HHS Public Access

Author manuscript

Min Metall Explor. Author manuscript; available in PMC 2021 February 16.

Published in final edited form as:

Min Metall Explor. 2020 ; 37(6): 1847–1856. doi:10.1007/s42461-020-00278-7.

The Impact of Black Lung and a Methodology for Controlling Respirable Dust

Jay F. Colinet[1]

[1]Pittsburgh Mining Research Division, National Institute for Occupational Safety and Health, 626 Cochrans Mill Road, Pittsburgh, PA 15236, USA

Abstract

Coal workers' pneumoconiosis (CWP), commonly known as black lung, is caused by the inhalation of respirable coal mine dust and is a disabling and potentially fatal lung disease with no cure. Historically, CWP has taken a tremendous human and financial toll in the US coal mining industry. Recent health surveillance data indicates that CWP continues to occur at elevated levels. Respirable coal dust exposure must be controlled to prevent the development of CWP. The Pittsburgh Mining Research Division of the National Institute for Occupational Safety and Health (NIOSH) conducts laboratory and mine-site research to identify control technologies that can be used to successfully reduce respirable dust levels. Various technologies, using multiple methods of control, can be applied in order to reduce dust levels. An overview of CWP's impact and a general methodology for controlling respirable dust in underground coal mines are discussed in this paper.

Keywords

Coal workers' pneumoconiosis; Respirable dust; Engineering controls; Underground coal mining

1 Introduction

During the mining, transport, and processing of coal, respirable-sized dust (defined as less than 10 μm in diameter) can be released into the ambient mine air. Inhalation of this respirable coal mine dust can lead to the development of coal workers' pneumoconiosis (CWP), commonly known as black lung [1]. CWP is a disabling and potentially fatal lung disease that occurs in simple and complicated forms, with the severity determined through chest radiograph standards established by the International Labour Office (ILO) [2]. In the ILO system, specific scarring characteristics that appear on chest radiographs are used to numerically rank simple CWP as Category 1, 2, or 3. The complicated or most severe form of the disease is known as Progressive Massive Fibrosis (PMF) with severity ranked as

Jay F. Colinet, JColinet@cdc.gov.

Compliance with Ethical Standards

Conflict of Interest The author declares that he has no conflict of interest.

Disclaimer The findings and conclusions in this report are those of the author and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company name, product, or software does not constitute endorsement by NIOSH.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Category A, B, or C. Figure 1 contains chest radiographs illustrating healthy and diseased lungs, with dust deposition and scarring appearing as white spots/areas in the lungs. The damage caused to the lungs by CWP is irreversible and can continue to progress even after dust exposure ceases, so the goal is to reduce respirable dust exposure to prevent initial development of the disease.

The Mine Safety and Health Administration (MSHA) is responsible for enforcing regulations applicable to mining in the USA including respirable dust regulations, which were first established by the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91–173). This act created a respirable coal mine dust exposure limit of 2.0 mg/m^3, limited respirable crystalline silica exposure, required periodic respirable dust sampling by mine operators and federal inspectors, created a Black Lung Benefits Program, and specified that a respiratory disease surveillance program be created for underground coal miners. The benefit program is administered by the Department of Labor and provides monetary and medical benefits for coal miners disabled with CWP and their surviving dependents [3]. Within the Centers for Disease Control and Prevention (CDC), the National Institute for Occupational Safety and Health (NIOSH) administers the Coal Workers' Health Surveillance Program (CWHSP) to monitor respiratory disease in miners [4]. In this surveillance program, each miner is required to have a chest radiograph at the beginning of their mining employment and can then volunteer to have subsequent radiographs on approximately 5-year intervals. If NIOSH determines that a miner has CWP, the miner is notified and has a legal right as defined in the Code of Federal Regulations [5] to work in an area of the mine with a maximum dust standard of 0.5 mg/m^3 while retaining their regular rate of pay. The CWHSP has allowed NIOSH to examine miners and compile data on the prevalence and severity of CWP in the US mining workforce since 1970. The historic and ongoing impact of CWP on the health of the mining workforce and the financial impact of the Black Lung Benefits Program will be discussed.

To assist mine operators with controlling respirable dust exposures, research on identifying and evaluating dust control technologies was initiated in the 1970s at the US Bureau of Mines (USBM). This research was subsequently transferred to NIOSH in 1996. Laboratory and mine-site research have identified numerous control technologies that can successfully reduce respirable dust levels in continuous and longwall mining operations [6]. These technologies use a variety of methods to control respirable dust exposures in underground coal mines. A general methodology on how to approach controlling respirable dust by utilizing these different types of controls will be discussed in the sections that follow.

2 Impact of CWP on US Coal Mining

In the 1969 Act, the CWHSP was only made available to active underground coal miners. Promulgation of a new dust rule by MSHA in 2014 [7] expanded the surveillance program to include surface coal miners and contractors, as well as adding pulmonary function testing (spirometry). Coal miners can voluntarily participate in the surveillance program at no cost to themselves. During the conduct of this program, it takes approximately 5 years for NIOSH to complete a round of surveillance for the nationwide coal mining industry. Figure

2 illustrates CWP prevalence data summarized over these 5-year surveillance intervals for miners with different lengths of service in the mining industry [8].

