A Summary of USBM/NIOSH Respirable Dust Control Research for Coal Mining

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ABSTRACT: Workers in the coal mining industry can be exposed to elevated levels of respirable coal and silica dust, which can lead to the development of Coal Workers' Pneumoconiosis or silicosis. These lung diseases can be disabling or fatal depending upon the dose of dust exposure that is received. Research into the development of dust control technologies for coal mining operations was initiated in the United States Bureau of Mines and continues today within the National Institute for Occupational Safety and Health. A summary of the historical developments of this dust control research and its impact on the coal mining industry will be provided.

INTRODUCTION

Inhalation of excessive levels of respirable coal mine dust can lead to the development of Coal Workers' Pneumoconiosis (CWP), commonly called Black Lung Disease, a chronic disease of the lungs. Likewise, excessive inhalation of respirable silica dust can result in the lung disease called silicosis. Both of these lung diseases can be disabling or fatal. In coal mining occupations, dust exposure typically occurs for 10 years or more before signs of the disease can be detected. Once contracted, there is no cure for these lung diseases so the goal is to prevent the disease by limiting the dust exposure of mine workers through the implementation of effective dust control technologies.

In the United States (US), the passage of the Federal Coal Mine Health and Safety Act of 1969 (1969 Act): established respirable dust standards to limit exposure to coal and silica dust, specified dust sampling requirements for assessing compliance with the dust standards, created a voluntary x-ray surveillance program for underground coal miners to detect CWP in the industry, and provided a benefits program for those miners that contracted CWP.

The 1969 Act established the respirable coal mine dust standard of 2 mg/m^3 over an 8-hour shift, as long as the dust sample contains 5% silica or less. If silica is greater than 5%, a reduced dust standard is calculated with the formula of 10 ÷ (% silica). Consequently, if a sample contains 10% silica, a reduced dust standard of 1 mg/m^3 is enforced. Enforcement of a reduced dust standard is designed to limit exposure to respirable silica dust to a maximum of 100 µg/m^3. The Mine Safety and Health Administration (MSHA) and mine operators are required to collect personal dust samples on a periodic basis to assess compliance with these dust standards. Researchers at the US Bureau of Mines (USBM) and now the National Institute for Occupational Safety and Health (NIOSH) routinely analyze this sampling data to identify high-risk occupations. Research is then directed at developing control technologies to reduce the dust exposures for these occupations.

The Division of Respirable Disease Studies of NIOSH administers the x-ray surveillance program for underground coal miners. Approximately every five years, underground coal mine workers can volunteer to have a chest x-ray taken and analyzed for signs of lung disease. Figure 1 illustrates the prevalence rate of CWP since the inception of the x-ray program (NIOSH 2008) and shows that significant reductions in CWP have been realized since the passage of the 1969 Act. From 1970–1975, nearly 33%

of examined miners with 25 or more years of experience were diagnosed with CWP. With a recent upturn in prevalence, approximately 8% of miners with 25 or more years of experience that were examined from 2000–2006 were diagnosed with CWP.

Although significant reductions in CWP have been realized, the human and financial toll of CWP on the coal mining industry has been staggering. From 1970 through 2004, CWP has been the direct or contributing cause of 69,377 deaths of underground coal mine workers (NIOSH 2008). In addition, from 1980–2005, over $39,000,000,000 in CWP benefits have been paid to underground coal miners and their families (NIOSH 2008).

With the passage of the 1969 Act, a major reorientation and expansion of the USBM's research efforts were realized (Tuchman and Brinkley 1990). Health research with a significant focus upon dust control was added to traditional USBM research related to fires, explosions, and explosives. Research was conducted to address various sources of dust and examine a variety of control technologies. This paper will summarize a number of control technologies that were developed through USBM/NIOSH research that have been shown to be successful in reducing dust levels and have had a positive impact on the dust control efforts of the coal industry.

