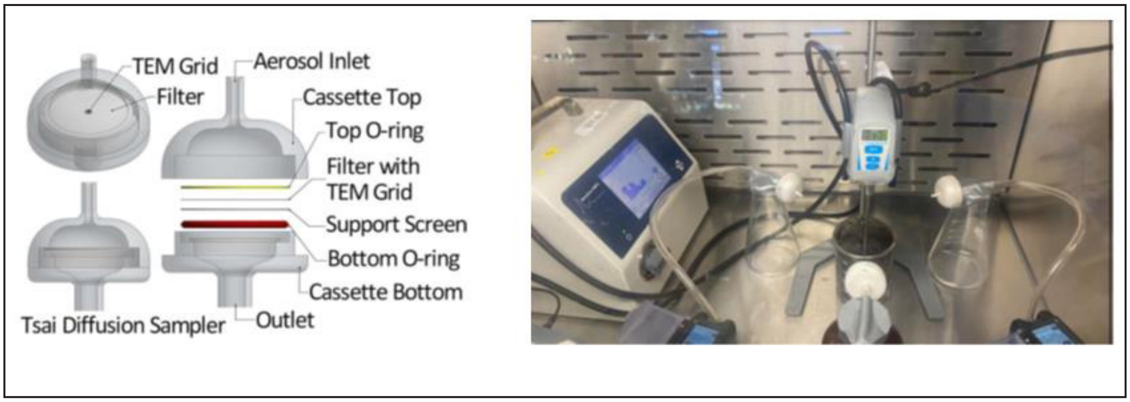

Figure 1. The Tsai diffusion sampler components (left) and the experimental test setup used to test the Tsai diffusion sampler (right)

Active Contracts

Development of a Silica Dust Direct Reading Sampler with Selectivity for Dust Components and Size—Colorado State University

A 25-mm personal sampler containing a capacitive sensor, which collects/measures respirable particles, has been designed and used during drilling activities to collect numerous nano- to micrometer-sized particles. It is currently being modified to accommodate the 37 mm filter commonly used in the mining industry for respirable silica dust sampling. This device (Figure 1) uses capacitive sensors to monitor the volume of deposited particles and convert the detection results to a real-time exposure level and then use coordinated optical and capacitive sensor responses to determine the total quantity of silica.

Development of Non-regulatory Runtime Respirable Coal and Silica Dust Monitor Using Quantum Cascade Laser-based Cavity Ringdown Spectroscopy—RingIR, Inc.

RingIR is developing a simple, miniaturized, low-weight, personal dust monitor for non-regulatory respirable coal and silica dust measurement using QCL-based cavity ringdown spectroscopy. RingIR plans to use their Agnoscis AG-4000 spectrometer in conjunction with the QCL-based direct spectroscopy as the basis for their instrument. Using a laser and photo-detector, the AG-4000 measures IR absorption of molecules in the 7–11 µm mid-IR range and will be used to measure the unique IR absorption profiles of coal and silica dust to determine the appropriate discrete wavelengths to utilize in the development of a miniaturized personal dust monitor. The prototype device (Figure 2) has been constructed and additional testing is required for validation to compare its resulting concentrations of RCMD and RCS dust with the NIOSH FAST, NIOSH 7500, and NIOSH 7603 methods for crystalline silica quantification.

Figure 2. The RingIR dust monitor prototype

Novel Application of Fourier-Transform Infrared Spectroscopy and Optical Particle Counting for the Real-Time Quantification of Respirable Crystalline Silica and Dust in the Mining Environment—Microaeth Corporation

Integration of a FTIR spectrometer and suitable light source with the hardware of an AethLabs MA200 UV-IR black carbon monitor, a palm-sized, battery-powered, wearable, multi-wavelength unit (Figure 3) with a mechanized filter tape advance mechanism, is being performed in order to develop a wearable RCS monitor. Candidate FTIR interferometers, detectors and light sources have been evaluated and a FTIR has been selected to incorporate into the design to finalize the development of the integrated analyzer. A performance comparison of this unit to a laboratory-grade

Figure 3. An AethLabs MA200 personal real-time Black Carbon/Elemental Carbon monitor

FTIR for quantification of RCS lab-generated and field-collected samples is underway.

Development of a Personal Real-time Respirable Coal Dust and Respirable Silica Dust Monitoring Instrument Based on Photoacoustic Spectroscopy—University of Nevada-Reno

The focus area of this research is to develop a real-time personal coal and silica dust monitoring instrument. The new monitor's dust assessment system will be based on photoacoustic spectroscopy using optical design principles. The newly developed hardware components and associated software will enable the unit to continuously measure concentrations of coal dust and silica dust in underground coal mines and metal/nonmetal mines as well as surface operations. A prototype photoacoustic spectrometer is being tested using sources of alpha quartz, coal, and kaolinite.

