NIOSH Mining Program Information Circular IC 9532

Best Practices for Dust Control in Coal Mining

Second Edition

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

Information Circular 9532

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Jay F. Colinet, Cara N. Halldin, Joseph Schall

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Office of Mine Safety and Health Research
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ACRONYMS AND ABBREVIATIONS USED IN THIS REPORT

AA	air atomizing
ACGIH	American Conference of Governmental Industrial Hygienists
ASABE	American Society of Agricultural and Biological Engineers
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
CM	continuous miner
CPDM	continuous personal dust monitor
CT	computed tomography
CWHSP	Coal Workers' Health Surveillance Program
CWP	coal workers' pneumoconiosis
DA	designated area
DO	designated occupation
DOL	Department of Labor
DWP	designated work position
DS	dry scrubber
EPA	Environmental Protection Agency
FAST	Field Analysis of Silica Tool
FC	full cone
FF	flat fan
FTIR	Fourier transform infrared
HA	hydraulic atomizing
HC	hollow cone
HDPE	high-density polyethylene
HEPA	high-efficiency particulate air
IARC	International Agency for Research on Cancer
ILO	International Labour Office
IOM	Institute of Occupational Medicine
ISO	International Organization for Standardization

LTA	low-temperature ashing
MMU	mechanized mining unit
MERV	minimum efficiency reporting value
MRE	Mining Research Establishment
MSHA	Mine Safety and Health Administration
NIOSH	National Institute for Occupational Safety and Health
ODO	other designated occupation
PCD	polycrystalline diamond
PDM	personal dust monitor
pDR	personal DataRAM
PEL	permissible exposure limit
PF	protection factor
PPE	personal protective equipment
PVC	polyvinyl chloride
PMF	progressive massive fibrosis
RB	roof bolter
SiO_2	silicon dioxide
TEOM	tapered-element oscillating microbalance
USBM	U.S. Bureau of Mines
VFD	variable frequency drive

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cfm	cubic feet per minute
cm	centimeter
dynes/cm	dynes per centimeter
fpm	feet per minute
gal/yd^2	gallons per yard squared
gpm	gallons per minute
in. wc	inches of water column
lb$_f$/in^2	pound force per square inch
L/min	liters per minute
µg/m^3	micrograms per cubic meter of air
µm	micrometers
mg/m^3	milligrams per cubic meter of air
mph	miles per hour
mm	millimeters
psi	pounds per square inch

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FIRST EDITION

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SECOND EDITION

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Best Practices for Dust Control in Coal Mining

Second Edition

Jay F. Colinet,[1] Cara N. Halldin,[2] Joseph Schall[3]

INTRODUCTION

Respirable dust, defined as minus 10 micrometers (µm) in size [ACGIH 2007], can be inhaled into the gas exchange region of the lungs and has long been known to be a serious health threat to workers in many industries. In coal mining, overexposure to respirable coal mine dust can lead to coal workers' pneumoconiosis (CWP), commonly known as black lung. CWP is a lung disease that can be disabling and fatal in its most severe form, progressive massive fibrosis (PMF). In addition, miners can be exposed to high levels of respirable silica dust, which can cause silicosis, another disabling and/or fatal lung disease. Once contracted, there is no cure for CWP or silicosis. The goal, therefore, is to limit worker exposure to respirable dust to prevent development of these lung diseases.

Prior to the passage of the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173), no respirable dust exposure limits had been established in the U.S. coal mining industry. Also, no personal dust sampling was required to monitor the exposure of mine workers. However, in 1968, the U.S. Bureau of Mines (USBM) conducted personal dust sampling at a limited number of mines to assess worker exposures. The results from this sampling are summarized in Table I-1. These results show that mean respirable dust concentrations at these mines were substantially above contemporary dust standards, with maximum exposure levels approaching 40 milligrams per cubic meter of air (mg/m^3) for two of the sampled occupations.

Table I.1. Respirable dust concentrations by occupation in 1968 [USBM 1970]

Occupation	No. of mines	No. of samples	Dust concentration range, mg/m^3	Mean, mg/m^3
Continuous miner operator	21	178	0.02–21.44	4.08
Continuous miner helper	19	131	0.44–18.90	3.47
Roof bolter operator	25	296	0.09–38.50	2.46
Cutting machine operator	15	98	0.71–15.42	3.69
Loading machine operator	18	97	0.25–39.56	3.75

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The passage of the Federal Coal Mine Health and Safety Act of 1969 was the initial regulatory step in controlling the respirable dust exposure of mine workers in the United States. This act established a respirable coal mine dust standard of 2 mg/m^3 (MRE equivalent concentration[4]), implemented a method designed to control silica exposure to a limit equivalent to 100 micrograms per cubic meter of air (µg/m^3), defined dust sampling requirements for federal inspectors and mine operators, created a CWP surveillance program for underground coal miners, and established a CWP benefits program to provide compensation to affected miners and their surviving families.

After passage of the 1969 Act, the Coal Workers' Health Surveillance Program (CWHSP) was established by the National Institute for Occupational Safety and Health (NIOSH) [NIOSH 2019a]. Initial CWHSP data showed that approximately one in three examined miners with 25 or more years of experience was diagnosed with CWP [NIOSH 2019b]. A substantial drop in the prevalence of this lung disease was then observed in examined miners over the next 30 years. However, CWHSP data collected since 2000 has shown an upturn in the prevalence of CWP, particularly for the longest-tenured mine workers. Recent health surveillance data has also shown rapidly developing cases of CWP [Antao et al. 2005; Cohen et al. 2016] and a significant increase in miners diagnosed with PMF [Almberg et al. 2018].

Consequently, a new federal dust regulation was promulgated by the Mine Safety and Health Administration (MSHA) in 2014 [79 Fed. Reg.[5] 24814 (2014)] in an effort to further reduce the respirable dust exposure of coal mine workers. This new dust rule reduced the respirable coal mine dust standard to 1.5 mg/m^3 (MRE equivalent concentration), specified 100 µg/m^3 as a silica limit, required mine operators to use a new dust sampling instrument with real-time feedback to the miner, increased the number of compliance samples that need to be collected by mine operators, made surface coal mine workers eligible to participate in the CWHSP, added spirometry testing to the CWP surveillance program, and changed additional dust sampling requirements.

NIOSH supports the traditional hierarchy of controls approach to controlling occupational hazards, which is illustrated in Figure I-1. Generally, the controls are considered to be the most protective of workers as one proceeds from the top to the bottom of the inverted pyramid. Unfortunately, the nature of mining—where the extraction, processing, and transport of the desired product creates the respirable dust hazard—does not typically lend itself to using the elimination or substitution methods of controls. Administrative controls and personal protective equipment (PPE) are often used to supplement existing control technologies when hazards cannot otherwise be routinely controlled. However, these methods require a sustained effort by workers (e.g., diligently wearing a respirator) and management (e.g., respirator training or limiting time in an occupation) to avoid reducing the afforded protection. Therefore, the focus in mining is on developing and implementing engineering controls to protect workers.

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[4] Mining Research Establishment (MRE) equivalent concentration defined in Chapter 2.

[5] Federal Register. See Fed. Reg. in references.

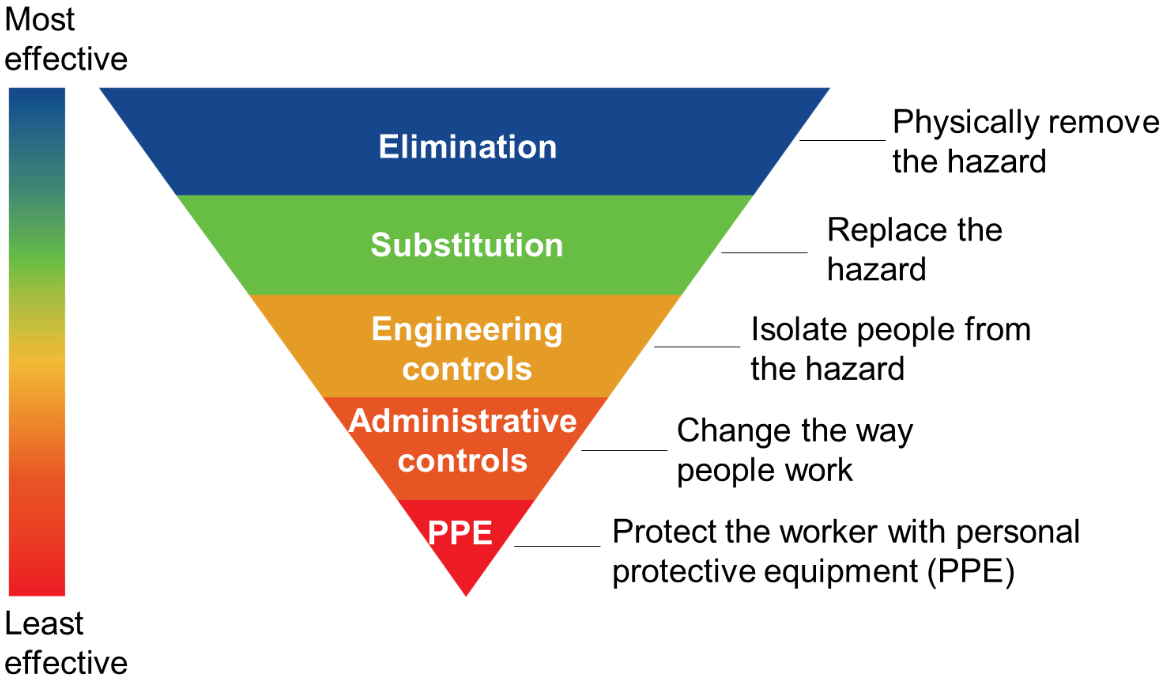

Figure I.1. Hierarchy of controls approach for reducing workplace hazards [NIOSH 2015].

Considering the ongoing increase and severity of lung disease in coal mining and changes in federal dust regulations, this handbook was updated to identify available engineering controls that can help the industry reduce worker exposure to respirable coal and silica dust. The controls discussed in this handbook range from long-utilized controls that have developed into industry standards to newer controls that are still being optimized and implemented. The intent is to identify the best practices that are available to control respirable dust levels in underground and surface coal mining operations.

A general methodology for controlling respirable dust generation and worker exposures is provided in Table I.2. As shown, the initial step should be to minimize the quantity of respirable dust that is generated through efficient cutting. If the dust is not created, it does not have to be controlled through other means. The next step would be to prevent the respirable dust that is generated from becoming airborne so that it cannot harm workers. For the dust that does get entrained into the ventilating air, the next step would be to remove it with dust collectors and dilute it with ventilation. Another step would be to prevent any remaining airborne respirable dust from reaching the breathing zones of workers. If the dust is not inhaled by workers, it cannot contribute to the development of lung disease. The last step in the process is to maintain the controls that have been implemented to retain their effectiveness.

In addition to the health hazards associated with respirable dust generated during coal mining, float coal dust generation creates a potential safety hazard. Float coal dust is defined as minus 75 µm in size and settles out of the ventilating air onto the floor, roof, and ribs of mine entries [Harris et al. 2009]. This dust has contributed to numerous mine disasters by being lifted back into the air, typically by a methane gas explosion, and propagating a more violent coal dust explosion throughout the mine. MSHA regulations require that rock dust be applied in sufficient quantities to inert deposited coal dust. In recent years, NIOSH has initiated research into developing engineering controls that reduce the quantity of float coal dust deposition in mine entries, which will provide mine operators additional tools for controlling this safety hazard.

Table I.2. Methodology for controlling respirable dust generation and worker exposure [Colinet 2020]

Step	**Goal**—approach (examples)
1	**Minimize the quantity of respirable dust generated** —employ efficient cutting (drum and bit design, cutting method)
2	**Prevent respirable dust from getting into the ventilating air** —wet dust at generation point (water sprays) —enclose the dust source (stageloader, belt transfers)
3	**Remove respirable dust from the ventilating air** —dust collectors (flooded bed scrubbers, vacuum collectors) —water sprays (nozzle type, operating parameters)
4	**Dilute remaining airborne dust** —ventilation quantity (maximize) —increase distance from dust source (shield advance, continuous miner cuts)
5	**Prevent respirable dust from reaching workers' breathing zones** —ventilation velocity (quickly move dust) —move air with water sprays (directional sprays, blocking sprays) —physical barriers (belting, enclosed cabs)
6	**Regular maintenance of controls to retain effectiveness**

It cannot be stressed enough that after appropriate control technologies are implemented, the ultimate success of ongoing protection for workers depends on the proper use and continued maintenance of these controls. At some mining operations, NIOSH researchers have observed appropriate controls installed, but the effectiveness of these controls was diminished because of the lack of proper maintenance. For example, worn cutting bits [Pollock et al. 2010] and reduced flooded-bed scrubber airflow [NIOSH 2011; NIOSH 2013] can result if controls are not being maintained at necessary intervals, particularly when cutting rock. At these operations, mine operators must make the maintenance of these dust control technologies a higher priority and provide mine workers the training, resources, and time needed to complete this maintenance.

This handbook provides general information on engineering control technologies along with extensive references. In some cases, the full reference or references will need to be consulted to gain in-depth information on the testing or implementation of the control of interest. The handbook is divided into six chapters. Chapter 1 discusses the health effects of exposure to respirable coal and silica dust. Chapter 2 discusses dust sampling instruments and sampling methods. Chapters 3, 4, and 5 focus on respirable dust control technologies for longwall mining, continuous mining, and surface mining, respectively. Chapter 6 discusses float coal dust sampling and control technologies.