LONGWALL DUST CONTROLS

Longwall mining was introduced in the US in the 1960s (Arentzen 1970) and initially was not very productive. Average longwall production was 490 tons per shift during compliance sampling by MSHA inspectors in 1970 (Niewiadomski 2009). Longwalls continued to improve in performance and by the mid 1980s, 112 longwalls were operating (Sprouls 1986) and averaged 1500 tons per shift during MSHA compliance sampling (Niewiadomski 2009). Continuing increases in the power of longwall equipment, improvements in equipment availability and mining practices, and increases in panel size have allowed longwall mining to substantially increase in production. Despite having 46 active longwall faces in 2008 (Fiscor 2009), longwall mining accounted for 50% of the total underground coal production in the US (EIA 2009). Average shift production during MSHA compliance sampling increased to 5200 tons per shift in 2008 (Niewiadomski 2009). Unfortunately, higher production generates greater quantities of respirable dust (Webster, Chiaretta, and Behling 1990).

Shearer Dust Control

On average, the shearer accounts for approximately 50% of the dust generated on the longwall face (Colinet, Spencer, and Jankowski 1997) and shearer operators can have some of the highest dust exposures of underground coal mine workers. Water sprays can be used to suppress dust before it becomes airborne, "capture" dust out of the airstream, or act as small fans by inducing airfow. Various water spray types and spray locations were evaluated on shearer drums to identify the most effective combination. Pick face flushing sprays operated at 100 psi or less were shown to be the most effective for dust control (Shirey, Colinet, and Kost 1985).

One of the most successful uses of water sprays was a directional spray system for the shearer, commonly called the shearer-clearer (Jayaraman, Jankowski, and Kissell 1985). This spray system utilizes the air moving capabilities of the water sprays to direct shearer-generated dust away from the shearer operators. The sprays create a split in the ventilating air coming down the longwall face so that dust from the shearer is held near the longwall face. A physical barrier provided by a "splitter arm" mounted on the headgate side of the machine also helps develop this split in the face airflow. These directional sprays, which are mounted on the splitter arm and the shearer body, are directed at an angle with the ventilating air so that they move air without forcing dust into the walkway. Figure 2 combines a schematic illustrating the principle of the shearer clearer spray system with a photo of the sprays operating on a shearer at an underground face. Recent surveys on 10 longwall faces across the US revealed that all operations were using some variation of this directional spray system (Rider and Colinet 2007).

Headgate Dust Control

In the past, the stageloader-crusher unit was a significant source of dust liberation (Colinet and Jankowski

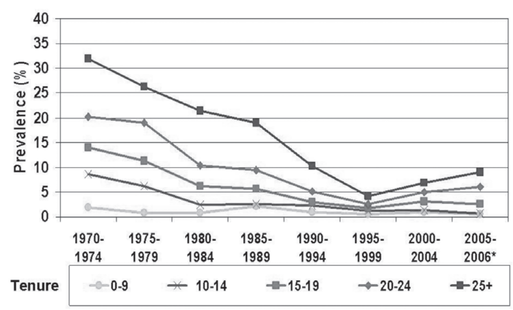

Figure 1. Trends in CWP prevalence by tenure among examinees employed at underground coal mines, National Coal Workers' X-ray Surveillance Program

1997) and this dust had the potential to expose all workers on the longwall face. Improvements in dust control for the stageloader-crusher include the use of high volume/low pressure water sprays to suppress dust before it becomes airborne and completely enclosing the stageloader-crusher to prevent generated dust from being entrained into the airstream (USBM 1985a). Research indicated that the quantity of water applied at the crusher was more important than the pressure at which it was applied. High pressure sprays could force dust out of the crusher unit, allowing it to become entrained. Likewise, by completely enclosing the crusher and stageloader, the dust would be isolated from the ventilating air and not contaminate intake air to the face. Figure 3 illustrates these controls for the stageloader-crusher.

Ventilation can improve dust control through two methods. Increasing the quantity of air can further dilute generated dust, while increasing air velocity can more quickly move dust clouds away from the breathing zone of workers. Therefore, it is desirable to utilize all available ventilating air on the longwall face. Unfortunately, because of roof bolting in the headgate entry, the gob area behind the shields at the headgate may stay open longer than other areas of the gob. This open area allows intake air coming up the headgate entry to flow into the gob and away from the face. The installation of a section of line brattice between the first shield and the rib (gob curtain), as shown in Figure 4, can increase air velocity down the face by 35% (Jankowski, Jayaraman, and Potts 1993). During recent longwall surveys, several mines were found to extend this curtain along the first five to ten shields to maximize the quantity of intake air that travels down the face (Rider and Colinet 2007).