Adaptation of Wearable Respirable Dust Monitor Prototypes for Use in Underground Coal Mines - University of Illinois-Chicago

This contract further develops the initial miniaturized wearable respirable dust exposure monitor (WEARDM), developed under a previous contract. This monitor provides near real-time dust concentrations to the wearer. Prototypes are to be fully adapted to use in underground coal mine operations and evaluated in an operating underground coal mine. The proposed adaptation includes the development of rugged prototypes for continuous reliable operation in the mining environment, certification to achieve MSHA permissibility requirements, and performing a demonstration and evaluation of the adapted and certified WEARDM technology in an actual mine environment. Prior to a submission to MSHA for permissibility certification, the WEARDM is to undergo a series of lab (Figure 4) and field tests to demonstrate its ability to provide accurate dust concentrations.

Filter Media and Holder Compatible with Personal Dust Monitor and End-of-Shift Crystalline Silica Quantification by Raman and FTIR Spectroscopy—Desert Research Institute.

DRI is testing filter media that can be used for both CPDM mass measurement and RCS quantification. Different filter material types were reviewed for suitability for silica measurement using the CPDM. Recommendations were made for the best material types for silica analysis and testing is underway to determine their suitability. A redesign of the CPDM filter holder so that the filter can be easily retrieved

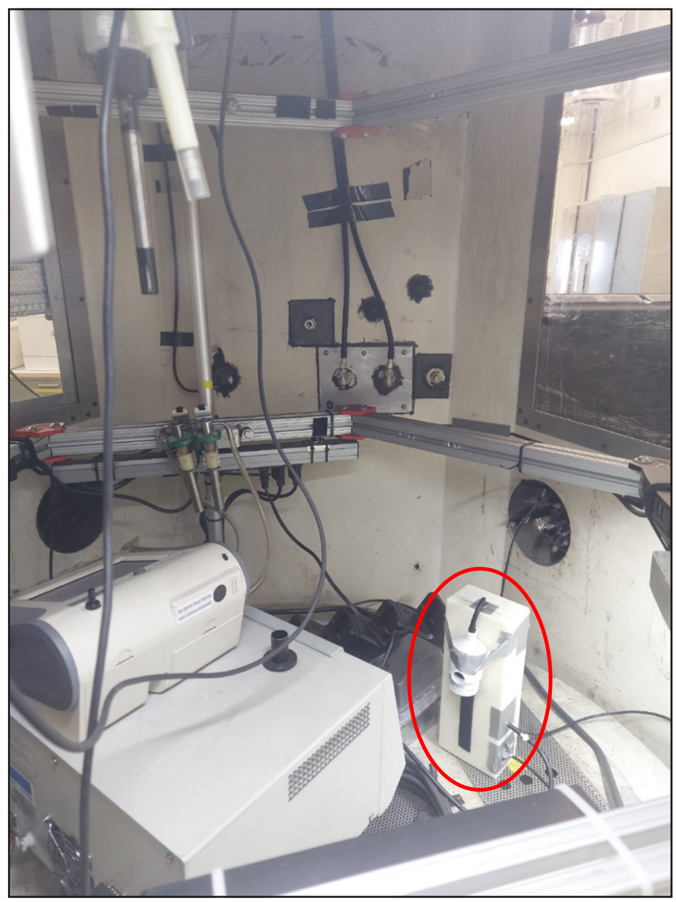

Figure 4. Testing the WEARDM (highlighted in red oval) in the Marple chamber at the NIOSH Pittsburgh Respirable Dust Laboratory

for direct-on-filter measurement by FTIR and Raman spectrometers and the development of an end-of-shift RCS quantification method by Raman spectroscopy is also being performed.

PDM3700-compatible Filter Module Usable with Portable/ Field-Deployable Silica Monitoring Instruments - Thermo Environmental Instruments

The CPDM is required for sampling at coal mines in the U.S. by MSHA. The CPDM provides near real-time respirable dust concentrations (concentrations averaged over a 30-minute time period) and the dust being sampled is collected on a filter which is ultimately discarded. Thermo Fisher Scientific is developing a filter module (filter material, a holder, and possibly additional supporting elements and an adaptor) for the CPDM that can be used with a portable FTIR, QCL, or other infrared (IR) absorption method that is used to determine the silica content of the dust being sampled. A review has been completed on the filter material compatible with silica analysis and variations of filter body designs have been created and reviewed for suitability. Figure 5 shows the newly designed filter attached to the CPDM transduce where the respirable dust is collected during sampling.