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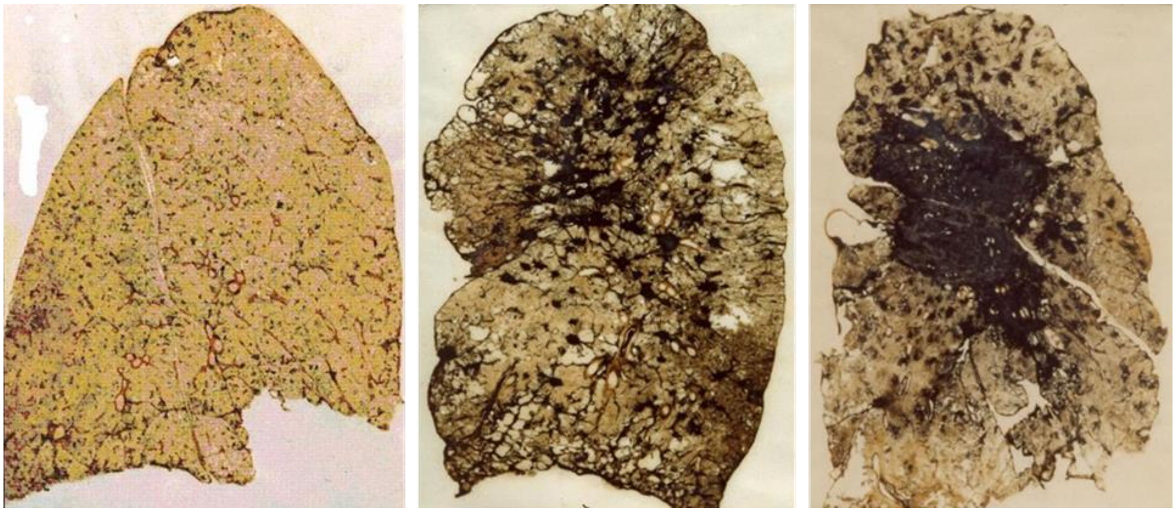
CHAPTER 1: HEALTH EFFECTS OF OVEREXPOSURE TO RESPIRABLE COAL AND SILICA DUST

Pneumoconioses are lung diseases caused by the inhalation and deposition of respirable mineral dusts in the lungs. Pneumoconioses associated with working in an industry such as mining are coal workers' pneumoconiosis (CWP), mixed dust pneumoconiosis, and silicosis. Once these diseases manifest, they cannot be cured and can continue to progress in severity. Therefore, it is critical to limit worker exposure to airborne respirable dust to prevent the development of these diseases.

Coal Workers' Pneumoconiosis

CWP, commonly called black lung disease, is a chronic lung disease that results from the inhalation and deposition of coal mine dust in the lung and the lung tissue's reaction to its presence. It is associated with workers who mine, process, or ship coal. In addition to CWP, coal mine dust exposure increases a miner's risk of developing chronic bronchitis, chronic obstructive pulmonary disease, and pathologic emphysema [NIOSH 1995].

With continued exposure to coal mine dust, the lungs undergo structural changes that are eventually seen on a chest x-ray. In the early stage of disease (simple CWP), there may be no symptoms. However, when symptoms do develop, they include cough (with or without mucus), wheezing, and shortness of breath (especially during exercise). If a person has inhaled too much coal mine dust, simple CWP can progress to progressive massive fibrosis (PMF) where the structural changes in the lung are called fibrosis. PMF is the formation of large tough, fibrous scar tissue deposits in the areas of the lung that have become irritated and inflamed, thus replacing the regions of the lung where oxygen/carbon dioxide exchange normally occurs. The development of PMF causes the lungs to become stiff and their ability to expand fully is reduced. This ultimately interferes with the lung's normal exchange of oxygen and carbon dioxide and breathing becomes very difficult. The patient's lips and fingernails may have a bluish tinge, and there may be fluid retention and signs of heart failure. Figure 1.1 shows whole lung sections of a normal lung (left), simple CWP (center), and PMF (right).



Photos by NIOSH

Figure 1.1. Whole lung sections of normal lung (left), simple CWP (center), and PMF (right).

Simple CWP is characterized by the presence of small opacities (opaque spots) on the chest x-ray that are less than 10 millimeters (mm) in diameter. The profusion (density) of small opacities is classified as major category 1, 2, or 3 as defined by the International Labour Office (ILO) guidelines [ILO 2011]. Category 0 is defined as the absence of small opacities or opacities that are less profuse than the lower limit of category 1. Within the ILO profusion scale, each major category may be followed by a subcategory if an adjacent main category was considered during classification (e.g., classification 1/2 was judged as category 1, but category 2 was seriously considered) [NIOSH 1995].

PMF is classified as category A, B, or C when large opacities with a combined area of 1 centimeter (cm) or larger are found on the chest radiograph. PMF usually develops in miners already affected by simple CWP but can develop in miners with no previous radiographic evidence of simple CWP [NIOSH 1995]. Figure 1.2 provides radiographic examples of healthy and diseased lungs based upon the ILO severity classification system. In radiographs, unobstructed lungs appear black, while the bones, heart, diaphragm, and dust-impacted areas of the lungs appear white.

Photos by NIOSH

Figure 1.2. ILO Standard Radiographs demonstrating no pneumoconiosis (left), simple CWP category 2/2 (center), and PMF category C (right).

There is no specific therapy for these diseases. Primary prevention of lung disease in miners must include continued efforts to reduce coal mine dust exposure. Medical management is best directed at prevention, early recognition, and treatment of complications. The major clinical challenges are the recognition and management of airflow obstruction, respiratory infection, hypoxemia (an abnormally low amount of oxygen in the blood), respiratory failure, cor pulmonale (enlargement of the right side of the heart), arrhythmias (abnormal heart rhythm), and pneumothorax (collapsed lung).

With the passage of the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173), the Mine Safety and Health Administration (MSHA) enforced regulations designed to limit mine workers' exposure to respirable coal mine dust to a maximum of 2 milligrams per cubic meter of air (mg/m^3) if the silica content in the sample is less than 5%. MSHA inspectors and mine operators conducted periodic sampling to demonstrate compliance with this dust limit. In underground coal mines, airborne dust concentrations are typically the highest for workers involved in production activities at the mining face. Longwall shearer operators, jacksetters, continuous miner operators, and roof bolter operators are occupations with greater potential for exposure to excessive levels of respirable coal mine dust. Workers in some aboveground coal mining support operations also have increased exposure to coal mine dust. These include workers at preparation plants where crushing, sizing, washing, and blending of coal are performed and at tipples where coal is loaded into trucks, railroad cars, river barges, or ships.

Also included in the 1969 Act was the establishment of the NIOSH Coal Workers' Health Surveillance Program (CWHSP) [NIOSH 2019a]. As part of this program, underground coal miners are required to have an initial chest x-ray when they begin employment. Underground coal miners also have the opportunity to voluntarily receive periodic chest x-rays (free of charge to the miner) in an effort to detect the presence of CWP at its earliest stage of development. An individual miner is eligible to receive an x-ray approximately every five years.

Because underground coal miners are eligible to participate in the CWHSP about every five years, surveillance data has been summarized over five-year periods to provide an industry-wide assessment of CWP over time as shown in Figure 1.3. The rates of black lung observed in examined miners steadily declined from 1970 through 1999 [NIOSH 2019b]. However, more recent data shows that the declines have stopped and rates are rising. For miners with 25 or more years of experience who were examined in the CWHSP after the year 2000, the rate of black lung being found across the industry has more than tripled to over 14% [Hale 2021]. However, this increase has not been seen uniformly across the U.S. mining industry. In the central Appalachian region that includes eastern Kentucky, southern West Virginia, and southwestern Virginia, approximately 20% of examined miners were found to have CWP [Blackley et al. 2018a]. In addition, CWP is being found in younger miners and is advancing to more severe stages more rapidly than seen before, particularly in the central Appalachian mining region [Antao et al. 2005].

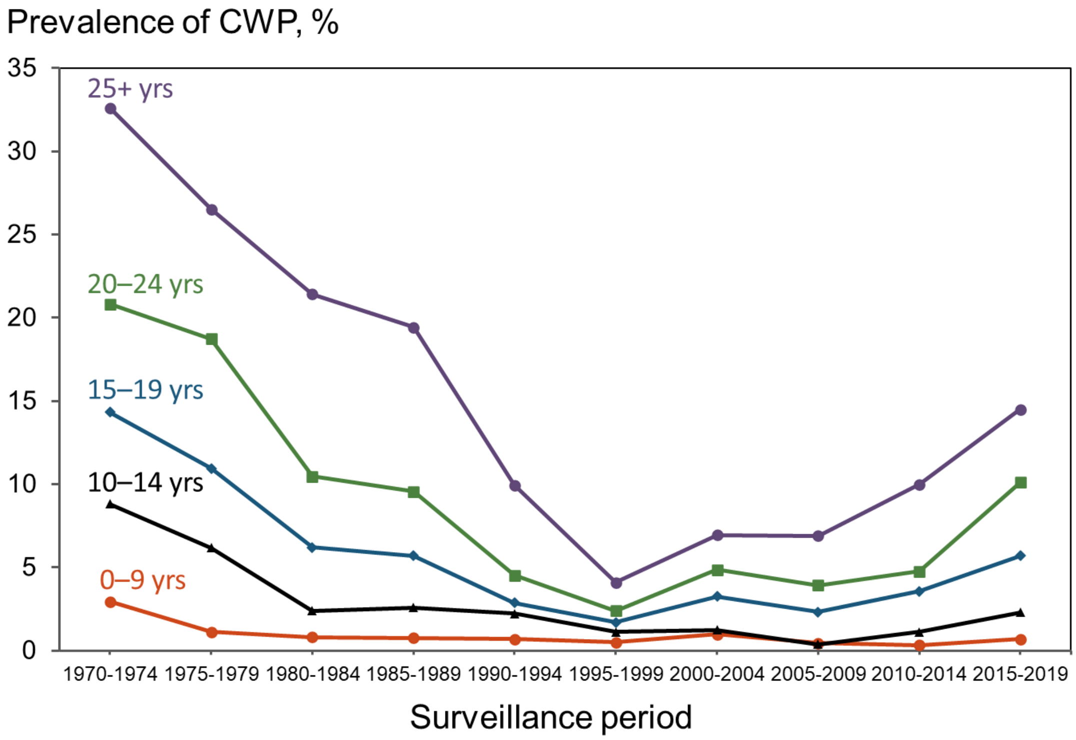


Figure 1.3. Percentage of examined underground coal miners with CWP Category 1 or greater by tenure in mining.

Data is also available that quantifies coal miners' deaths where CWP was recorded as the underlying or contributing cause. From 1970 through 2016, CWP was identified in the deaths of 75,178 miners [CDC 2019].

The occurrence of PMF has also seen an unexpected increase in prevalence over the last 20 years. In the CWHSP database [NIOSH 2019b], the prevalence of PMF for active underground miners with 10 or more years of experience had dropped to a program low of 0.1% in the 1990 to 1994 surveillance period as shown in Figure 1.4. However, from 2010 to 2019, the prevalence of PMF increased over 10-fold to over 1% [Hale 2021]. Recent research with former coal miners found that CWP can develop and/or progress to PMF absent further coal mine dust exposure, even among miners with no radiographic evidence of CWP when leaving the industry [Almberg et al. 2020]. For nearly half of these miners, the disease progression occurred in five years or less, illustrating the importance of regular medical surveillance even after employment ceases.

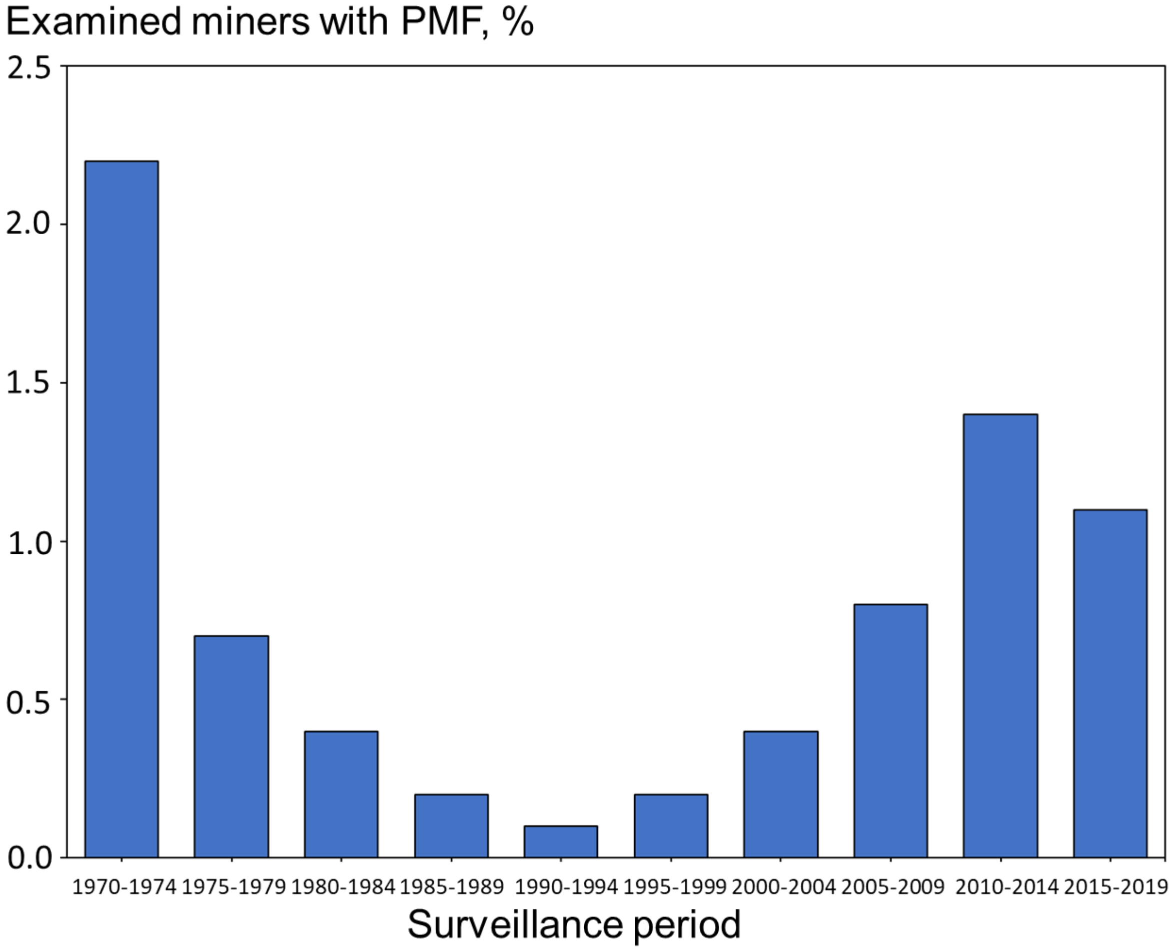


Figure 1.4. Percentage of underground miners examined in the CWHSP that were found to have PMF.

Additional evidence of increases in cases of PMF is found when examining data from miners filing for benefits under the Federal Black Lung Benefits program. Since its inception, the percentage of these miners that were found to have PMF in each decade has increased over five-fold [Almberg et al. 2018], as shown in Figure 1.5.