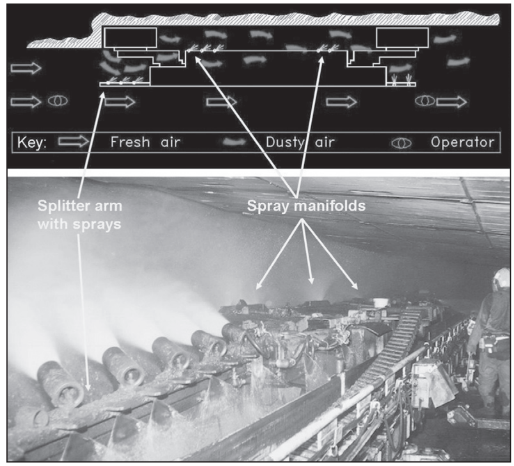

Figure 2. Schematic of shearer-clearer water spray system (above) and sprays installed on a shearer (below)

CONTINUOUS MINER DUST CONTROLS

Cutting Techniques

One of the most effective methods of reducing worker exposure to respirable dust is by minimizing the quantity of dust generated. Research has shown that this can be accomplished by utilizing optimized cutting techniques along with optimally designed bits. Undercutting of roof rock can reduce the amount of respirable dust generated, particularly dust potentially containing high quantities of silica (USBM 1985b). Likewise, research on various bit designs showed that dust generation can be minimized when the bit is designed with a large carbide insert and

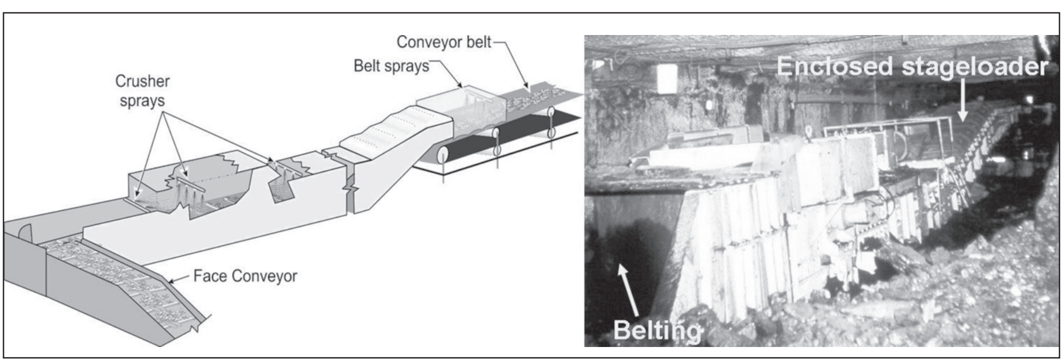

Figure 3. Schematic of sprays and enclosed stageloader-crusher (left) and actual installation (right)

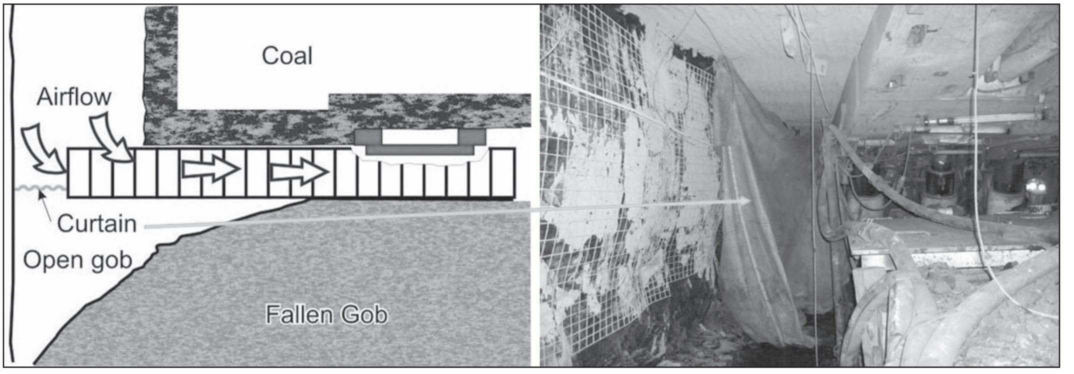

Figure 4. Schematic of gob curtain location (left) and photo of gob curtain installed (right)

smooth transition to the bit body (Organiscak, Khair, and Ahmad 1996). Finally, regardless of cutting technique or bit selection, a key to minimizing dust generation during cutting is to routinely inspect the bits and replace worn bits. This is especially critical when cutting rock since silica becomes a concern and bits tend to wear more quickly.