As shown in Fig. 2, the longer the tenure of the examined miner, the greater the likelihood of developing CWP. During the 1970–1974 surveillance period, approximately one out of every three examined miners with 25 or more years of work experience was diagnosed with CWP Category 1 or greater. The prevalence of CWP in subsequent 5-year surveillance intervals dropped dramatically, reaching less than 5% for the longest tenured miners in the 1995–1999 period. However, since that time, the prevalence for the longest tenured miners has increased so that it is above 10% for the last 5-year surveillance period for which complete information was available.

Even more disturbing is the prevalence of PMF that is being found in the mining workforce. For those miners filing for benefits under the Federal Black Lung Benefits Program, the percentage of these miners that are found to have PMF has increased over five-fold as shown in Fig. 3 [9]. Similarly, an unprecedented number of PMF cases have been identified over the last several years in the central Appalachian coal fields. Using data from NIOSH's CWHSP, more than 5% of working underground miners with 25 or more years of experience who were screened in Kentucky, Virginia, and West Virginia over the last full 5-year surveillance period were found to have PMF [10]. At a radiology practice in eastern Kentucky, 60 cases of PMF were identified in former miners examined between January 2015 and August 2016 [10]. Between 2013 and 2017, 416 cases of PMF among former and current coal miners were identified at a small network of federally funded black lung clinics in southwestern Virginia [11].

In addition to CWP surveillance, data is available that monitors coal miners' deaths with CWP as the underlying or contributing cause. From 1970 through 2016, 75,178 deaths are attributed to CWP [12]. Beginning in the mid-1980s, the number of yearly deaths from CWP has shown a declining trend that is likely related to a combination of the declining size of the mining workforce and the positive impact of the 1969 Act. After the passage of this act, coal industry employment peaked at over 260,000 in 1979 but dropped to less than 83,000 in 2018 [13].

From a financial perspective, federal benefits, including monthly compensation payments and medical expenses, paid through the Black Lung Benefits Program are documented by the Department of Labor. For 2018, over $250 million in benefit payments were made with a total of $46.9 billion in payments made from 1971 through 2018 [14]. Furthermore, lung transplants in patients with CWP have become more common over the past 10 years, with 51 completed since 2008, each costing an average of $1.2 million, and most being paid with some form of public insurance [15].

It is apparent that CWP has taken a tremendous human and financial toll in the US coal industry. Unfortunately, recent medical data indicates that CWP continues to afflict the mining industry at unexpectedly elevated levels. In order to prevent future development of lung disease, effective control technologies must be implemented, properly utilized, and maintained to reduce the dust exposure of mine workers.

3 Methodology for Controlling Respirable Coal Mine Dust

Many control technologies have been identified and implemented that can successfully reduce respirable dust levels in underground coal mines. These controls can vary in the method by which they reduce dust levels and where the controls are applied. A general methodology for implementing control technologies is listed in Table 1. A discussion for each of the individual goals with examples of each type of control follows.

3.1 Minimize Respirable Dust Generation

The first goal in controlling respirable dust exposure should be to minimize the amount of respirable dust created. If respirable dust generation is minimized, then a lesser quantity must be controlled with other technologies. Efficient cutting is needed to minimize the amount of respirable dust generated. Efficient cutting is obtained through proper drum design for the mining conditions, appropriate bit selection, maintaining sharp cutting bits, and effective cutting techniques. Research has shown that cutting bit selection can impact dust generation, with bits having large carbide inserts with smooth transitions between the insert and bit body resulting in less dust [16]. If roof rock must be extracted, undercutting the roof rock and then backing up to cut the rock allows breakage to a free face, which produces less respirable dust [17]. Also, reducing cutting drum rpm while maintaining the same advance rate will result in greater bit penetration and generation of fewer fine-sized particles [18]. Figure 4 illustrates these concepts.

3.2 Prevent Respirable Dust from Getting into the Ventilating Air

Once dust generation has been minimized through efficient cutting, the next goal is to prevent the respirable dust that has been generated from being entrained into the ventilating air- stream. This is accomplished by wetting the dust at the generation point and enclosing the dust source to physically prevent the dust from getting into the ventilating air. Different types of water sprays are available, and each type is best suited for different purposes. Research has shown that full-cone (Fig. 5, left) and flat-fan type sprays are typically effective in wetting material at the breakage point [19]. In addition, the selected sprays should provide full coverage of the area where coal breakage is occurring. To provide effective wetting, the sprays typically should be located close to the dust generation point. On longwall faces, spray nozzles are located immediately in front of or behind the cutting bits on the drums (Fig. 5, center) with the spray directed at the cutting tip of the bits. On continuous miners, sprays are typically located behind the cutting drum in the boom, with top-mounted sprays directed at the top bits in the cutting drum (Fig. 5, right) and under boom sprays directed at the bottom of the cutting drum and into the gathering pan. For wetting dust at the generation point, water flow quantity is usually more important than water pressure.

Dust generation sources can also be enclosed to physically prevent the generated dust from reaching the ambient ventilating airstream [20]. Examples of commonly enclosed dust sources include the stageloader/crusher on longwall faces (Fig. 6, left) and conveyer belt transfer locations throughout the mine. Depending upon the mining operation, enclosures are often made from steel plate or conveyor belting. For water sprays operating inside these enclosures (Fig. 6, right), caution should be used to not over-pressurize the enclosure in order to prevent airborne dust from being forced out of the enclosure by the elevated water pressure. Full product coverage with the spray patterns should also be obtained, with full-cone and flat-fan sprays typically utilized.