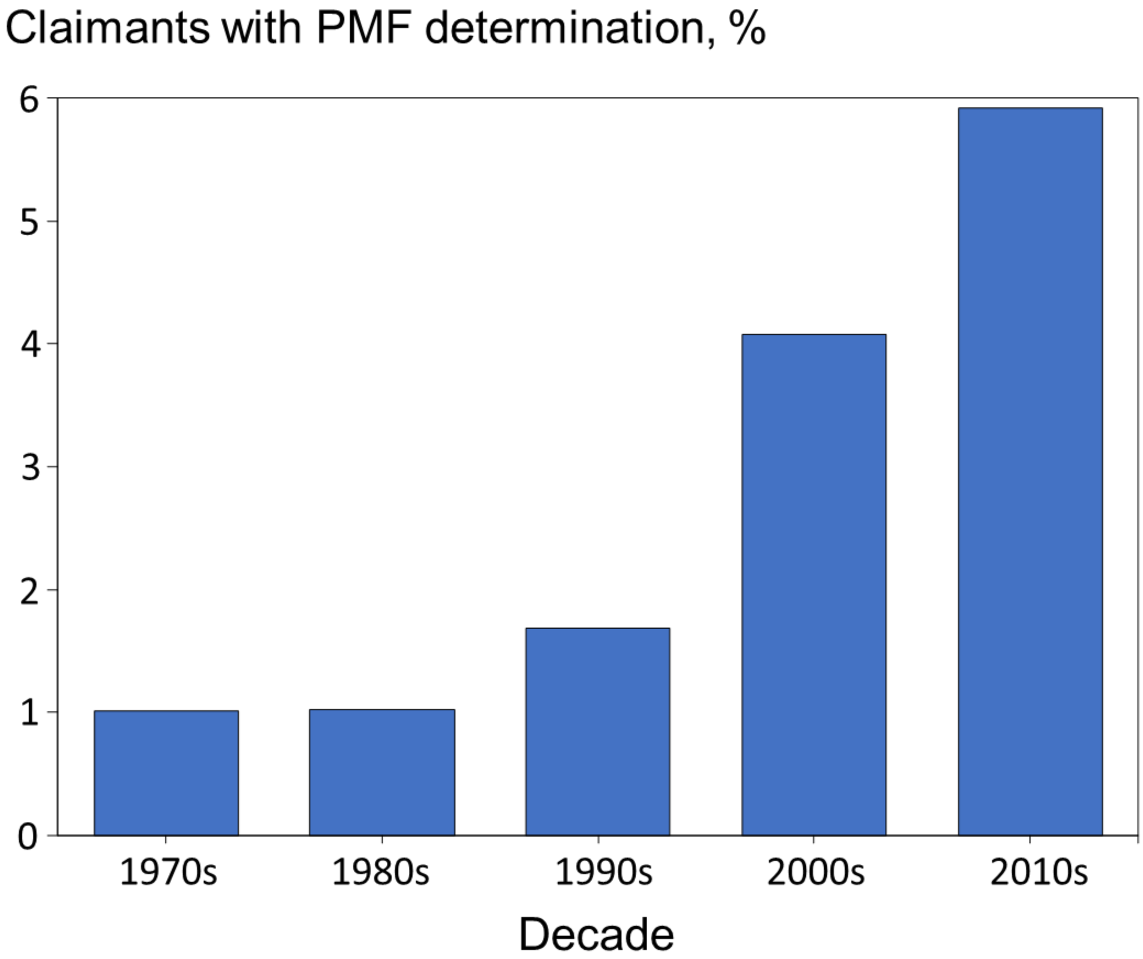


Figure 1.5. Percentage of miners filing for federal black lung benefits between 1970 and 2016 that were found to have PMF.

At a radiology practice in eastern Kentucky, 60 cases of PMF were identified in former miners examined between January 2015 and August 2016 [CDC 2016]. Between 2013 and 2017, 416 cases of PMF were identified among current and former coal miners at a small network of black lung clinics in southwestern Virginia [Blackley et al. 2018b].

The 1969 Act created a federal Black Lung Benefits Program. In this program, underground coal miners that have become disabled could apply for benefits, which include monthly compensation and medical expense payments. The Office of Workers Compensation within the Department of Labor (DOL) now administers this program and documents yearly costs [DOL 2021]. In 2020, over $220 million in benefits were paid. From 1971 through 2020, over $47.3 billion in payouts were made.

The 1969 Act also established procedures (30 CFR[6] Part 90) for miners with evidence of pneumoconiosis the right to work in an area of a mine where the average concentration of respirable dust in the mine atmosphere during each shift is continuously maintained at or below 1.0 mg/m^3. The rule set forth procedures for miners to exercise this option and established the right of miners to retain their regular rate of pay and receive wage increases. The rule also set forth the mine operator's obligations, including respirable dust sampling requirements for these Part 90 miners. The goal is to prevent further development of pneumoconiosis in the affected miner. However, between 1986 and 2016, only 14.4% of the miners eligible for Part 90 rights exercised this option [Reynolds et al. 2018a]. Of the miners who exercised their Part 90 transfer option and afterwards also participated in the CWHSP at least once, 32% showed further progression after exercising the Part 90 option. These miners had more severe disease prior to exercising, compared to miners that did not show progression, suggesting the importance of early detection of pneumoconiosis and prompt reduction in respirable dust exposure to prevent progression to severe disease [Hall et al. 2020].

The unexpected increases in CWP and PMF contributed to MSHA promulgating a new dust rule in 2014 [79 Fed. Reg.[7] 24814 (2014)]. Among the many changes contained in this rule, the respirable dust standard was lowered to 1.5 mg/m^3, while the standard for Part 90 miners was lowered to 0.5 mg/m^3. Implementation of these new dust standards began on August 1, 2016. This rule also requires occupational compliance sampling to be conducted with a continuous personal dust monitor (discussed in Chapter 2) and to encompass the entire work shift regardless of length. In the 1969 Act, compliance sampling was only conducted for eight hours even if the scheduled work shift was 10 or 12 hours long. Also, production must be at least 80% of the average tonnage over the last 30 shifts compared to 50% of the average tonnage from the last sampling period in the 1969 Act. Consequently, the new rule provides an opportunity to gain a more realistic measure of the full-shift dust exposure of coal mine workers. Also, as recommended by NIOSH [1995], the rule added lung function testing (spirometry) and a respiratory assessment questionnaire to the medical screening program and extended screening to surface coal miners.

Silicosis

Occupational exposures to respirable crystalline silica occur in a variety of industries and occupations because of its extremely common natural occurrence. Workers with high exposure to crystalline silica include miners, sandblasters, tunnel builders, silica millers, quarry workers, foundry workers, and ceramics and glass workers. As taken from the NIOSH Hazard Review publication [NIOSH 2002], silica refers to the chemical compound silicon dioxide (SiO_2), which occurs in a crystalline or noncrystalline (amorphous) form. Crystalline silica may be found in more than one form: alpha quartz, beta quartz, tridymite, and cristobalite [USBM 1992a; Heaney 1994]. In nature, the alpha form of quartz is the most common [Virta 1993]. This form is so abundant that the term quartz is often used instead of the general term crystalline silica [USBM 1992b; Virta 1993].

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[6] Code of Federal Regulations. See CFR in references.

[7] Federal Register. See Fed. Reg. in references.

Quartz is a common component of rocks. Underground mine workers are potentially exposed to quartz dust when rock within or adjacent to the coal seams is cut, crushed, and transported. In surface coal mining, rock strata above the coal seam is typically drilled, blasted, and removed, resulting in occupations such as drillers and bulldozer operators being exposed to quartz dust. Occupational exposures to respirable crystalline silica are associated with the development of silicosis, lung cancer, pulmonary tuberculosis, and airways diseases. These exposures may also be related to the development of autoimmune disorders, chronic renal disease, and other adverse health effects [NIOSH 2002]. In 1996, the International Agency for Research on Cancer (IARC) reviewed the published experimental and epidemiologic studies of cancer in animals and workers exposed to respirable crystalline silica. The IARC concluded that there was sufficient evidence to classify silica as a human carcinogen [IARC 1997]. In a subsequent update, the IARC cited additional research and reaffirmed silica as a human carcinogen [IARC 2009].

Silicosis is also a fibrosing disease of the lungs caused by the inhalation, retention, and pulmonary reaction to the crystalline silica. The main symptom of silicosis is usually dyspnea (difficult or labored breathing and/or shortness of breath). This is first noted with activity or exercise and later at rest as the functional reserve of the lung is also lost. However, in the absence of other respiratory disease, there may be no shortness of breath and the disease may first be detected through an abnormal chest x-ray. The x-ray may at times show quite advanced disease with only minimal symptoms. The appearance or progression of dyspnea may indicate other complications, including tuberculosis, airways obstruction, PMF, or cor pulmonale. A productive cough is often present.

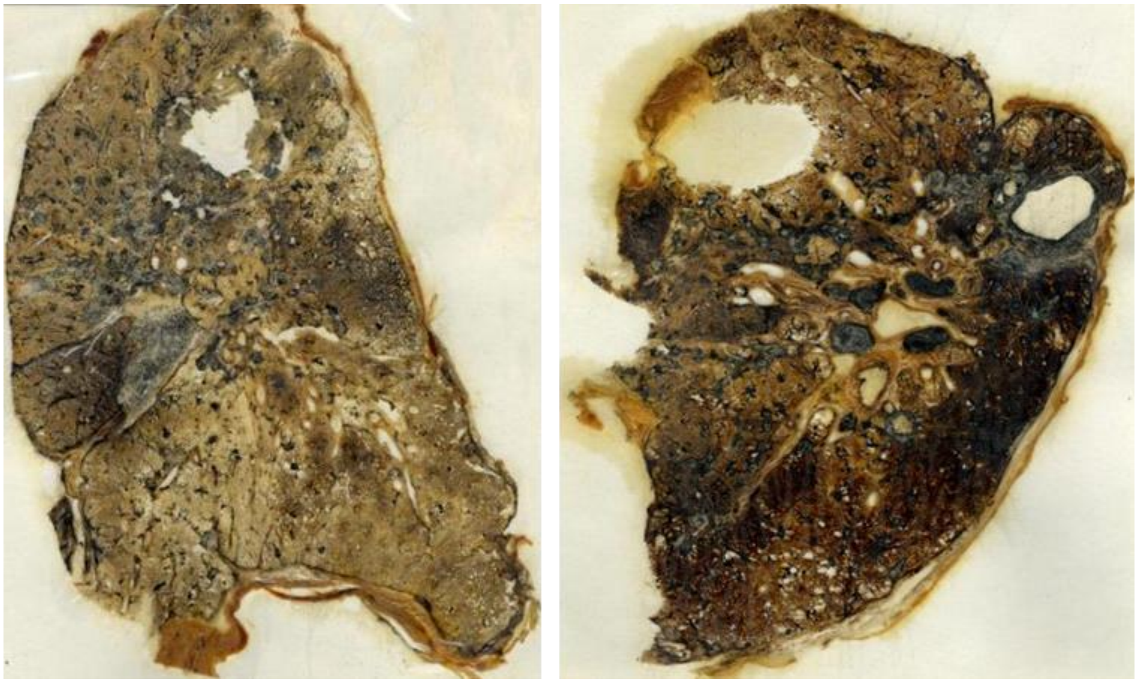
A worker may develop one of three types of silicosis, depending on the airborne concentrations of respirable crystalline silica that were inhaled:

(1) *Chronic Silicosis:* Usually occurs after 10 or more years of exposure at relatively low concentrations. Swellings caused by the silica dust form in the lungs and chest lymph nodes. This disease may cause people to have trouble breathing and may be similar to chronic obstructive pulmonary disease.

(2) *Accelerated Silicosis:* Develops 5–10 years after the first exposure. Swelling in the lungs and symptoms occur faster than in chronic silicosis.

(3) *Acute Silicosis:* Develops after exposure to high concentrations of respirable crystalline silica and results in symptoms within a period of a few weeks to five years after initial exposure [Parker and Wagner 1998; Peters 1986]. The lungs become very inflamed and can fill with fluid, causing severe shortness of breath and low blood oxygen levels.

PMF can occur in either chronic or accelerated silicosis but is more common in the latter. Figure 1.6 shows sections of lungs that have been damaged by silicosis.



Photos by NIOSH

Figure 1.6. Sections of freeze-dried human lungs with silicosis (left) and PMF (right).

To prevent the development of silicosis, MSHA began regulating the exposure of mine workers to silica in the 1969 Act. For coal mining operations, gravimetric samples collected to monitor compliance with the 2 mg/m^3 dust standard could be analyzed for quartz content. For quartz levels up to 5% in these compliance dust samples, no additional action was taken. However, if the percent quartz in the sample exceeded 5%, a reduced dust standard in mg/m^3 was calculated by dividing 10 by the percent quartz. For example, if a sample contained 10% quartz, the reduced standard would be equal to 1 mg/m^3 (10 ÷ 10% quartz). These regulations were designed to limit the exposure to respirable quartz to 100 micrograms per cubic meter of air (µg/m^3), although this limit was not specifically quantified in the regulation.

An analysis of MSHA compliance sampling data indicated that this indirect method of controlling silica exposure did not always achieve the desired results. This analysis showed that 11.7% of samples that were below the applicable respirable dust standard had silica levels that exceeded 100 µg/m^3 [Joy 2012]. Additionally, 4.4% of samples containing less than 5% quartz had quartz content exceeding 100 µg/m^3. Subsequently, in the 2014 MSHA dust rule, a limit of 100 µg/m^3 is specifically identified and silica levels in compliance samples are compared to this limit directly to determine compliance. If elevated silica levels are present, a reduced dust standard is calculated in the same manner as described in the previous paragraph, but the reduced standard cannot exceed the general 1.5 mg/m^3 dust standard.

As noted in the previous section, the prevalences of CWP and PMF have shown unexpected and dramatic increases since 2000. One factor that has been mentioned as a possible contributor to these trends is increased exposure to silica dust. Miners from central Appalachia diagnosed with PMF have indicated that substantial amounts of rock were extracted with the coal during routine mining at the face [Reynolds et al. 2018b; CDC 2016]. In addition, some of these miners reported cutting through sandstone rolls or driving slopes through rock for extended periods.

Compliance sampling would not likely capture exposures during these nonroutine but high-dust-producing mining events.

When examining chest radiographs, the presence of r-type opacities has been associated with silica exposure and silicosis pathology [Ruckley et. al. 1984; Soutar and Collins 1984]. NIOSH conducted a retrospective analysis of chest radiographs from underground coal miners examined in the decades of the 1980s through the 2010s. The presence of r-type opacities was quantified as shown in Figure 1.7 [Hall et al. 2019]. This data indicates that greater exposure to silica dust has been occurring in the central Appalachian region and likely contributes to the observed increase in CWP and PMF in these mines.