Water Spray Systems

As early as 1939, water sprays were shown to be a significant improvement in reducing airborne dust when compared to dry cutting (Kobrick 1970). In the 1980s, USBM research focused upon improving the performance of water sprays by researching a number of variables that could impact dust control and included nozzle type, nozzle location, spray quantity, and spray pressure. Results from this research indicated that different nozzles were better suited for different applications. In general, it was found that sprays located close to the cutting bits and operated at pressures less than 100 psi were effective in suppressing dust at the cutter head without creating turbulence to force dust to roll back toward the miner operator (Jayaraman, Kissell, and Schroeder 1984). In addition, large-orifice sprays operated at low pressure were mounted on the underside of the cutting boom to wet the coal as it is being loaded by the gathering arms, while also minimizing turbulence (Foster-Miller, Inc. 1986).

More recently, NIOSH research has shown that the air moving capabilities of sprays can be utilized to help confine dust in the face area (Goodman 2000). Blocking sprays were mounted on each side of the miner and sprayed at an angle away from the miner body to induce airflow toward the face and prevent roll back along the sides of the machine.

For spray systems to be effective, the nozzles must remain open and free of debris that can cause clogging. Dirt and rust particles in the water line are the primary cause of clogging. A simple, non-clogging water filtration system was designed and offers improved protection for spray nozzles (Divers 1976).

Flooded-bed Scrubbers

A flooded-bed scrubber is a fan-powered dust collector mounted on the continuous miner and is capable of removing over 90% of the respirable dust from the air that is drawn into the collector (Colinet 1997). In addition, the scrubber helps move air toward the cutting face, which has enabled mine operators to receive approval from MSHA to take cuts greater than 20 feet in depth. The combination of these operating characteristics has led to scrubbers being used today on the majority of continuous mining machines.

Flooded-bed scrubbers capture dust-laden air through inlets located near the cutting boom of the miner, carry this air through ductwork to the rear of the miner, and pass the air through a filter panel that is wetted with water sprays, as shown in the schematic on the left in Figure 5. As dust particles impact and travel through the filter panel, they mix with water droplets and are removed from the airstream by a mist eliminator. The cleaned air is discharged from the scrubber back into the mine environment. The density and type of media used in the filter panel influence the dust collection efficiency and air-moving capacity of the scrubber. NIOSH conducted research to quantify the dust collection efficiency of multiple scrubber filters and their impact on scrubber airflow (Colinet and Jankowski 2000). Filters ranged in efficiency from nearly 75% for less dense filters to over 90% for the densest filter, as shown in the graph on the right side of Figure 5. This research also showed that the overall performance of a flooded-bed scrubber depends on the collection efficiency of