Completed Contracts

Feasibility Testing of a Near Real-time Respirable Silica Monitor—Thermo Fisher Scientific

Thermo Fisher researchers reviewed real-time monitoring of RCS that may be enabled through the development of

Figure 5. The new PVC filter for silica analysis shown attached to the CPDM transducer where the respirable dust sample is collected

Figure 6. The prototype of the QCL test system for real-time measurements of respirable silica dust.

a promising technology: a quantum cascade laser (QCL) The QCL is a source of IR light that enables the generation and detection of RCS features in IR spectra. This work developed and tested hardware and a measurement system that could be developed into a wearable configuration to measure respirable silica dust during a miner's working shifts. The performance of QCL technology as it relates to a potentially field-deployable, wearable, near real-time silica measurement system that supports OSHA and MSHA silica standards was determined. The weight of the developed test system was 6.5 pounds and measured 17"× 4"× 6" in size (408 cubic inches) (Figure 6). This weight and volume do not include either a battery or main power supply. The work conducted during this contract has demonstrated that microgram levels of RCS can be measured utilizing this detection technique. The presence of coal dust does degrade detection as compared to RCS alone and therefore, further research is required to improve the performance.

CONCLUSION

With the proposed silica rule introducing new requirements to the mining industry, NIOSH has anticipated the need for continuing research for developing new near real-time respirable silica monitors, effective dust controls, and innovative intervention methods for compliance assistance. NIOSH maintains a portfolio of research provide information, new interventions, and innovative measurement methods related to respirable coal and respirable silica dust.

Summarizations of the historical research for the CPDM for respirable coal mine dust measurement and FAST method for silica measurement were provided. This summarization describes the timeline for developing both methods; one a near real-time method for RCMD dust measurement the other a step towards real-time measurement of respirable silica dust. These two projects demonstrate the successful research accomplished by NIOSH. However, in this review, the pathway to success for each project had a long timeframe: over 45 years since the USBM initiated research into real-time respirable dust measurement methods for respirable coal mine dust (CPDM) and respirable silica dust (FAST). In other words, the road to success has been a long one. NIOSH continues research to improve existing and develop new methods of real-time respirable dust measurement through its internal research program and through its external research program.

The external research program, through the BAA contracts, develops research over a broad range of subjects beyond the contracts related to respirable coal and respirable silica dust described in this summarization. However, without diminishing the need for research on ground control, hearing loss, traumatic injuries, mine refuge and escape, etc., and other mine safety and health research; a current focus has been related to reducing respiratory illnesses due to the proposed silica rule from MSHA. Administering contracts on respirable dust characterization and measurement has allowed NIOSH to collaborate with external partners whose knowledge and technological expertise complement the NIOSH's respirable dust research program. These contracts allow NIOSH to leverage resources both monetarily and intellectually to advance the goals of reducing mine workers' risk of occupational illnesses as it pertains to respiratory diseases.

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Driving Open Autonomy and Innovation

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ABSTRACT

As the mining industry faces increased challenges with declining ore grades and harder to access deposits, operating mine sites in an environmentally responsible and economically viable manner will require innovations that improve efficiency in energy logistics, and automation.

Technological advancements in mining have been successful primarily because of the willingness and capability of these solutions to share information with one another, for example OEM payload systems sending information to Fleet Management Systems, and in turn Fleet Management Systems interfacing to ERP systems. To promote and facilitate the sharing of data, there has been a push towards open standards with initiatives led by organizations like ISO, ISA, EMESRT, and GMG. These efforts are aimed at creating a more collaborative and interoperable environment within the sector. However, when it comes to implementing autonomous solutions, a different trend dominates—closed-stack solutions.

These closed stack solutions not only prohibit a mine site from selecting best-of-breed solutions, by blocking the competition from entering the market, they also risk slowing innovation that could help overcome the challenges the mining industry faces.

Open Autonomy, an internationally published standard that allows any FMS to work with any Autonomous solution, breaks this closed-stack approach and invites competition from other industries. This competition comprises of autonomous suppliers from other industries and manufacturers of smaller, civil-sized haul trucks.

The availability and capabilities of these smaller-sized autonomous haul trucks will help tackle the challenges of responsibly and economically mining lower quality ore grades and mining harder to access deposits.

INTRODUCTION

Wenco provides a comprehensive suite of fleet management applications for surface mining operations of all sizes worldwide. Our current offerings include a scalable FMS that focuses on production management and operator

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