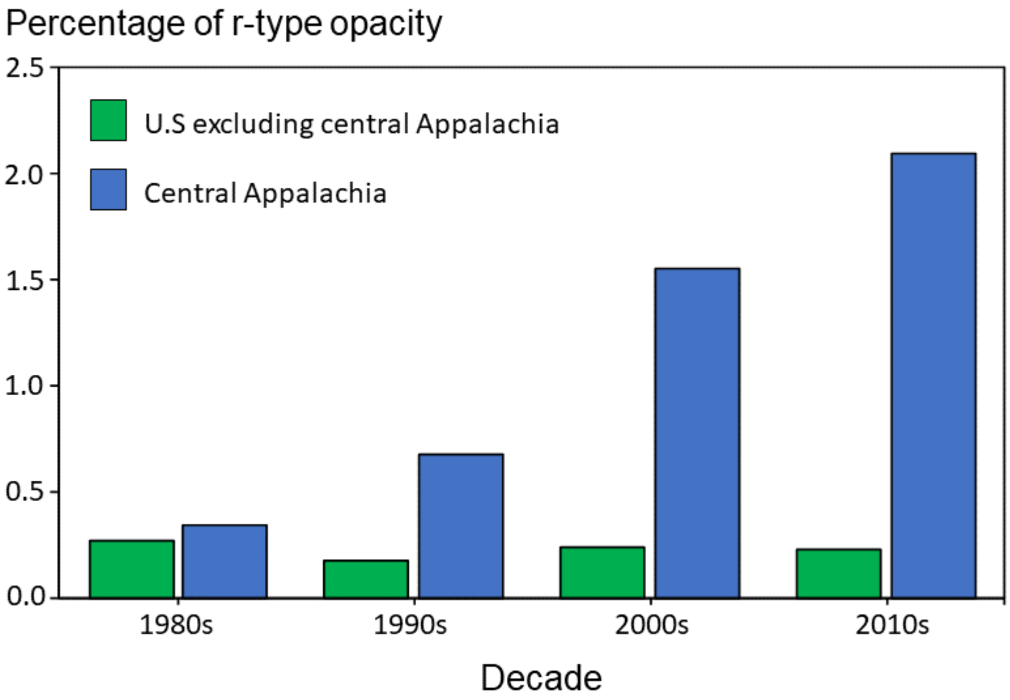


Figure 1.7. Percentage of r-type opacities by region and decade from 1980 through 2018.

In 2010 and 2011, NIOSH obtained chest radiographs from 2,257 surface coal miners through the CWHSP's mobile outreach program and found CWP in 46 miners (2%), with 12 of these miners having PMF [CDC 2012]. Thirty-seven of the miners with CWP and nine with PMF had never worked underground, indicating that their occupational dust exposure came from surface coal mining work. A case-series follow-up of the nine surface miners with PMF revealed that all had worked as a drill operator and/or blaster for a majority of their careers [Halldin et al. 2015].

A high proportion of these radiographs contained r-type opacities, suggesting exposure to respirable crystalline silica. For the miners diagnosed with CWP and PMF, 31 (67%) and 10 (83%) of these miners, respectively, were from the central Appalachian region, while central Appalachian miners only accounted for 37% of the miners examined.

Diagnosis and Treatment of Pneumoconioses

CWP or silicosis may be diagnosed based on the combination of an appropriate history of exposure to coal mine dust or silica, compatible changes in chest imaging or lung pathology, and absence of plausible alternative diagnoses. A chest radiograph is often sufficient for diagnosis, but in some cases a computed tomography (CT) scan of the chest can be helpful. Lung biopsy, a procedure where a sample of lung tissue is taken for lab examination, is not usually required if a compatible exposure history and findings on chest imaging are present. Pulmonary function tests and blood tests to measure the amounts of oxygen and carbon dioxide in the blood (arterial blood gases) can help in objectively assessing the level of impairment caused by CWP or silicosis.

As provided in the NIOSH Hazard Review [NIOSH 2002], epidemiologic studies of gold miners in South Africa, granite quarry workers in Hong Kong, metal miners in Colorado, and coal miners in Scotland have shown that chronic silicosis may develop or progress even after occupational exposure to silica has been discontinued [Hessel et al. 1988; Hnizdo and Sluis-Cremer 1993; Ng et al. 1987; Kreiss and Zhen 1996; Miller et al. 1998]. Therefore, removing a worker from exposure after diagnosis does not guarantee that silicosis or silica-related disease will stop progressing or that an impaired worker’s condition will stabilize [Parker and Wagner 1998; Weber and Banks 1994; Wagner 1994].

Treatment of CWP or silicosis may include use of bronchodilators (medications to open the airways) or supplemental oxygen use. Once disease is detected, it is important to protect the lungs against respiratory infections. Thus, a doctor may recommend vaccinations to prevent influenza and pneumonia. In some cases of severe disease, a lung transplant may be recommended, with transplants resulting from CWP increasing in recent years [Blackley et al. 2016]. Prognosis depends on the specific type of pneumoconiosis and the duration and level of dust exposure. Among those with CWP receiving a lung transplant, the median post-transplant survival time was 3.7 years.

There is no cure for these lung diseases, and they can be deadly. Effective control technologies must be implemented and continually maintained to prevent initial development of the disease. If either CWP or silicosis does develop, early detection is advantageous for the long-term health and care of the worker. Consequently, participation in the CWHSP at recommended intervals throughout a miner’s career is a valuable asset available to U.S. coal miners and is encouraged by NIOSH. Participation in the Part 90 program is another valuable asset that can help reduce subsequent dust exposure for miners continuing to work after being diagnosed with CWP.

Faces of Black Lung Videos and Information Booklet

To illustrate the severe impact that CWP, especially PMF, can have on someone’s life, NIOSH has produced two videos in which miners suffering from PMF were interviewed.[8] In the 2008 video (Faces of Black Lung, Figure 1.8, left), a 55-year-old and a 58-year-old miner at the time of being interviewed discussed how their disease limited their normal abilities and impacted their family life. The 58-year-old miner died seven months after being interviewed. The 55-year-old miner eventually had a double-lung transplant but then died four months afterward at the age of 60.

In the 2020 video (Faces of Black Lung II, Figure 1.8, right), three younger miners suffering from PMF were interviewed. These miners were only 39, 42, and 47 years old at the time of the interviews. These miners also discuss the impact the disease has had on their lives and their families. The 42-year-old miner died between the time of his interview and the video being released.

An information booklet to accompany the Faces of Black Lung II video is also available on the NIOSH website.[9]

Figure 1.8. Covers of original Faces of Black Lung videos produced by NIOSH.

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[8] Faces of Black Lung video on the NIOSH YouTube channel: https://www.youtube.com/watch?v=H2U9Onrxepg
Faces of Black Lung II video on the CDC YouTube channel: https://www.youtube.com/watch?v=X-agtyN4py4

[9] Faces of Black Lung II informational booklet: https://www.cdc.gov/niosh/docs/2020-109/pdfs/2020-109.pdf?id=10.26616/NIOSHPUB2020109

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CHAPTER 2: SAMPLING TO QUANTIFY RESPIRABLE DUST GENERATION

The respirable fraction of airborne mine dust is the dust that reaches the gas exchange region of the lungs and can lead to the development of coal workers' pneumoconiosis (CWP) or silicosis. The American Conference of Governmental Industrial Hygienists (ACGIH) and the International Organization for Standardization (ISO) have adopted airborne particulate sampling conventions for use in assessing possible health effects [ACGIH 1994; ISO 1995]. The respirable fraction is currently defined by the size distribution shown in Table 2.1, representing dust with aerodynamic diameters of less than 10 micrometers (µm) with a 50% cut point of 4 µm. Aerodynamic diameter is defined as the diameter of a hypothetical sphere of 1 gram per cubic centimeter density having the same settling velocity in calm air as the particle in question, regardless of the particle's geometric size, shape, and true density This size distribution was selected as being representative of particle deposition within the alveolar region of the human respiratory tract [NIOSH 1995].

Table 2.1. ACGIH/ISO size distribution definition of respirable dust [ACGIH 1994; ISO 1995]

Particle aerodynamic diameter (µm)	Respirable particulate mass collected (%)
0	100
1	97
2	91
3	74
4	50
5	30
6	17
7	9
8	5
10	1

Individual respirable dust particles cannot be seen with the eye. Conversely, if a dust cloud is visible, it is likely that a portion of the airborne dust will be in the respirable size range. To accurately quantify the amount of potentially harmful respirable dust in the mine air, sampling instrumentation must be used. Accurate respirable dust sampling is important to quantify worker exposures, identify dust sources, and evaluate the effectiveness of control technologies.

Respirable Dust Samplers Used in Coal Mining

Electrical equipment intended for use at the mining face in underground coal operations must be certified by the Approval and Certification Center of the Mine Safety and Health Administration (MSHA). Testing is conducted by MSHA to ensure safe operation of this equipment in the methane gas environment found in underground mines [MSHA 2019a]. At the time of publication, only three respirable dust sampling instruments were certified for use in underground coal mines by MSHA: a gravimetric sampler, a continuous personal dust monitor, and a light-scattering instrument. All of these samplers can be worn by miners to quantify personal exposures or can be placed at specific locations to quantify area dust levels. Each of these instruments can provide unique information that can help mine operators assess dust sources, control technology effectiveness, and personal dust exposures.

In addition to these respirable dust sampling instruments, NIOSH has also developed a field-based method that can be utilized at the mine site to provide mine operators information on the respirable silica content of gravimetric samples immediately after sampling has been completed. A discussion for each of these respirable dust samplers and the silica analysis method follows. Also, NIOSH has adapted an inhalable dust sampler and the continuous personal dust monitor to collect airborne samples of float dust. These samplers are discussed in Chapter 6.

Gravimetric Sampler

The Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173) required respirable dust concentrations to be measured with a four-channel horizontal elutriator dust sampler developed by the Mining Research Establishment (MRE) of the National Coal Board, London, England, or “MRE-equivalent” concentrations measured with samplers approved by the Secretary of Health, Education, and Welfare. In 1970, a personal gravimetric respirable dust sampler was approved for use in the U.S. mining industry and was worn by miners as shown in the left photo of Figure 2.1. This type of sampler was used by both the mine operators and MSHA inspectors to collect all compliance samples until MSHA passed a new dust rule in 2014 [79 Fed. Reg.[10] 24814 (2014)]. Beginning on February 1, 2016, the 2014 dust rule required underground coal mine operators to use a continuous personal dust monitor (CPDM) to complete compliance dust sampling. However, under the new dust rule, the gravimetric sampler is still being used for compliance sampling by surface coal mine operators, for compliance sampling by MSHA inspectors including analyzing the samples for silica content, and for area samples at underground coal mines.

The main components of the gravimetric sampling system consist of a size-selective cyclone, a filter cassette, and a constant-flow sampling pump [Zefon International 2019a] as shown in Figure 2.1, right. The 10-millimeter (mm) Dorr-Oliver cyclone separates the oversize dust from the respirable fraction. The oversize dust is deposited into the grit pot at the bottom of the cyclone, while the respirable fraction is collected on a 37-mm-diameter polyvinyl chloride (PVC) filter. The cyclone and filter are placed in a metal holder equipped with an alligator clip to attach the holder to the lapel area when worn by a miner. The filter should be weighed by a qualified lab to determine the mass of respirable dust that has been collected during sampling. Care must be taken after a sample is collected to ensure that the cyclone assembly stays in an

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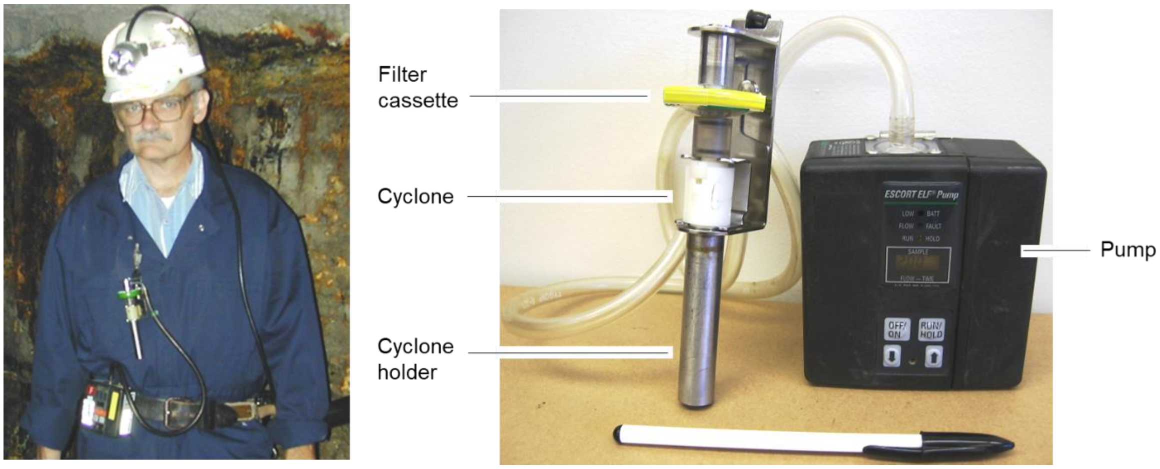
[10] Federal Register. See Fed. Reg. in references.

upright position. Otherwise, the oversize dust particles in the grit pot can fall through the cyclone body and be deposited onto the filter, invalidating the sample.



Photos by NIOSH

Figure 2.1. Miner wearing gravimetric sampler (left) and sampling system components (right).

The sampling pump alternately displays the flow rate and operating time while running, with sampling time displayed after the pump is turned off. The flow rate and sampling time are used to calculate the total volume of air sampled. The mass of dust collected on the filter and the volume of air sampled are used to calculate the average concentration of respirable dust in milligrams per cubic meter (mg/m^3) over the entire sampling period.