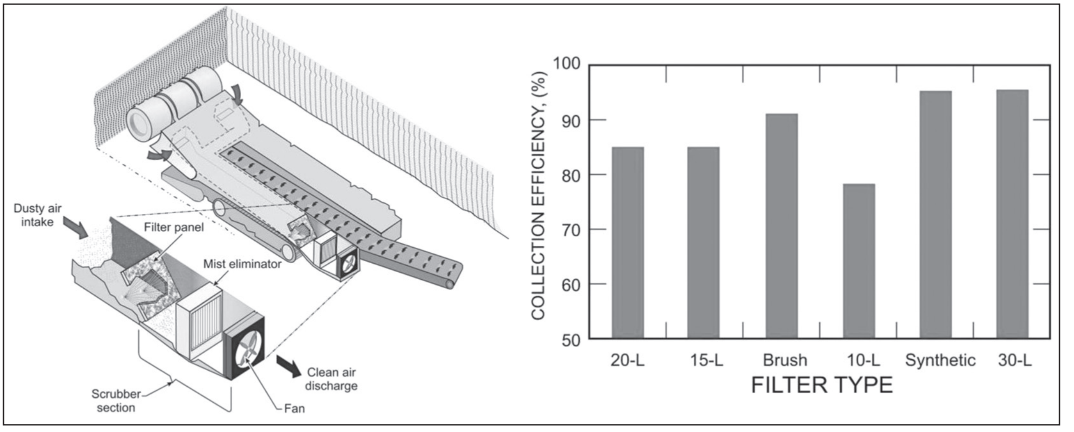

Figure 5. Schematic of flooded-bed scrubber (left) and collection efficiency for different filters (right)

the filter panel and the capture efficiency, which is the percentage of face air drawn into the scrubber. Both factors are impacted by filter selection.

ROOF BOLTER DUST CONTROLS

Roof bolter operators can have high silica dust exposures since their job requires them to drill through roof rock that may contain large quantities of silica. The primary means of controlling dust from roof bolting in the US is through the use of dry vacuum collection systems installed on the bolters. When operating properly, this system has been shown to be quite effective in capturing drill-generated dust (Beck and Goodman 2008). However, roof bolter operators can be exposed to several dust sources which include: dust not captured by the collection system and liberated at the drill hole, collected drill dust that passes through the collection system and is discharged back into the mine air, dust liberated while maintaining the collection system, and dust generated by the continuous miner when the bolter is downwind of the miner. It should also be noted that the mining cycle should be structured to eliminate or minimize the need of the bolter to work downwind of the miner.

Dry Dust Collectors

A vacuum pump pulls air and drill cuttings out of the drill hole, through the drill steel and hoses, and into a dust collector box. The collector box is equipped with cyclones and a cartridge filter to remove dust from the airstream before discharging the cleaned air back into the mine atmosphere. However, to operate effectively, all components of the system must be maintained on a periodic basis and this maintenance can expose the roof bolter operators to high dust levels.

Dust must be emptied from the collector box and typically, this is done by opening the door on the box and pulling the dust out onto the mine floor, left photo in Figure 6. Although relatively short in duration, a high concentration dust plume can be created and the collector dust can soil the clothes of the worker cleaning the box. Sampling of this activity has shown that dust levels up to 14 mg/m^3 were measured (Goodman and Organiscak 2002). If this technique is used, care must be taken so that the bolting machine in positioned in a entry with good air velocity. The mine worker should be positioned so that any dust generated by the emptying of the box is quickly carried away from the worker's breathing zone.

NIOSH recently evaluated a collector bag that was introduced to reduce dust exposure from the dust box cleaning. A retrofit kit is installed in the collector box that allows a bag to be inserted to capture the majority of the dust entering the collector box, right photo in Figure 6. The use of dust collector bags allows workers to easily remove the contained dust from the main compartment, which reduces dust exposure and cleaning time (Listak and Beck 2007). The bag can be deposited against the rib so that equipment running in the entry does not disturb the dust. Also, it was found that the cartridge filter can remain in operation for a much longer time period due to reduced dust loading. The popularity of this control continues to grow throughout the industry.

Drill Bits

Two common types of drill bits have been available for use on roof bolting machines. Shank type bits