3.3 Remove Respirable Dust from the Air

The next step in controlling dust exposure would be to remove as much of the dust that gets airborne from the ventilating air as possible with powered dust collectors and water sprays. Research has shown that fan-powered, flooded-bed scrubbers (FBS) are one of the most effective dust control technologies currently used in underground coal mining operations. The FBS is installed on continuous miners and pulls dust-laden air from the face through ductwork on the machine. This air passes through a filter panel (Fig. 7, left) that is wetted by water sprays mounted in the ductwork. The dust particles mix with the water droplets, which are then removed from the airstream with a wave-blade mist eliminator. Depending upon the density of the filter selected for use in the FBS, respirable dust collection of over 90% can be achieved [21] as shown in Fig. 7 (right). If space is available, FBS units have also been installed at stageloader/crushers to improve dust capture.

The majority of roof bolting machines in the USA are equipped with dry dust collection systems. These systems create a vacuum to pull dust-laden air through the drill steel and hosing back to a collector box mounted on the roof bolting machine. These collectors can be efficient in removing dust at the drill head, but a concern for worker exposure occurs during cleaning of the collector box. As shown in Fig. 8 (left), unconsolidated dust must be periodically cleaned from the collector box by hand, which allows dust plumes to rise into the breathing zone of the worker and also potentially contaminate clothing. A retrofit system is available where a collector bag (Fig. 8, center) can be installed to capture most of the dust pulled into the collector box (Fig. 8, right). When tested underground, the use of the collector bag reduced dust levels in the collector exhaust by 85% and also reduced dust box cleaning time from 4 min to 30 s [22].

To provide additional protection for roof bolter operators, particularly when working downwind of the continuous miner, NIOSH developed a canopy air curtain. As shown in Fig. 9 (left), this system uses a fan to pull entry air through a filter cartridge and then blows this filtered air down over the roof bolter operator when positioned under the drilling canopy. This system was tested underground and reduced dust levels while drilling by up to 53% [23]. The time that the bolter operator spends under the canopy impacts the overall effectiveness. This technology has been adopted by the leading roof bolter manufacturer and is offered as an option on their roof bolters (Fig. 9, right).

As noted previously, various types of water sprays are available with certain sprays being more suited to a specific application than others. For capturing airborne dust, research has shown that hollow-cone and air-atomizing sprays are the most effective. These sprays produce smaller-sized water droplets that are traveling at higher velocities, which lead to more effective capture of respirable-sized dust particles [24]. However, the adoption of air-atomizing sprays into the mining industry has been hindered by the necessity of supplying both water and compressed air to the spray nozzle and the greater likelihood for the smaller orifices in these nozzles to become plugged. As a result, hollow-cone nozzles are commonly used for airborne dust capture.

3.4 Dilute Airborne Dust

The remaining airborne dust should then be diluted as much as possible with the ventilating air. Increasing the quantity of air reaching the dust source will provide greater dilution, so it is important to utilize all available ventilating air. For example, on longwall faces, the gob area in the headgate often remains open longer than other areas of the gob because of roof bolts previously installed in the belt entry. The incoming intake air to the face will readily flow through the gap between the rib and first shield into this open gob area (Fig. 10, left). This air may or may not reenter the longwall face depending upon the gob composition. Even if the air returns to the longwall face, it may entrain dust and methane that is present in the gob and carry it onto the face. In order to minimize the amount of intake air flowing into the gob at the headgate, line brattice should be hung between the rib and first shield to turn as much air as possible down the longwall face. During underground trials, the average face air velocity increased 35% after the gob curtain was installed [25]. Some mines have extended the brattice curtain along the back of the first few shields to further assist in turning air down the face (Fig. 10, right).

Another means of improving dilution of airborne dust is to increase the distance between the primary dust source and exposed mine workers. The increase in distance provides greater opportunity for concentrated dust clouds to mix with the ventilating air and reduce the overall concentration to which miners would then be exposed.

3.5 Prevent Respirable Dust from Reaching Miners

If respirable dust in the ventilating air does not reach the breathing zone of miners, it cannot contribute to the development of CWP. Therefore, preventing airborne dust from reaching miners can be an effective means of dust control. This can be accomplished by using water sprays to direct dust-laden air or providing physical barriers to prevent dust from reaching workers.

All water sprays induce airflow to some degree and can be used to direct dust-laden air. One example is a directional spray system that has been successfully utilized on longwall shearers [26]. Hollow-cone or venturi sprays are mounted on a splitter arm with additional spray manifolds mounted along the length of the face side of the shearer body (Fig. 11, left). Additional sprays are mounted at the tailgate end of the shearer to help control dust generated by the tailgate drum (Fig. 11, right).

All of these sprays should have a downwind orientation and are designed to hold dust generated by the shearer drums near the face to prevent this dust from migrating into the walkway until downwind of the shearer operators. The splitter arm is a key component in this system in that it creates separation of the air ventilating the face and allows intake air to flow in the walkway, while the dust-laden air is held near the face. A key component of the splitter arm is belting that is hung from the arm down into the face conveyor. This belting provides a physical barrier that prevents dust released by coal landing in the face conveyor from moving into the walkway.

Research has also shown that blocking sprays mounted on each side of a continuous miner can confine dust near the face and prevent it from rolling back along the sides of the miner [27, 28]. This provides the FBS and boom-mounted water sprays a greater chance of removing the dust from the air before it can be carried outby the continuous miner.