For coal mining operations, the sampling pump is calibrated to operate at 2 liters per minute (L/min). At this flow rate, the Dorr-Oliver cyclone collects a respirable dust fraction that more closely matches the U.S. Atomic Energy Commission definition of respirable dust [USBM 1970; Sansone et al. 1973], which has a 50% cut point of 3.5 µm. It was determined that multiplying the calculated dust concentration at the 2 L/min flow rate by an empirically derived constant factor of 1.38 [USBM 1973] provides an MRE-equivalent dust concentration as required by the 1969 Act.[11]

A benefit of using the gravimetric sampler is that the PVC filter can be analyzed to determine the silica content in the collected dust. At the time of publication, this is the only way to determine the silica content for compliance purposes. After a dust sample is collected, the filter cassette is sent to the MSHA Dust Division analytical laboratory in Pittsburgh, PA. For samples collected in coal mines, the MSHA P-7 infrared analytical technique [Parobeck and Tomb 2000] is used to determine silica content.[12] For samples collected by mines for their own information on silica content, filter samples should be sent to an accredited laboratory for analysis. Alternatively, coal

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[11] There is no regulation for samples collected in metal and nonmetal mines to be MRE-equivalent. In metal and nonmetal mining operations, the gravimetric sampling pump is operated at 1.7 L/min. Research has shown [Bartley et al. 1994] that at 1.7 L/min the Dorr-Oliver cyclone results in dust collection that more closely matches the ACGIH/ISO definition of respirable dust shown in Table 2.1.

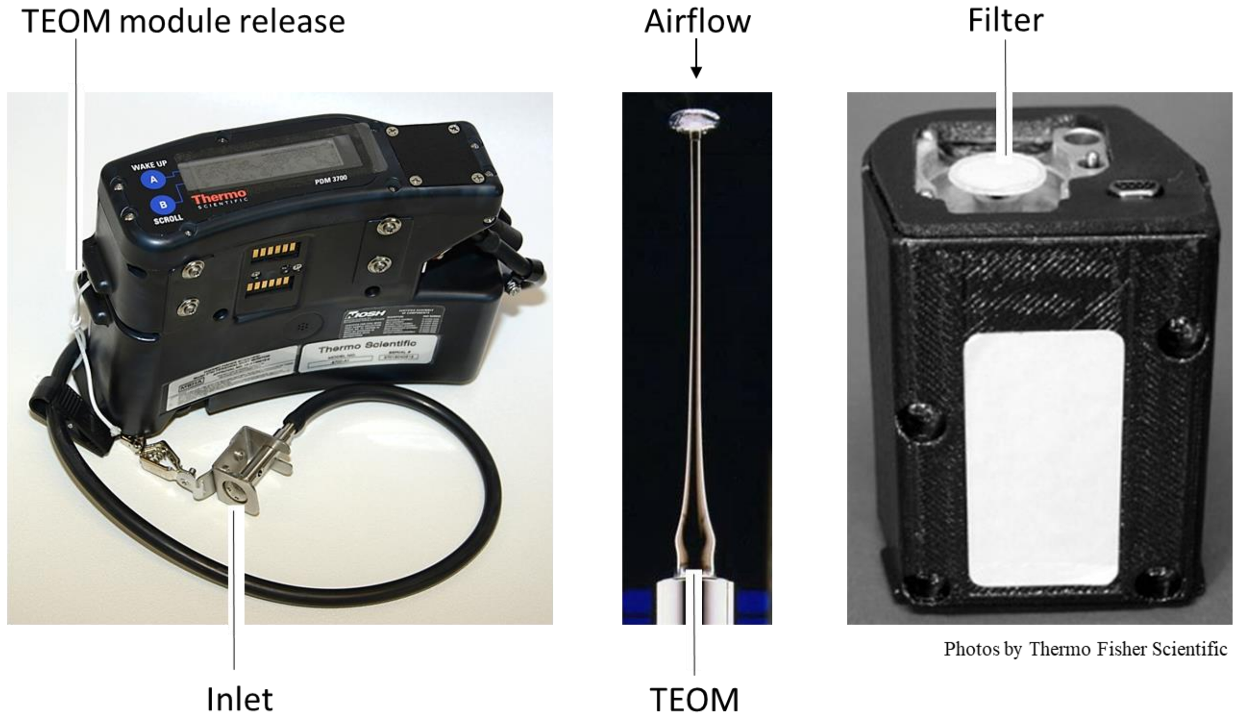
[12] In metal and nonmetal mines, additional minerals are present that can complicate the silica analysis. As a result, x-ray diffraction using NIOSH Method 7500 [NIOSH 2003] can better identify these confounding materials and is used to analyze samples from metal and nonmetal mines.

mine operators can now conduct their own on-site analysis using a field-based technique developed by NIOSH, which is discussed later in this chapter.

A great number of variables are encountered in mining operations that can impact airborne dust levels and create significant dust gradients [Kissell and Sacks 2002]. Consequently, when sampling to quantify dust sources and for evaluating control technologies, it is desirable to place multiple gravimetric samplers at a single location and calculate an average dust concentration. The use of multiple samplers increases the confidence that the measured dust levels are representative of the true dust concentration at that location.

Continuous Personal Dust Monitor

Through external contracts and associated internal research, NIOSH developed a compliance-grade personal dust monitor (PDM) that provides near real-time respirable dust exposure information to the miner during the shift and the average shift concentration immediately at the end of sampling [NIOSH 2006]. This sampler was certified by NIOSH in 2014 as meeting the performance criteria of a continuous personal dust monitor (CPDM) as specified in the Code of Federal Regulations (CFR) [30 CFR Part 74 Subpart C]. MSHA also approved the sampler as being intrinsically safe. The commercial version of this sampler is available from Thermo Fisher Scientific as the PDM3700 Personal Dust Monitor [Thermo Fisher Scientific 2019a] as shown in Figure 2.2, left. Beginning on February 1, 2016, underground coal mine operators have had to use a CPDM to obtain compliance dust samples on specified occupations.



Photos by Thermo Fisher Scientific

Figure 2.2. PDM3700 sampler (left), TEOM (center), and TEOM module removed from PDM (right).

The PDM uses tapered-element oscillating microbalance (TEOM) technology to obtain a gravimetric-based measure of respirable dust concentrations. The TEOM is a hollow tube with a filter mounted on top (Figure 2.2, center) that vibrates at a known frequency. As dust-laden air is drawn through the filter and tube, respirable dust is collected on the filter resulting in a change in TEOM frequency, which is directly correlated to the added dust mass. The TEOM and a section of airflow tubing inside the PDM leading to the TEOM are equipped with heaters. This heated flow path is designed to remove moisture from the collected dust [NIOSH 2006]. The added dust mass and the volume of sampled airflow are used to calculate a respirable dust concentration which is recorded each minute by the PDM for later download. Within the PDM, the TEOM is mounted in an independent module (Figure 2.2, right) that is removed from the instrument to change the filter.

The PDM is equipped with a lapel-style inlet to capture dust in a similar location as the gravimetric sampler. A Higgins-Dewell cyclone is mounted on the instrument and separates the respirable fraction of airborne dust. When operated at 2.2 L/min, the Higgins-Dewell cyclone has been shown [Bartley et al. 1994] to collect a sample distribution best matching the ISO definition of respirable dust as defined in Table 2.1. The actual dust concentration calculated by the PDM is multiplied by 1.05 to match the MRE-equivalent dust concentrations as measured with the gravimetric sampler [Page et al. 2008]. This MRE factor is the default setting in the PDM software but can be turned off if the PDM is going to be used for non-compliance sampling.

A key benefit of the PDM is the information provided to the wearer during the sampling shift which can be used to prevent overexposures from occurring. The PDM is equipped with a readout where wearer can scroll through several different screens of information to assess their dust exposure. The first screen (Figure 2.3, left) shows the dust concentration over the previous 30 minutes and the cumulative dust concentration to that point in the shift. The second screen (Figure 2.3, center) shows the permissible exposure limit (PEL) and the percentage of the PEL that has been reached to that point in the shift. The PDM programming software defaults to a PEL of 1.5 mg/m^3 to match the dust standard defined in the 2014 MSHA dust rule. However, if a mining section is operating on a reduced dust standard due to elevated quartz, the reduced dust standard can be entered into the PDM when programming for the shift’s sampling run. The last screen (Figure 2.3, right) shows a bar chart of dust levels throughout the shift with each bar representing a 30-minute time period, which can be reviewed to identify the highest exposure periods during the shift. The information on these screens can be used by the wearer to monitor dust exposure throughout the shift and assess the potential for a dust overexposure. For example, if the PEL reached on the second screen shows 50% and the shift is only two hours into a 10-hour shift, it would indicate that a dust overexposure is going to occur if no changes to the control technologies and/or operating procedures are made.

Photos by NIOSH

Figure 2.3. Information displayed on a PDM3700. The first PDM screen shows 30-minute and cumulative concentration (left), the second screen shows shift limit and percentage of limit (center), and the third screen shows a bar chart of 30-minute averages (right).

When the PDM completes its sampling run, the average shift concentration is displayed on the instrument screen and also stored internally with the shift data. Therefore, the mine will immediately know the average respirable dust concentration for the sampling shift.

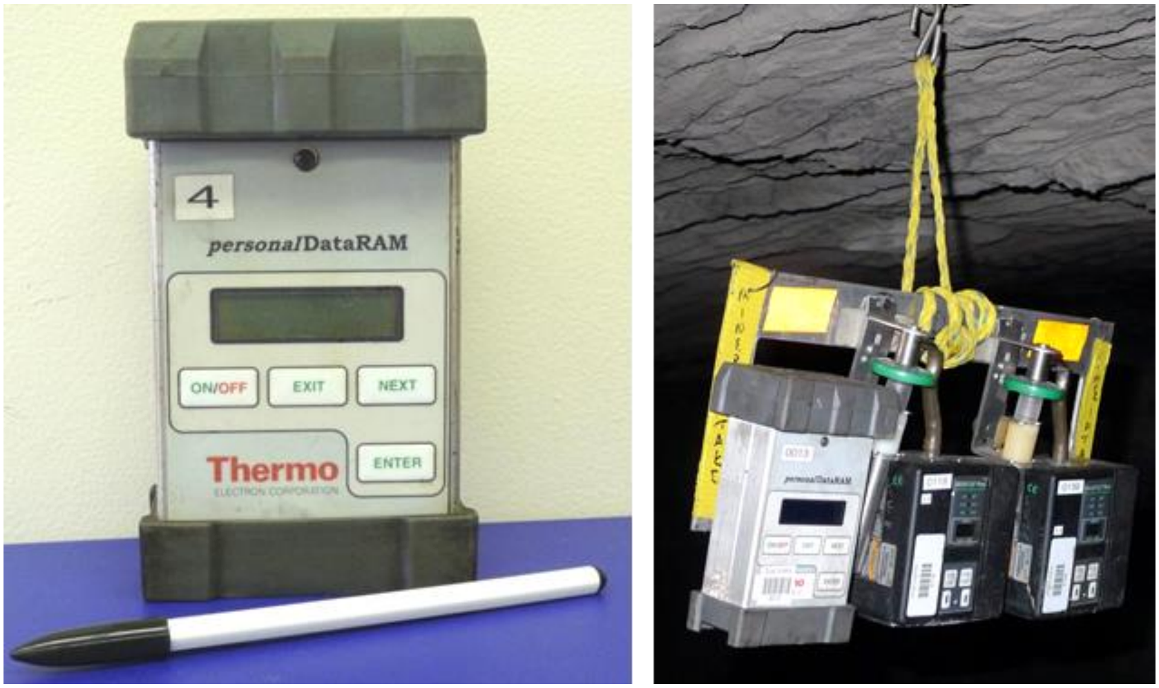
The PDM is currently configured to store two data files. One file is encrypted and must be transmitted to MSHA as the official record of compliance sampling. The second file can be downloaded and the recorded data can be reviewed by the mine operator to identify periods of elevated dusts concentrations or other periods of interest.

Another benefit provided by the PDM is that it monitors and records numerous operating parameters to confirm that the instrument is functioning properly. A few examples of operating parameters that are monitored include the mass gain/loss on the filter, airflow rate, and TEOM temperature control. If one of the operating parameters extends beyond its defined range that is incorporated into the operating software, the PDM generates a status code that identifies the operating parameter that is out-of-range and the time of occurrence. The status code is recorded in the data file and an “S” is displayed on the readout screen to alert the wearer [Thermo Fisher Scientific 2019b]. For example, if the sampler inlet is accidently pulled from the miner’s lapel and the inlet drops into a pile of dust, a large mass gain on the filter would be registered and would trigger generation of a “Mass Offset” status code. MSHA uses a number of these status codes [MSHA 2019b] to help determine if a compliance sample should be voided.

Light-scattering Real-time Dust Monitor

In addition to the gravimetric samplers, a real-time dust sampler had been approved by MSHA for use in underground mines but was not certified by NIOSH for compliance sampling purposes. However, a number of electronic components in the original design are no longer available; therefore, new MSHA-approved units are not available at the time of publication. Previously approved units can still be used in underground coal mines. Also, Thermo is pursuing MSHA approval for the modified instrument with updated electronics [Gallagher 2021].

The personal DataRAM 1000 AN (pDR) [Thermo Fisher Scientific 2019c] is a passive sampler (Figure 2.4, left) that has dust-laden air enter a sensing chamber where a light beam passes through the dust. A sensor measures the amount of light scatter caused by the dust and relates this scatter to a relative dust concentration. This concentration is correlated to the time when the sample was measured and is stored in the internal data logger. The data logging averaging period is user-selected and ranges from one second to one hour. The sample data can then be downloaded to a computer for analysis.



Photos by NIOSH

Figure 2.4. pDR 1000AN sampler (left) and pDR operated with gravimetric samplers in an underground coal mine (right).

Unfortunately, the accuracy of the light-scattering monitors can be compromised by dust clouds with changing size distributions, different dust compositions, and/or water mist in the air. Consequently, when NIOSH uses pDR samplers, a field calibration is completed as recommended by the manufacturer [Thermo Scientific 2013]. Gravimetric samplers are operated adjacent to the pDR as shown in Figure 2.4, right. Individual pDR dust measurements are adjusted based on the ratio between the average gravimetric concentration and the average pDR concentration. For example, if the average gravimetric concentration was 1.2 mg/m^3 over a 6-hour measurement period and the pDR average concentration was 0.9 mg/m^3 for the same 6 hours, then all individual pDR measurements would be multiplied by 1.33 (1.2 ÷ 0.9).

Figure 2.5 illustrates a graph generated from data obtained with the pDR. Mobile sampling (this sampling technique is discussed later in the chapter) was used to collect the data on a producing longwall face. The time-related dust data can be analyzed for specific time intervals (e.g., head-to-tail and tail-to-head passes on the longwall), with average dust concentrations calculated for each of these intervals.