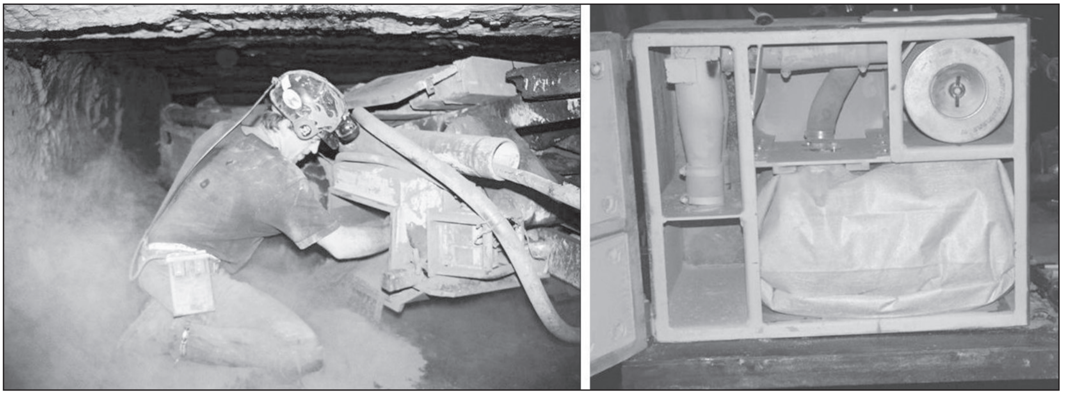

Figure 6. Miner cleaning dust collector box (left) and retrofitted collector bag filled with dust (right)

were mounted on the drill steel and dust from drilling was captured through a hole located in the drill steel. A second type of bit, the "dust hog" design, had a hole in the body of the bit for capture of the drill dust. This design placed the capture point closer to the dust generating bit tip, which was particularly beneficial in the first few inches of drilling. Testing was conducted that showed the dust hog bit to be at least 67% more effective in dust capture for the first 12 inches of the drill hole (Colinet, Shirey, and Kost 1985). The majority of bolting operations are using the dust hog style of bit.

SURFACE DRILL DUST CONTROLS

At surface coal mines, the greatest dust threat to mine workers is typically associated with silica dust exposure which occurs from the drilling and removal of the rock overlying the coal seam. Historic MSHA sampling results show that the surface drill operators are at greatest risk of overexposure to respirable silica dust. Bull dozer operators are typically the second highest occupation with silica overexposures. Research has focused upon developing controls for surface drills and also, improving the protection afforded by enclosed cabs on mobile equipment.

Controlling Surface Drill Dust

Dry dust collection systems are the most common type of dust control incorporated into surface drills by the original equipment manufacturers in the US because of their ability to be operated in freezing temperatures. The typical dry dust collection system is shown in Figure 7 and is comprised of a self-cleaning (compressed air back-pulsing of filters) dry dust collector sucking the dusty air from underneath the shrouded drill deck located over the hole. The greatest quantity of drill dust is generated by compressed air (bailing airflow) flushing the drill cuttings from the hole and blowing the dust into the ambient air.

Typically, conveyor belting or other rugged material is used to construct a deck shroud that encloses the drill table. As shown in Figure 7, this shroud is designed to confine dust within the shroud for capture by the dry collector. Research has shown that improved dust capture is realized when the gap between the shroud and the ground is minimized. This can be accomplished by better vertical positioning of the drill table shroud by the operator to minimize the ground-to-shroud gap (Organiscak and Page 1999). Also, the ground-to-shroud gap can be reduced by using a flexible shroud design that can be mechanically raised and lowered to the ground via cables and hydraulic actuators. An adjustable height shroud design maintains a better seal with uneven ground and was found to keep dust emissions next to the shroud below 0.5 mg/m^3 at several drill operations (Organiscak and Page 2005).

Two other parameters that can minimize dust escape from the shroud are an optimized collector-to-bailing-airflow ratio and a shrouded collector discharge. Research examined the relationship between the quantity of air sucked from under the shroud by the collector and the amount of bailing air used to flush the hole. Dust emissions were significantly decreased around the shroud when a collector-to-bailing airflow ratio at or above 3:1 was achieved, even in the absence of a tight shroud to ground seal (Organiscak and Page 2005). After the collector accumulates dust, this dust is dropped from a discharge port that can be several feet above the ground. With high wind velocities, this dust can be entrained into the air and expose the drill operator or nearby