3.6 Regular Maintenance of Controls to Retain Effectiveness

A number of successful dust control technologies have been discussed in this paper, with additional information available in a NIOSH-published handbook [6]. However, for these controls to retain their effectiveness in lowering dust exposures, maintenance of the controls must be a required part of the mining operation and culture, with adequate time allotted to complete this maintenance.

For example, NIOSH studies have shown that the filter panels of flooded-bed scrubbers (FBS) can quickly become clogged after one cut and result in a reduction in scrubber airflow of up to 35%. Twenty-layer filter panels exhibited this reduction in performance after being used in 12.2-m (40-ft) extended cuts [29], while 30-layer filter panels had similar results after being used in 6.1-m (20-ft) cuts [30]. Therefore, at these operations it should be required by the mine operator that the filter panels be changed or cleaned after each cut to maintain full FBS capability.

4 Summary

CWP has taken a tremendous human and financial toll on the US coal mining industry and continues to be identified with increased frequency and severity. The 2014 MSHA dust rule [7] includes a reduction in the respirable dust standard to 1.5 mg/m^3 and requires increased dust sampling with a continuous personal dust monitor. Although these are advances toward lowering dust exposures, the ultimate goal must be the implementation and maintenance of effective dust controls on a consistent basis in order to lower the daily dust exposure of coal miners to prevent the development of future cases of CWP and PMF.

A related issue of great concern is mine workers' exposure to respirable crystalline silica (RCS) dust, with quartz being the most common form. Inhalation of RCS can lead to silicosis, another disabling and potentially fatal lung disease with no cure. When examining chest radiographs, the presence of r-type opacities has been associated with silica exposure and silicosis pathology [31, 32]. NIOSH has reviewed radiographs from the last four decades to quantify the presence of r-type opacities in examined coal miners [33]. Among radiographs from Kentucky, Virginia, and West Virginia miners, there was a six-fold increase in the prevalence of r-type opacities between the 1980s and 2010s. When increased levels of silica are present in the mining environment, diligent application of dust control technologies, potentially at elevated levels (e.g., increased airflow, water quantity), is even more critical as silica has greater toxicity to lung tissue compared with coal dust [34].

References

1. NIOSH (1995) Criteria for a recommended standard: occupational exposure to respirable coal mine dust. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control

and Prevention, National Institute for Occupational Safety and Health, education and information division, DHHS (NIOSH) publication no. 95–106

2. ILO (2011) Guidelines for the use of the ILO international classification of radiographs of pneumoconioses. International Labour Office, Geneva
3. DOL (2019) U.S. Department of Labor, Office of Workers' Compensation Programs, Division of Coal Mine Workers' Compensation (DCMWC). https://www.dol.gov/owcp/dcmwc/
4. NIOSH (2019) Coal workers' health surveillance program. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/topics/cwhsp/default.html
5. Code of Federal Regulations (2019) Washington, DC: U.S. Government Printing Office Office of the Federal Register, Title 30 Part 90, Coal miners who have evidence of the development of pneumoconiosis
6. NIOSH (2010) Best practices for dust control in coal mining. By Colinet JF, Rider JP, Listak JM, Organiscak JA, Wolfe AL. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) publication no. 2010–110
7. 79 Federal Register 24814 (2014) Mine Safety and Health Administration: Lowering miners' exposure to respirable coal mine dust, including continuous personal dust monitors; final rule (to be codified at 30 CFR Parts 70, 71, 72, 75, and 90)
8. NIOSH (2019) Coal workers' health surveillance program (CWHSP) data query system. Centers for Disease Control and Prevention. National Institute for Occupational Safety and Health, Respiratory Health Division, Surveillance Branch https://webappa.cdc.gov/ords/cwhsp-database.html
9. Almberg KS, Halldin CN, Blackley DJ, Laney AS, Storey E, Rose CS, Go LHT, Cohen RA (2018) Progressive massive fibrosis resurgence identified in U.S. coal miners filing for black lung benefits, 1970–2016. Annals American Thoracic Society, 15(12): 1420–1426. Data accessed from online supplement: 10.1513/AnnalsATS.201804-261OC, Progressive Massive Fibrosis Resurgence Identified in U.S. Coal Miners Filing for Black Lung Benefits, 1970–2016
10. CDC (2016) Resurgence of progressive massive fibrosis in coal miners – eastern Kentucky, 2016. Morb Mortal Wkly Rep 65(49): 1385–1389
11. Blackley DJ, Reynolds LE, Short C (2018) Progressive massive fibrosis in coal miners from 3 clinics in Virginia. J Am Med Assoc 319(5):500–501
12. CDC (2019) Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Occupational Respiratory Disease Surveillance, National Occupational Respiratory Mortality System (NORMS) National Database https://webappa.cdc.gov/ords/norms-national.html
13. DOL (2019) U.S. Department of Labor, Coal fatalities for 1900 through 2018, Mine Safety and Health Administration. https://arlweb.msha.gov/stats/centurystats/coalstats.asp
14. DOL (2019) U.S. Department of Labor, Office of Workers' Compensation Program, Division of Coal Mine Workers' Compensation (DCMWC), Black Lung Program Statistics, Black lung benefit payment totals by year. https://www.dol.gov/owcp/dcmwc/statistics/TotalBenefitsPayment.htm
15. Blackley DJ, Halldin CN, Laney AS (2018) Continued increase in lung transplantation for coal workers' pneumoconiosis in the United States. Am J Ind Med 61 (7):621–624 [PubMed: 29732582]
16. Organiscak JA, Khair AW, Ahmad M (1996) Studies of bit wear and respirable dust generation. Society for Mining, Metallurgy, and Exploration Transactions, Vol 298:1874–1879
17. USBM (1985) How twelve continuous miner sections keep dust levels at 0.5 mg/m^3 or less. Pittsburgh, PA: U.S. Department of the Interior, U.S. Bureau of Mines, technology news 220
18. Ludlow J, Jankowski RA (1984) Use lower shearer drum speeds to achieve deeper coal cutting. Min Eng 36(3):251–255
19. BCR National Laboratory (1985) Dust control handbook for longwall mining operations. U.S. Bureau of Mines contract J0348000. NTIS No. PB 96–178159/AS
20. Foster-Miller (1990) Evaluate fundamental approaches to longwall dust control; subprogram C – stageloader dust control. U.S. Bureau of Mines contract J03118097. NTIS No. DE 90–015510