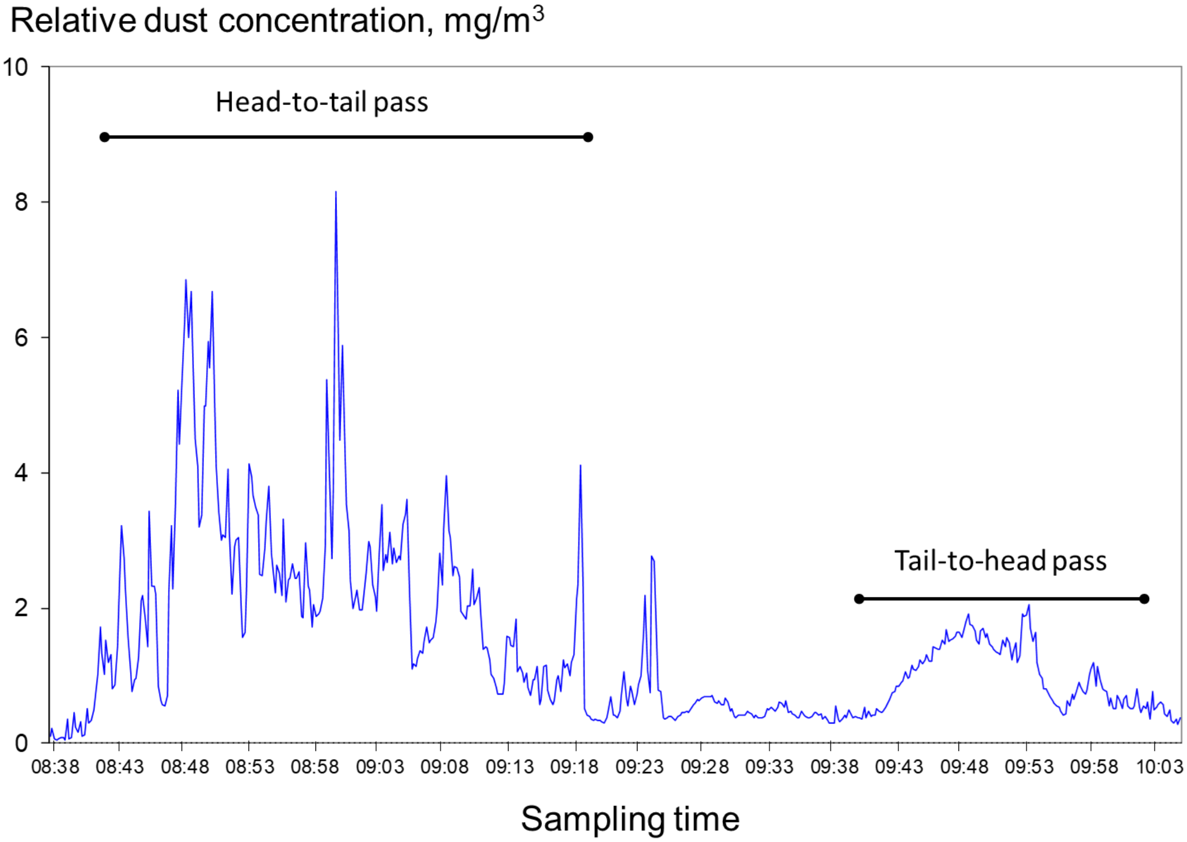


Figure 2.5. Dust measurements obtained with the pDR near the shearer on a longwall face.

A benefit of using the pDR is that data for short-term dust events can be collected and analyzed when the data is downloaded. This capability is particularly useful when trying to quantify dust levels for events that last a relatively short period of time. Examples of short-term events of interest in an underground coal mine may be the dust exposure for shuttle car operators while being loaded by the continuous miner or roof bolter operators cleaning their dust boxes. These types of activities can last less than one minute, but by selecting an appropriate logging time such as one to two seconds, many data points can still be obtained. Short-term dust spikes occurring during these events would also be identified with this sampling frequency, as shown in Figure 2.5 where a spike reaches over 8 mg/m^3.

Field-based Silica Analysis

Historically, the MSHA P-7 infrared analytical method has been used to quantify the respirable crystalline silica content of gravimetric samples collected at coal mining operations for compliance determination and continues to be used [MSHA 2018]. This method quantifies the alpha quartz in the sample, which is the most common of the crystalline silica polymorphs. After being received at the MSHA's Dust Division laboratory, a filter is removed from its sampling cassette and ashed in a low-temperature, radio frequency asher. This procedure removes the organic coal dust and filter material. The remaining material is redeposited onto a new filter for scanning with a Fourier transform infrared (FTIR) spectrometer to determine the quartz content. It can take one week or more from the time the dust sample is initially collected at a mine to when the mine is provided with the silica results. If mining conditions present when the sample was collected have not changed, then silica overexposures could continue to occur during the interim until the mine is notified of the elevated silica levels.

To address this time delay in obtaining silica analysis results, NIOSH has developed a field-based method that utilizes a portable FTIR instrument to analyze gravimetric filters at the mine site with no sample preparation needed [Cauda et al. 2016; Pampena et al. 2019; NIOSH forthcoming]. It should be noted that this method is not intended to be used for compliance determination. Four commercially available FTIR instruments (Figure 2.6) were used in initial NIOSH testing, with all units performing satisfactorily [Ashley et al. 2020].


Photo by NIOSH

Figure 2.6. Portable FTIR units used in NIOSH testing: Thermo Fisher (top left), Perkin Elmer (top right), Bruker Optics (bottom right), and Agilent manufacturers (bottom left).

Initially, the field-based method was developed by utilizing samples collected with the non-regulated coal dust sampling cassette [Zefon International 2019b], which is not the tamper-proof cassette used for compliance sampling. The filter capsule was removed from its plastic cassette holder and inserted into a portable FTIR unit for analysis. NIOSH-developed software known as Field Analysis of Silica Tool (FAST) [NIOSH 2019a] takes the output from the FTIR instrument and calculates the quartz content in terms of mass concentration. In approximately three minutes, the quartz content is known. If elevated silica is present, mine personnel can use this knowledge to take action on the next shift in an effort to prevent additional silica overexposures.

To improve accuracy and facilitate filter handling, NIOSH worked with a filter manufacturer [Zefon International 2019c] to design a new four-piece cassette (Figure 2.7, left) for obtaining a gravimetric sample. By using this cassette, the dust deposition is more uniformly distributed across the filter. This improves the accuracy of the silica analysis, since only the center of the filter is analyzed by the FTIR. Also, the filter remains encased within the two center sections of the cassette (Figure 2.7, center), and this entire section is placed in the FTIR analyzer (Figure 2.7, right). This significantly reduces handling of the filter—thus minimizing the potential for disturbing the deposited dust.

NIOSH has also designed specific filter cassette cradles for use in the portable FTIR instruments which align the cassette for analysis. A 3-D printer can be used to produce these cradles, and NIOSH has made the design files for 3-D printing available on a government website [NIH 2020]. Additional information on the hardware and software requirements for using this field-based respirable crystalline silica monitoring method is available on the NIOSH website [NIOSH 2019b].

Photos by NIOSH

Figure 2.7. Four-piece cassette (left) with filter contained within two center sections (center) and being loaded into an FTIR instrument cradle (right).

Because this method is non-destructive, the filter cassette can then be sent to a laboratory for traditional P-7 analysis for comparison to results obtained from the field-based method. Initial NIOSH research compared results from the portable FTIR and the MSHA P-7 method, as shown in Figure 2.8 [Miller et al. 2012]. The accuracy observed for these laboratory-generated samples provided the confidence to move forward with further development and testing of the field-based method for coal mines.

It should be noted that the array of minerals found in dust samples collected in metal and nonmetal mines adds complexity to the analysis and is still being researched by NIOSH. Also, it is worth noting again that the original goal was to develop a method that could be easily used by mine operators to evaluate trends in silica levels and determine the relative effectiveness of implemented control technologies. At this time, this method is not intended to be used for determining compliance with MSHA dust limits.

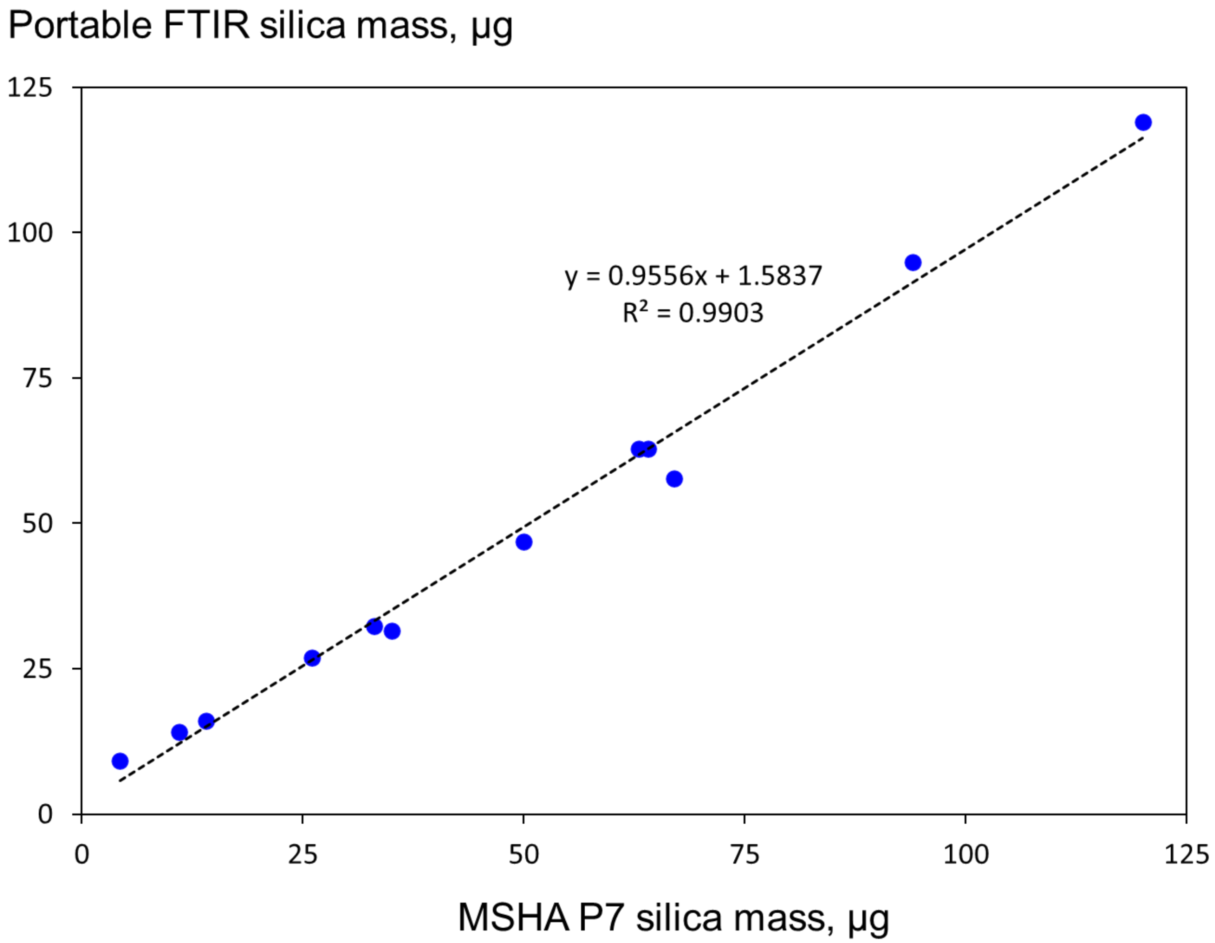


Figure 2.8. Comparison of results obtained with portable FTIR and P7 silica analysis techniques.

Sampling Strategies

To effectively control the respirable coal and silica dust exposure of mine workers, it is necessary to identify the sources of dust generation and quantify the amount of dust liberated by each of these sources. After the dust sources have been quantified, dust control technologies can then be applied that offer the greatest protection to the mine workers.

To quantify the amount of dust liberated by a source, dust sampling must be conducted in a manner that isolates the identified dust-generating source. This is achieved by placing dust samplers upwind and downwind of the source in question. The difference between these measurements is used to calculate the quantity of dust liberated by this source.

For example, in an underground coal mine working face, samplers can be placed in the immediate intake and return of the continuous miner to determine the amount of dust liberated by the miner while cutting and loading in the face. In this case, samplers are positioned upwind and downwind of the miner to sample the airborne dust levels throughout the cut. Figure 2.9, left, shows these sampling locations for a continuous miner while using exhausting ventilation in the face. Figure 2.9, right, shows a sampling package containing two gravimetric samplers and a pDR hung in the intake air to the miner.

If gravimetric samplers are used for this evaluation, it is necessary to ensure that sufficient mass is collected during sampling. As a result, it may be necessary to sample during multiple continuous miner cuts. In this case, the sampling pumps should be started when the continuous miner has been positioned in the face and begins cutting coal. After the first cut has been completed, the sampling pumps should be placed on hold to suspend sampling while the miner is repositioning into the next face. While on hold, the sampling pumps should be repositioned to the second cut in the same relative locations as for the first cut sampled. When the miner is ready to resume mining, the sampling pumps can be restarted.

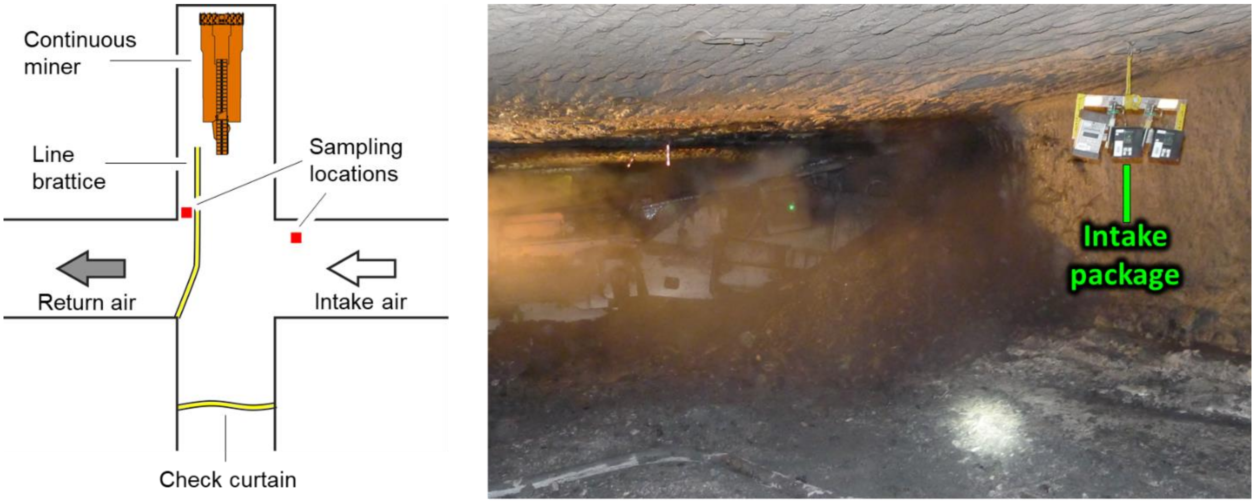


Photo by NIOSH

Figure 2.9. Sampling locations used to isolate dust generated by a continuous miner (left) and sampling package positioned in intake air to the miner (right).