21. Colinet JF, Jankowski RA (2000) Silica collection concerns when using flooded-bed scrubbers. Min Eng 52(4):49–54
22. Listak JM, Beck TW (2008) Laboratory and field evaluation of dust collector bags for reducing exposure of roof bolter operators. Min Eng 60(7):57–63
23. Listak JM, Beck TW (2012) Development of a canopy air curtain to reduce roof bolters' dust exposure. Min Eng 64(7):72–79
24. Pollock D, Organiscak J (2007) Airborne dust capture and induced airflow of various spray nozzle designs. Aerosol Sci Technol 41(7): 711–720
25. Jankowski RA, Kissell FN, Harrison DJ (1986) Longwall dust control: an overview of progress in recent years. Min Eng 38(10):953–958
26. USBM (1986) Improved shearer-clearer for longwall dust control. Pittsburgh, PA: U.S. Department of the Interior, U.S. Bureau of Mines, technology news 245
27. Organiscak J, Beck T (2010) Continuous miner spray considerations for optimizing scrubber performance in exhaust ventilation systems. Min Eng 62(10):41–46
28. Klima SS, Organiscak JA, Colinet JF (2019) Reducing shuttle car operator dust exposure by improving continuous miner blowing face ventilation parameters. SME annual meeting, Preprint 19–078, February 25–27, 2019
29. NIOSH (2011) Evaluation of face dust concentrations at mines using deep-cutting practices. By Potts JD, Reed WR, Colinet JF. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) publication no. 2011–131, RI9680
30. NIOSH (2013) Impact on respirable dust levels when operating a flooded-bed scrubber in 20-foot cuts. By Colinet JF, Reed WR, Potts JD. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) publication no. 2014–105, RI 9693
31. Ruckley VA, Femie JM, Chapman JS, Collings P, Davis JMG, Douglas AN, Lamb D, Seaton A (1984) Comparison of radiographic appearances with associated pathology and lung dust content in a group of coal workers. Br J Ind Med 41(4):459–467 [PubMed: 6498110]
32. Soutar CA, Collins HPR (1984) Classification of progressive massive fibrosis of coal miners by type of radiographic appearance. Br J Ind Med 41(3):334–339 [PubMed: 6743580]
33. Hall NB, Blackley DJ, Halldin CN, Laney AS (2019) Continued increase in prevalence of r-type opacities among underground coal miners in the USA. Occup Environ Med 76(7):479–481 [PubMed: 31023786]
34. Castranova V (2000) From coal mine dust to quartz: mechanisms of pulmonary pathogenicity. Inhal Toxicol 12(sup3):7–14

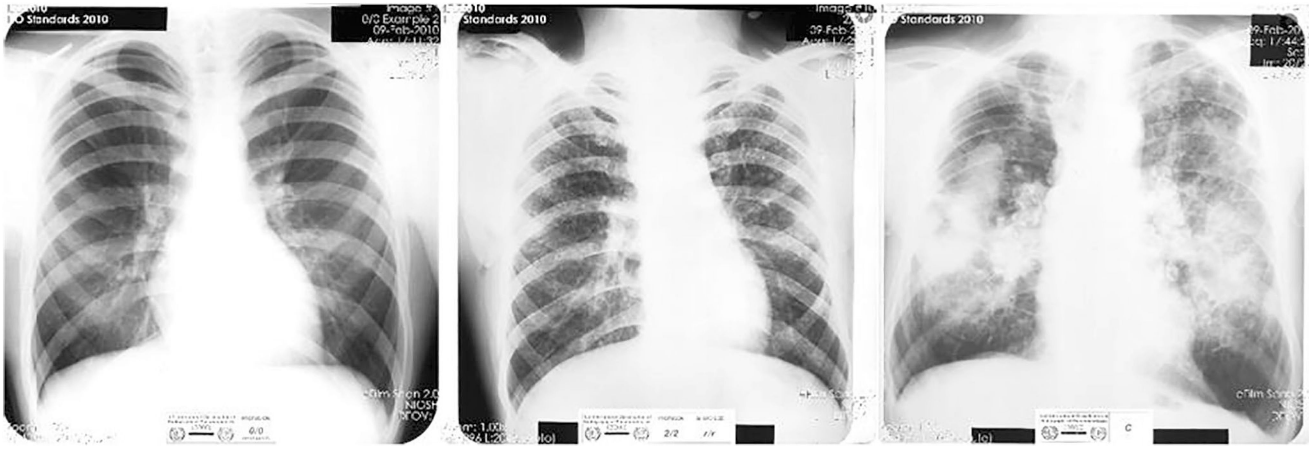

Fig. 1.

Chest radiographs of healthy lungs (left), simple CWP Category 2 (center), and PMF Category C (right) (source: International Labour Office)

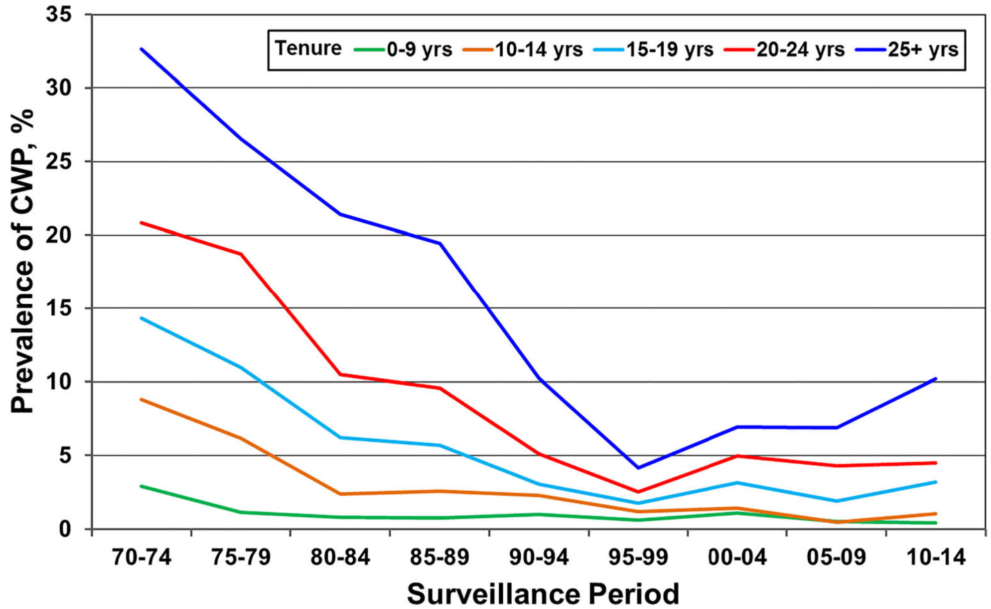

Fig. 2.

Percentage of examined miners with CWP Category 1 or greater by tenure in mining

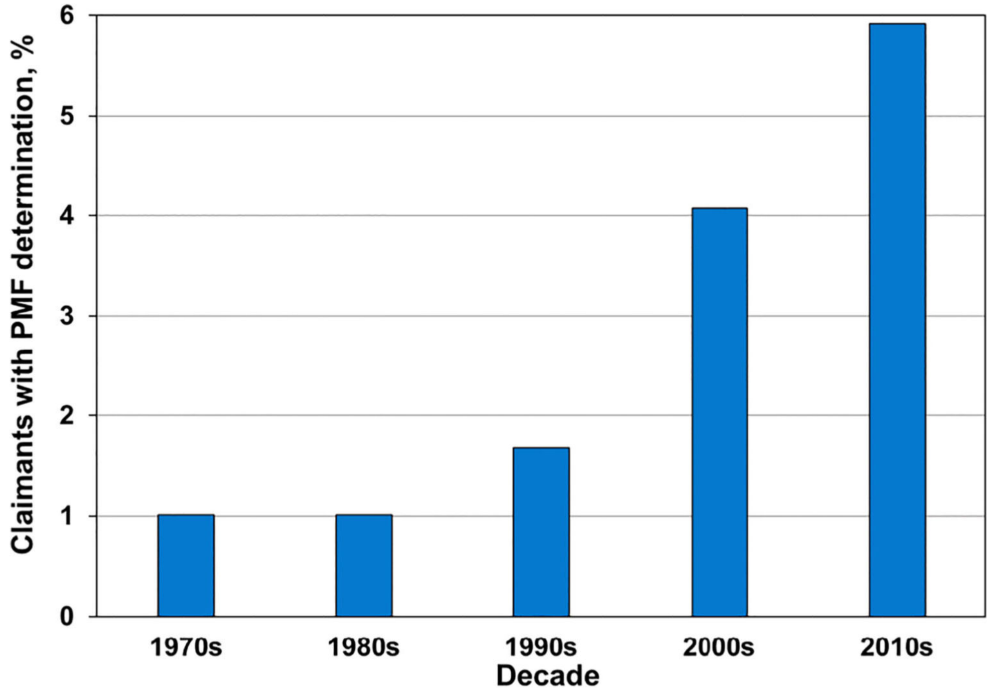

Fig. 3.
Percentage of miners filing for federal black lung benefits by decade that were found to have PMF