For a more mobile piece of equipment, such as a longwall shearer, a mobile sampling strategy must be used to isolate the dust generated by the equipment as it cuts coal. Two sampling personnel would be required to travel with the shearer as it mines across the longwall face, Figure 2.10. One person would be located upwind of the shearer while the second would be located downwind. These sampling personnel would maintain their respective distances from the shearer as it mines across the face. Figure 2.11, left, shows a NIOSH researcher wearing gravimetric sampling pumps and carrying a pDR as he travels with the shearer across the face. It should be noted that some mines prohibit personnel from going completely downwind of the shearer, so the downwind sampler may need to be positioned near the tailgate shearer operator or jacksetter.

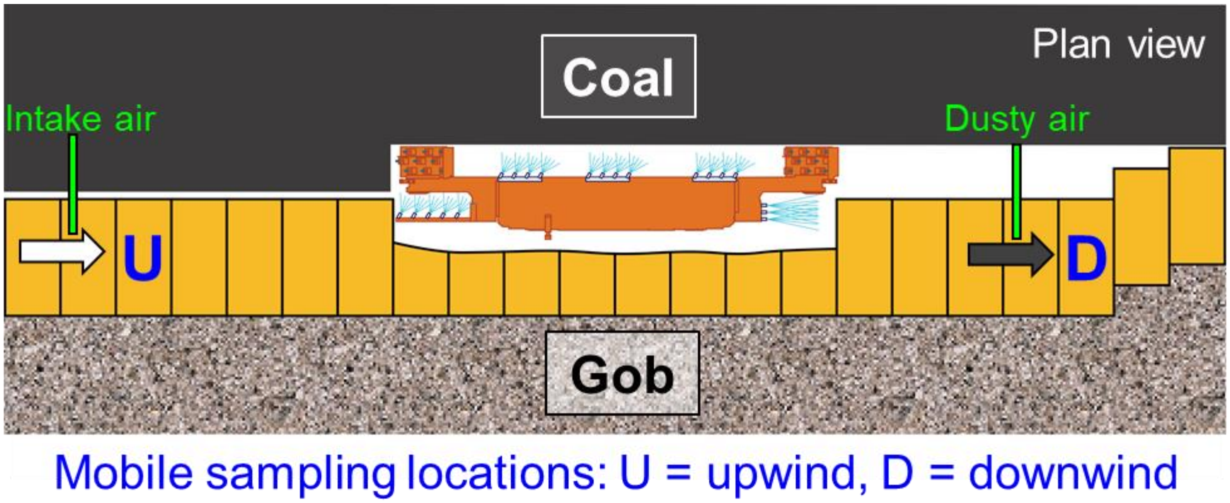
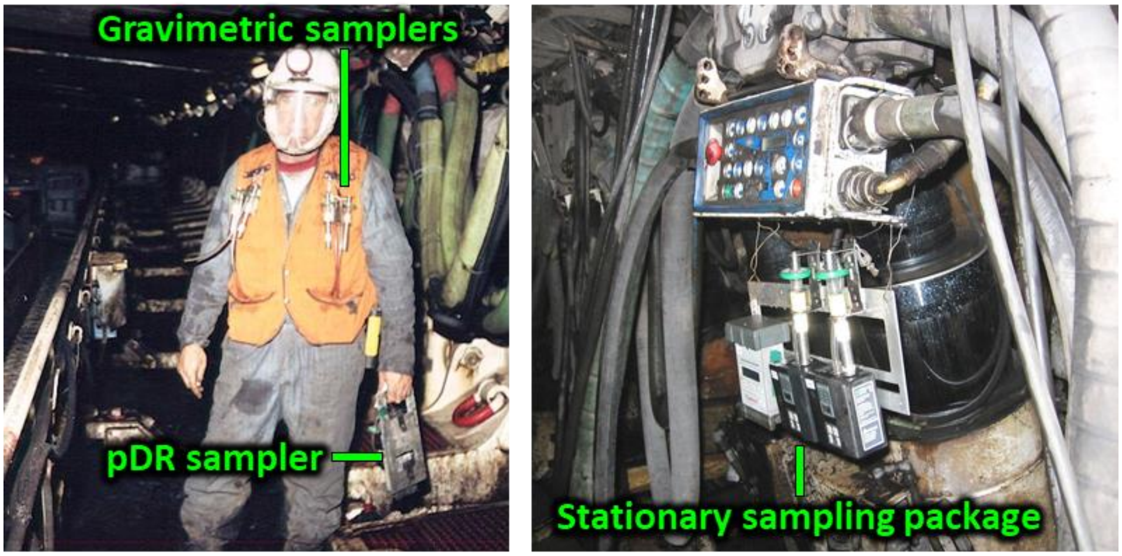


Figure 2.10. Mobile sampling used to quantify dust generated by the shearer as it completes a tailgate-to-headgate cut across the longwall face.

As was discussed for continuous miner operations, stationary sampling packages can also be used on longwall faces to isolate and quantify dust sources, such as from the stageloader-crusher unit. Coal leaving the longwall face at the headgate passes through a crusher and is then carried by the stageloader to the section conveyor belt for transport out of the mine. The stageloader and crusher are connected and viewed as one potential dust source. For U.S. longwalls, the shields are numbered consecutively down the face with the number 1 shield located in the headgate entry. Figure 2.11, right, shows a sampling package hung at shield 10, which quantifies the amount of dust in the intake air coming onto the longwall face. Dust levels from similar sampling packages located in the intake and belt entry can be subtracted from dust levels at shield 10 to determine the amount of dust being generated by the stageloader-crusher unit.



Photos by NIOSH

Figure 2.11. NIOSH researcher conducting mobile sampling by tracking the shearer across the face while wearing gravimetric samplers and carrying a pDR (left) and a stationary sampling package hung on shield 10 (right).

If an operator is positioned on a mobile piece of equipment such as a shuttle car or scoop and the dust exposure within the operator's compartment is desired, dust sampling instrumentation can be placed inside the compartment. Light-scattering instruments in conjunction with gravimetric samplers for correction, as shown in Figure 2.12, can be used to identify different periods of exposure. However, to identify the different exposure periods, the dust data would need to be augmented with time study information to isolate the activities and location of the equipment during these activities.

As an example, to assess the dust exposure during the load-haul-dump cycle of the shuttle car, it would be necessary to position someone near the continuous miner to track when the car is being loaded and also at the feeder-breaker to track when the car is dumping. The tram times would be the difference in time between leaving the miner/feeder and arriving at the other location.

Photo by NIOSH

Figure 2.12. Sampling package hung in cab on shuttle car.

Figure 2.13 illustrates the dust levels NIOSH observed for one load-haul-dump cycle with a sampling package placed just inby the operator's cab, with a 2-second sampling interval selected for the pDR. Although loading behind the miner only lasted for 44 seconds, the short sampling interval allows for adequate data collection, as illustrated by the dust spikes occurring during loading.

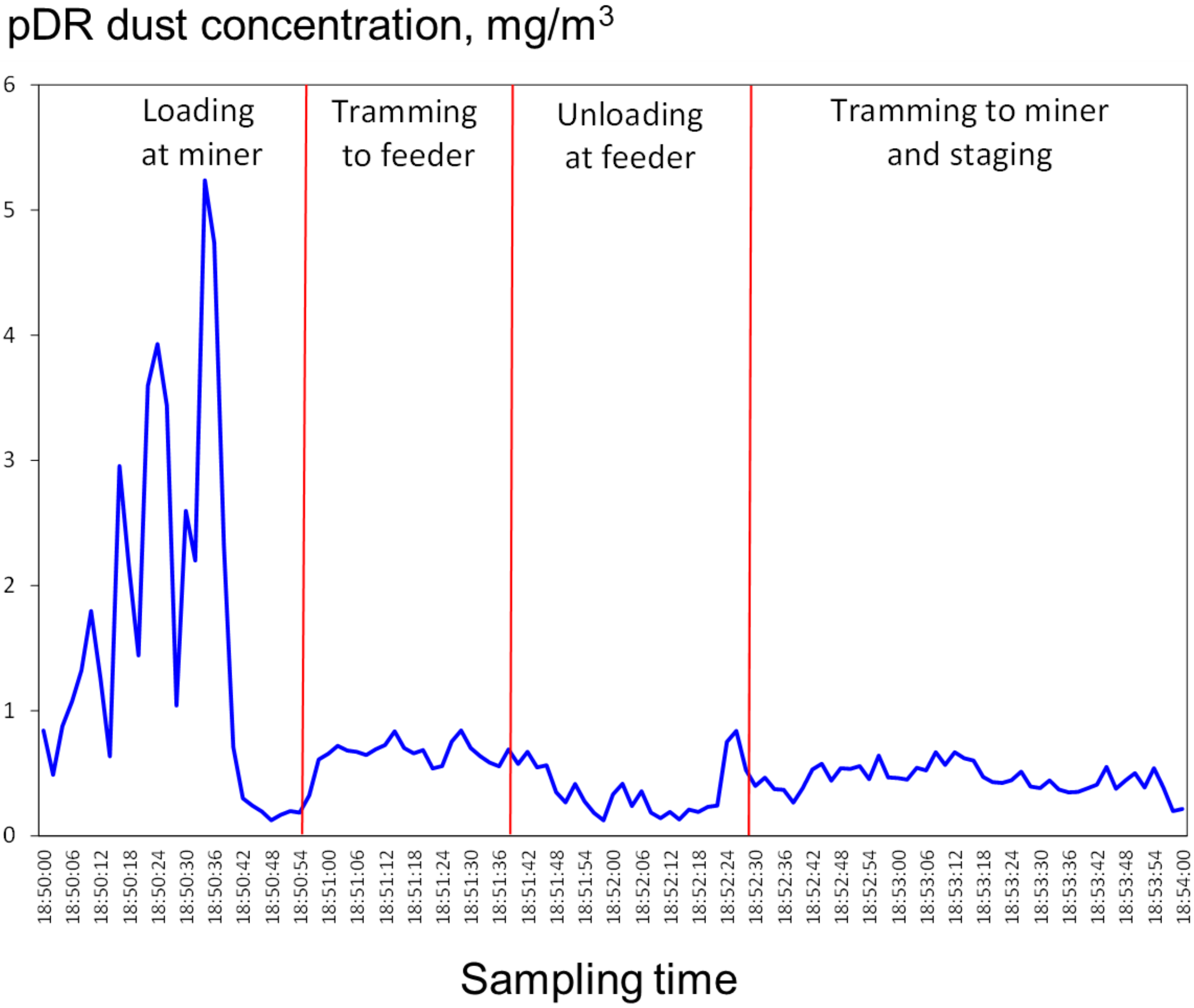


Figure 2.13. Graph illustrating dust concentrations for different segments of a shuttle car load-haul-dump cycle.

These sampling examples represent underground coal mines where a well-defined ventilation pattern is typically present. However, this is not always the case. For example, to quantify the amount of respirable dust generated by a drill at a surface mine, it would be necessary to place an array of samplers around the drill to account for dust liberated during changing wind directions. The dust concentrations from these samplers would be averaged to quantify dust liberation around the drill. It would also be necessary to place a background dust sampler far enough away from the drill, so that it is not impacted by drill dust, to monitor ambient dust levels approaching the drill. The dust levels from the ambient sample would be subtracted from the drill samples that have been averaged to determine the dust liberated by the drill. Figure 2.14, left, shows a schematic of sampling locations around a surface drill and a photo of a sampling stand positioned next to the drill table (right).

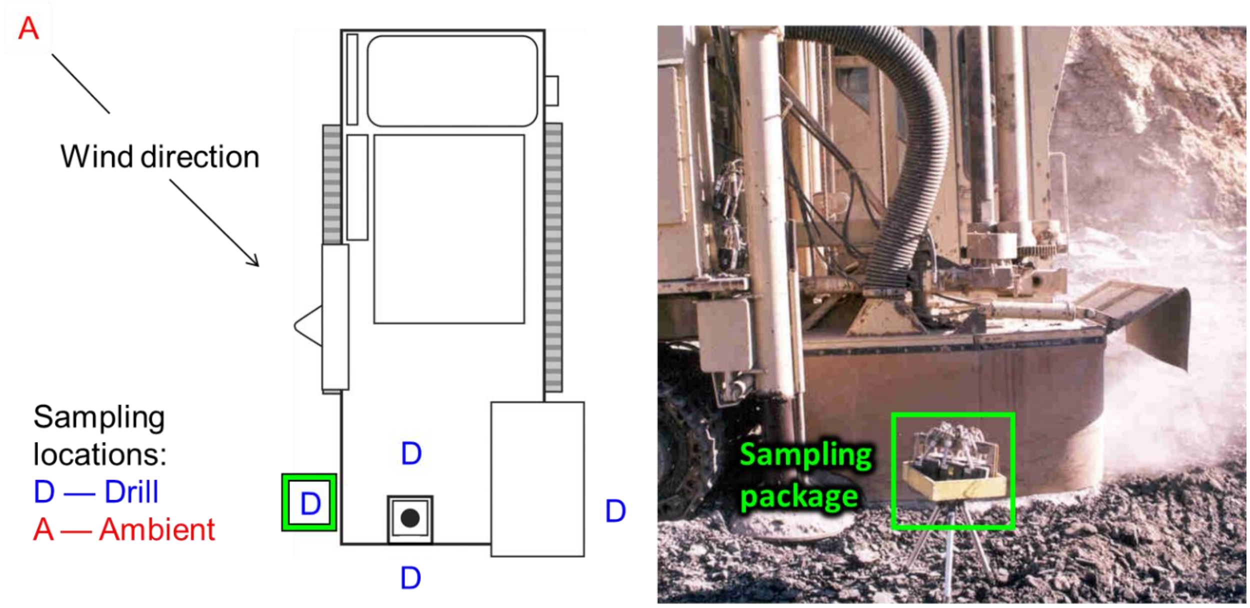


Photo by NIOSH

Figure 2.14. Sampling locations around a surface drill (left) and a gravimetric sampling package positioned near the drill table (right).