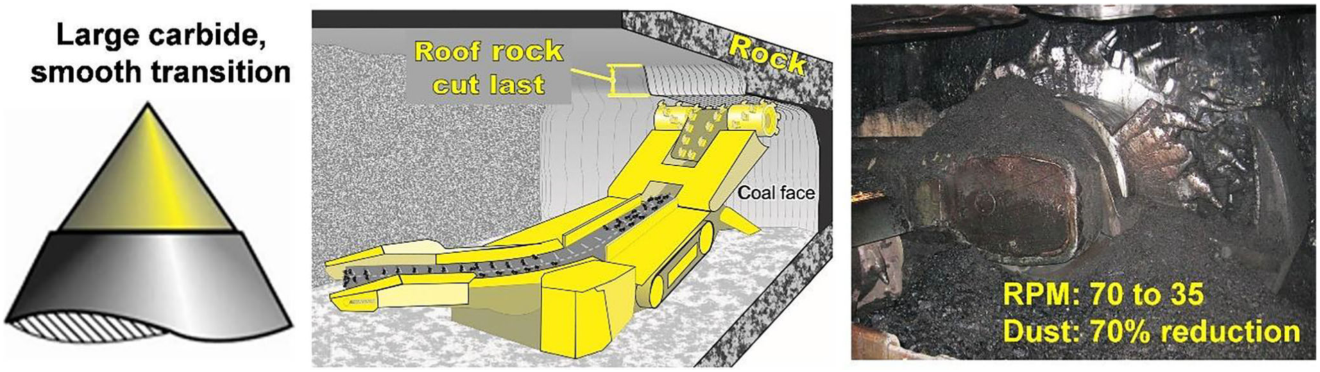

Fig. 4.

Efficient cutting with proper bit design (left), undercut roof rock (center), and reduced drum rpm (right)

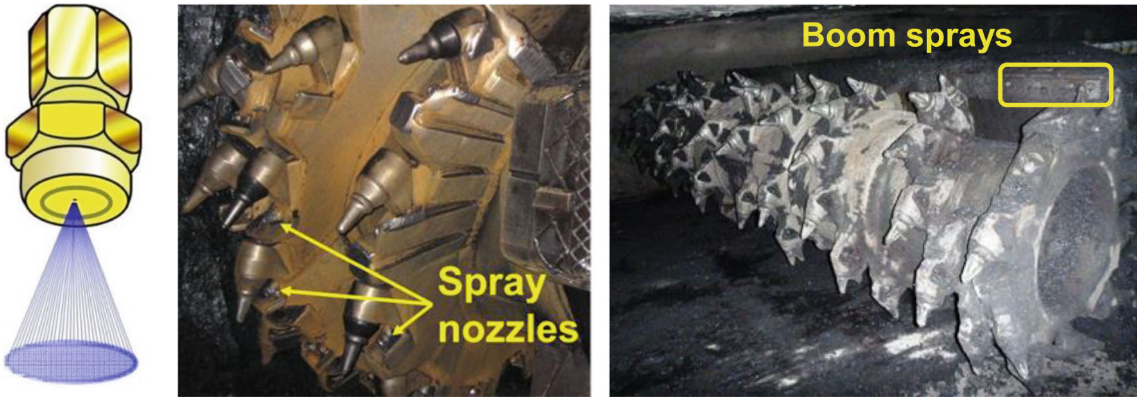

Fig. 5.

Full-cone spray pattern (left), typical spray locations on a shearer drum (center) and a continuous miner (right)

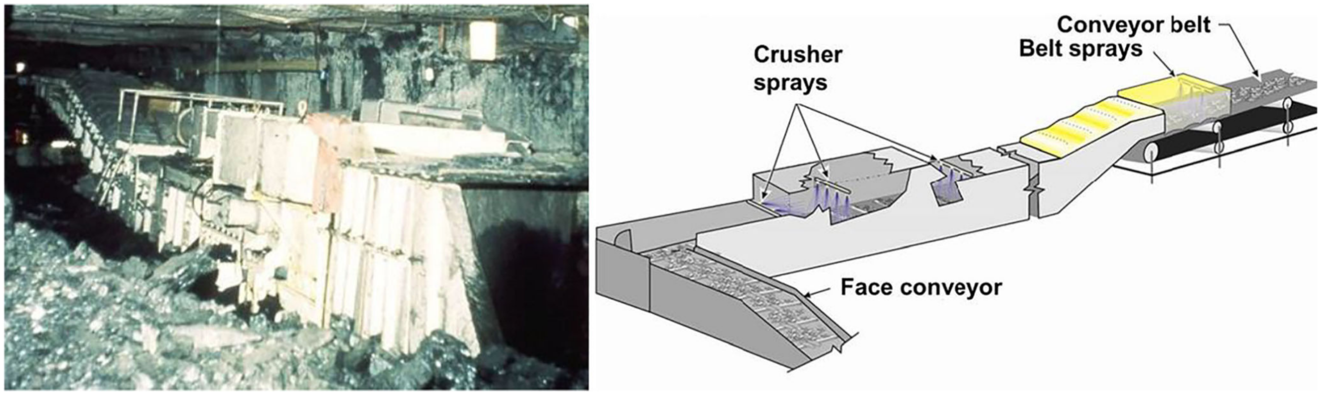

Fig. 6.
Enclosed stageloader/crusher (left) and schematic illustrating internal spray locations (right)

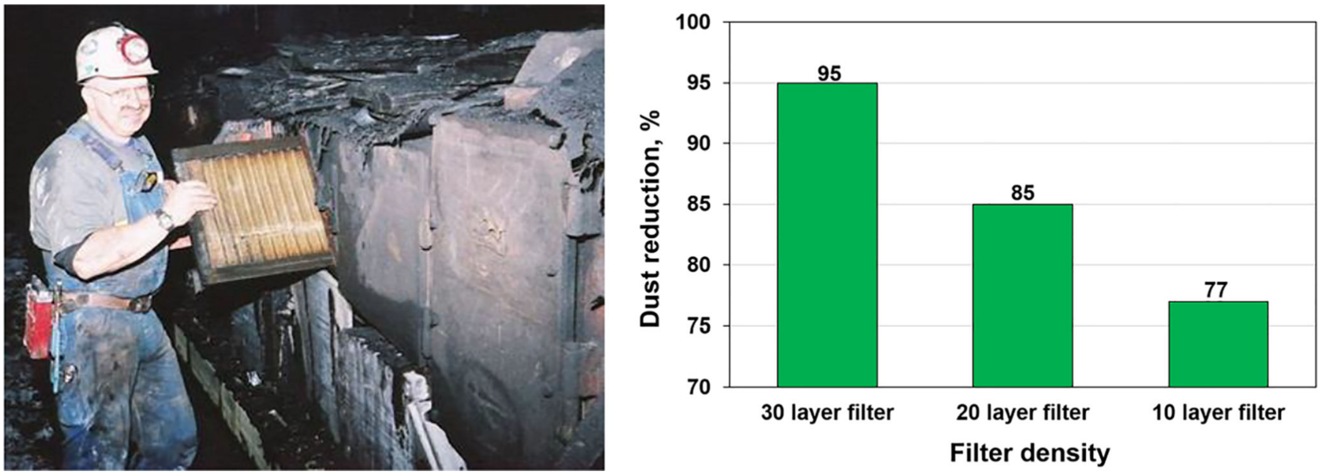

Fig. 7.
Miner removing filter from scrubber (left) and graph showing respirable dust reductions with different density filters (right) (source: NIOSH)

Fig. 8.
Cleaning dust from collector box (left), collector bag (center), and dust captured in bag (right)

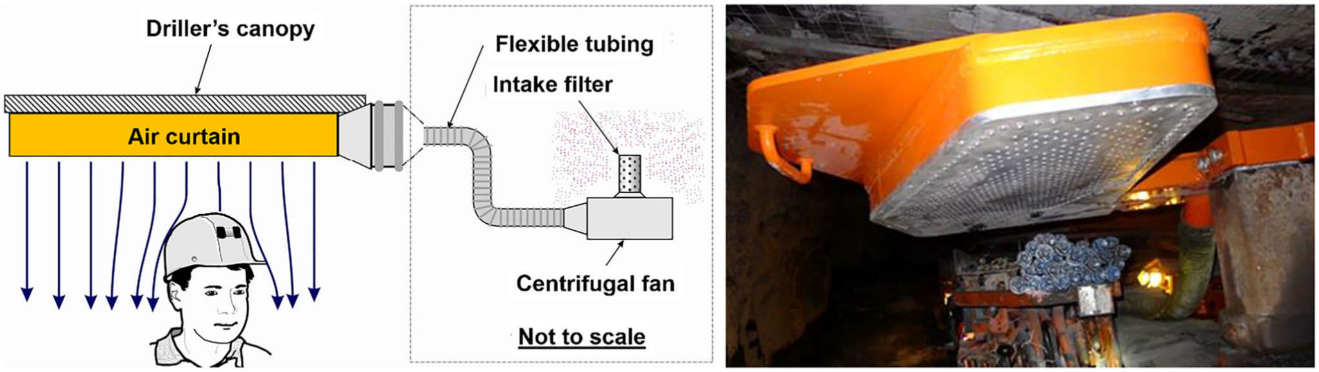

Fig. 9.

Canopy air curtain provides filtered air to operator (left) and commercially available unit (right)

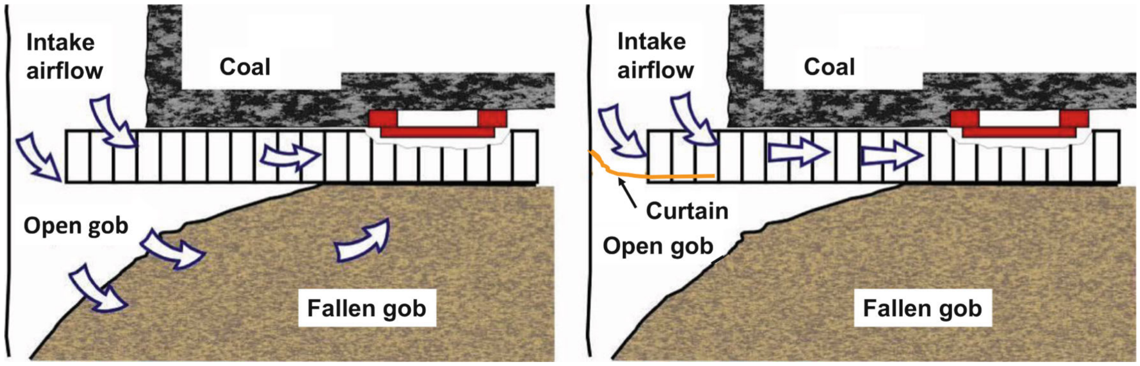

Fig. 10.
Intake air flowing into gob at headgate (left) and gob curtain turning airflow down the face (right)

Fig. 11.

Directional spray system on longwall shearer with venturi sprays mounted on the splitter arm and hollow-cone sprays on shearer body (left) and tailgate-side sprays (right)

Table 1

Methodology for controlling respirable dust

Step	Goal—approach
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)
6	Regular maintenance of controls to retain effectiveness