After identifying and quantifying the most significant dust sources, appropriate dust controls should be selected and implemented. To determine the impact of the added controls, sampling would once again be conducted. Typically, an A-B comparison would be needed to quantify the impact of added control technologies. The A-portion of the sampling would be conducted with the original operating conditions to establish baseline dust levels. The control technology of interest would then be installed, and the B-portion of the testing completed. To maximize the validity of the test results, both portions of the testing should be completed under similar operating conditions. The dust levels measured under each test condition would be compared to quantify the effectiveness of the installed control.

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CHAPTER 3: CONTROLLING RESPIRABLE DUST ON LONGWALL MINING SECTIONS

Longwall mining has the highest productivity of underground coal mining methods in the U.S. In 2018, longwall mines produced an average of 5.41 tons per employee hour, while continuous mining operations averaged 3.04 tons per employee hour [EIA 2019]. From 2006 through 2018, longwall mines accounted for an average of 54% of U.S. underground coal production, with an average of 174.4 million tons per year [EIA 2020]. In 2018, 12 longwalls produced over six million tons per face [Fiscor 2019]. Unfortunately, greater coal extraction can lead to higher levels of respirable dust generation, creating the need for more effective control technologies.

Historically, shearer operator and jacksetter occupations have the highest dust exposure of underground coal mining occupations. Mine Safety and Health Administration (MSHA) inspector sampling data from 2010 through 2019 was downloaded from MSHA's website [MSHA 2020a] and analyzed on a yearly basis for occupations located at the longwall and continuous miner production faces. Figure 3.1 shows the average respirable dust concentrations for each of these occupations and indicates that the tailgate shearer operator and jacksetter occupations continue to have higher respirable dust exposures than those found on continuous miner faces. In 2019, the average exposure for the two longwall occupations was over 0.3 milligrams per cubic meter of air (mg/m^3) higher than the average of the three continuous miner occupations.

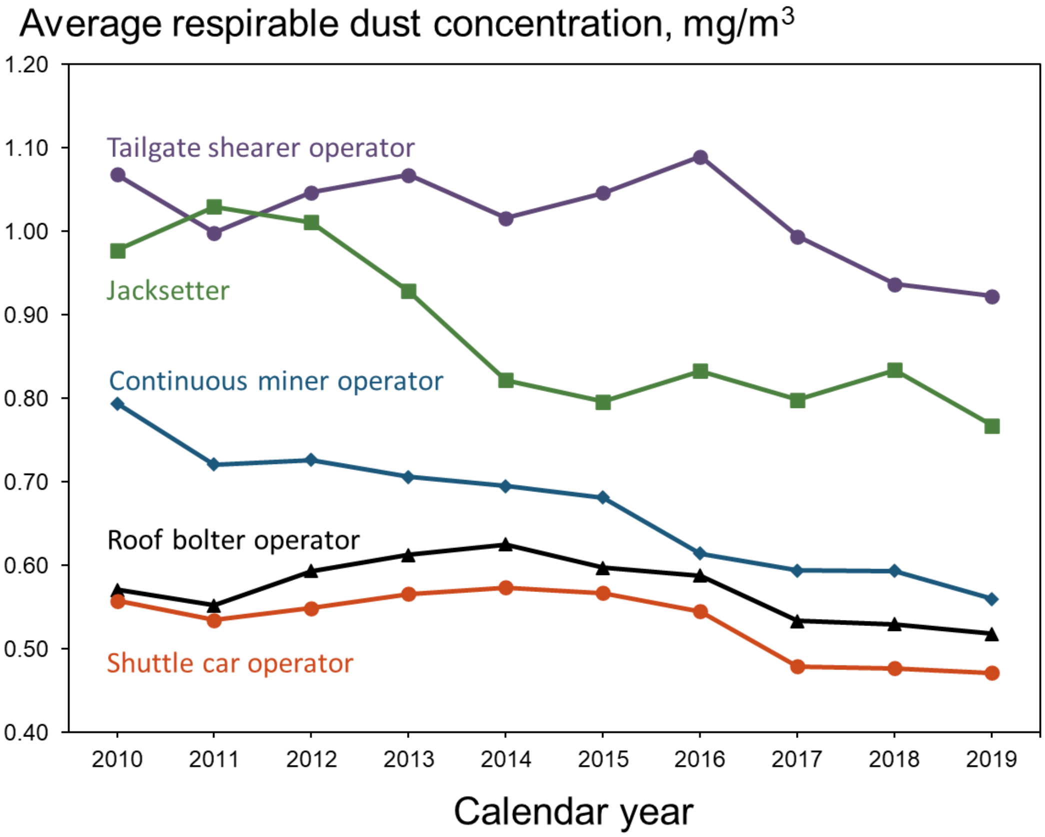

Figure 3.1. Average respirable dust concentrations calculated from samples collected by MSHA inspectors from 2010 through 2019.

The average dust levels in Figure 3.1 also show a general downward trend, particularly after 2016 for four of the five occupations. This data follows the industry-wide downward trend in dust levels that were previously reported by NIOSH [Doney et al. 2019]. In 2016, the respirable dust standard was lowered to 1.5 mg/m^3, and underground mine operators were required to use a continuous personal dust monitor (CPDM) for compliance sampling as final changes included in the 2014 MSHA dust rule [79 Fed. Reg.[13] 24814 (2014)]. It appears that the changes to the respirable dust sampling regulations and mine operators' responses to these changes are reducing the exposure of underground coal mine workers.

Quartz dust sampling results for 2000 through 2020 for the tailgate shearer and jacksetter occupations were downloaded from the MSHA website [MSHA 2020b] and analyzed. Data was omitted for the transition period in sampling regulations beginning on August 1, 2014, when the initial parts of the 2014 MSHA dust rule were implemented until the last change on August 1, 2016, when the reduced dust standard was implemented. Figure 3.2 summarizes these sampling results and shows the percentage of samples that contained greater than 5% quartz, which was the historic criteria for enforcing a reduced dust standard. The jacksetter had a higher percentage of samples exceeding 5% quartz than the tailgate shearer operator until after the 2014 dust rule was fully enacted, when they are nearly equal. Although a substantial percentage of these samples exceeded 5% quartz, data presented in Chapter 4 shows that even higher percentages of samples for continuous miner and roof bolter operators contained more than 5% quartz.

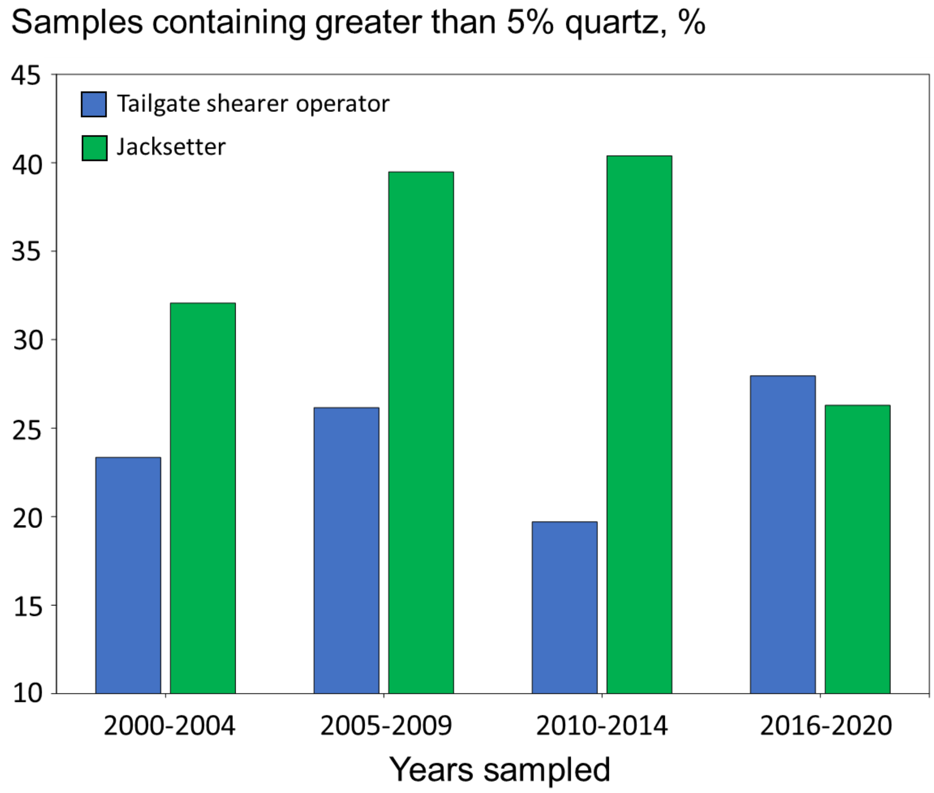

Figure 3.2. Percentage of MSHA inspector samples analyzed for quartz for the tailgate shearer operator and jacksetter that exceeded 5% quartz.

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[13] Federal Register. See Fed. Reg. in references.

Longwall workers can be exposed to harmful respirable dust from multiple dust generation sources, including the intake entry, belt entry, stageloader-crusher, shearer, and shield advance. This chapter discusses dust control technologies that are available to reduce dust liberated from each of these sources. Emerging controls that have the potential to provide additional dust reductions but currently not in use will also be discussed at the end of the chapter.

Primary Dust Controls

All underground mining operations utilize ventilating air and water sprays as primary methods for controlling respirable dust generation and worker exposures. Each of these control methods reduces mine workers' dust exposure through several different means. Proper application of each of these controls will optimize the opportunity for controlling respirable dust.

Ventilation

Ventilating air is supplied throughout underground mines to dilute airborne contaminants such as dust, methane, and diesel exhaust to safe levels and to move these contaminants away from mine workers. The quantity and velocity of air supplied may be the most critical component of controlling mine worker exposure to these airborne contaminants. Therefore, underground coal mine regulations [30 CFR 75.325[14]] require minimum quantities of air at specific locations for each type of mining. Also, mine operators are required to develop a ventilation plan for each working section or mechanized mining unit (MMU) and to submit this plan for approval to the MSHA district manager before mining can begin production on that MMU. This plan will specify the minimum quantity of air that will be supplied to the MMU, and this minimum quantity must be maintained at all times. Typically, the minimum quantities specified in these plans will exceed the minimums specified in the CFR.

For a given volume of dust generated by any source, increasing the quantity of ventilating air will lead to greater dilution of the dust and lower the concentration to which workers are potentially exposed. In addition, the velocity of the ventilating air dictates the speed at which dust is moved away from workers and into the return. Higher velocities will minimize the time that dust remains in the vicinity of workers. Consequently, air quantity and air velocity are both important factors in controlling the respirable dust exposure of mine workers.

For longwall faces in the U.S., intake air is directed from the headgate-to-tailgate. This allows workers in the headgate entry and the headgate shearer operator to be upwind of the dust being generated by the shearer, which has historically been the largest source of dust generation on longwalls [Colinet et al. 1997; Rider and Colinet 2011].

Water Sprays

Water sprays can help control the dust exposure of mine workers through three different methods: suppression, airborne dust capture, and redirection.

- For *suppression*, water is applied at the point of dust generation (e.g., cutting bits, conveyor transfer points, crushers) to wet the coal so respirable particles adhere to one

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[14] Code of Federal Regulations. See CFR in references.

another or larger particles. The goal is to keep the respirable dust that was generated from getting entrained by the ventilating air.

- For *airborne dust capture*, water spray droplets attempt to impact and agglomerate with dust particles in order to increase the mass of the particles so that they settle out of the airstream. As shown in Figure 3.3, water droplets that are closer in size to the dust particle are more likely to impact the dust particle, as opposed to the particle following the airstreams around the droplet.
- For *redirection*, all water sprays induce airflow movement to some degree with their spray pattern. If properly located, sprays can then be used to help direct airborne dust away from the breathing zone of mine workers.

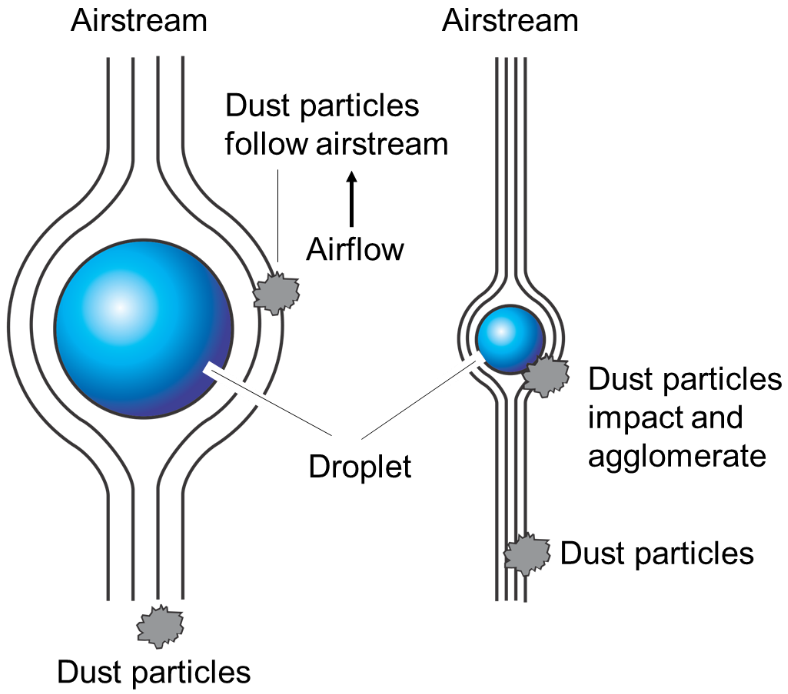

Figure 3.3. Effect of water droplet size on particle impingement (adapted from Schowengerdt and Brown [1976]).

The type of nozzle, operating parameters, and nozzle location and orientation are critical components in determining the relative success of each spray application, depending on the method of dust control desired. A general description of nozzle types typically available for use in mining are provided here, with specific information related to spray implementation for different dust sources provided throughout this handbook. The unique code for this document is 298608

Hollow Cone Spray

Hollow cone spray nozzles (Figure 3.4, left) produce a circular, outer-ring spray pattern as shown in Figure 3.4, right. When compared at the same flow rate to the other nozzles discussed below, hollow cone sprays typically produce droplets that are smaller in size. Past research has shown that smaller and faster moving droplets increase the capture of airborne respirable dust [Pollock and Organiscak 2007]. In addition, hollow cone nozzles induce more airflow movement