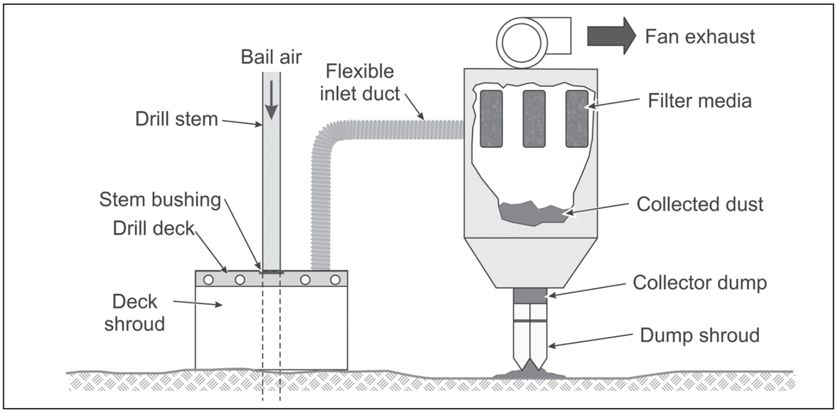

Figure 7. Typical dry dust collection system used on surface drills

workers. Research showed that this dust can be minimized by installing a simple shroud on the collector dump (Reed, Organiscak, and Page 2004) that extends to the ground as shown in Figure 7. These shrouds can be fabricated by wrapping brattice cloth around the perimeter of the collector discharge port and securing it with a hose clamp in a few minutes.

Enclosed Cabs

An enclosed cab filtration system is the primary engineering control for reducing exposure to airborne respirable dust for mobile equipment operators at surface mines. Enclosed cabs with heating, ventilation, and air conditioning (HVAC) systems are typically integrated into the drills and mobile equipment to protect the operator from the outside environment. Air filtration is often part of the HVAC system as an engineering control for airborne dusts. When new, these enclosed cabs and filtration systems can offer acceptable protection to the equipment operator. However, as the equipment ages, the effectiveness of the filtration systems and the integrity of the cab degrades and may not offer suitable protection.

A number of research efforts were completed to demonstrate the potential of retrofitting filtration and pressurization systems onto enclosed cabs. These research efforts identified several factors that are critical in order to control dust levels inside the cab to less than 10% of levels observed outside of the cabs. Significant improvements were achieved in the protection provided by older cabs in field studies where positive cab pressures at or above 0.07 inches of water gauge were achieved (Cecala et al. 2003). The positive pressure prevents dust from outside of the cab from being blown into the cab. Improvements in cab integrity were achieved by sealing cracks and gaps with silicone and sealing doors with closed cell foam tape.

The filters used for the intake air circuit must be 95% efficient or higher in removing respirable sized dusts (Organiscak et al. 2004). Also, a recirculation circuit substantially improved the protection afforded by enclosed cabs. Laboratory experiments showed an order of magnitude increase in cab protection factors when using an 85% to 95% efficient filter as compared to no recirculation filter (Organiscak and Cecala 2007). This testing also showed that the time for the interior cab concentration to decrease and reach stability after the door has been opened and closed was cut by more that half when using a recirculation filter.

DISCUSSION

Prior to the 1969 Act, mandatory dust sampling was not required by the federal government and dust exposures and CWP rates were high. In April of 1968, the USBM initiated a study to measure the dust exposure of numerous occupations in underground coal mines (Doyle 1970). Table 1 lists the dust concentrations obtained with a gravimetric sampler for a number of occupations. The range and mean concentrations are the actual concentrations that were measured, while the MRE equivalent column of the 1968 data shows the mean dust levels after being multiplied by 1.38. These data then become comparable to today's MSHA compliance sampling results, which use the same 1.38 MRE equivalency factor (Tomb et al. 1973).

Table 1 also shows mean dust levels for 2008 from the MSHA inspector compliance sampling database for these same occupations. All occupations show substantial reductions in MRE equivalent dust

Table 1. Comparison of dust levels from 1968 and 2008 for select occupations

	USBM Dust Samples Collected in 1968					MSHA 2008 Samples	
Occupation	Number of Mines	Number of Samples	Range, mg/m^3	Mean, mg/m^3	MRE Equiv* mg/m^3	Number of Samples	Mean, mg/m^3
Continuous miner operator	21	178	0.02–21.44	4.08	5.63	3,830	0.89
Cutting machine oper.	15	98	0.71–15.42	3.69	5.09	92	1.14
Loading machine oper.	18	97	0.25–39.56	3.75	5.18	139	0.32
Roof bolter operator	25	296	0.09–38.50	2.46	3.39	5,147	0.68

* MSHA calculates a MRE equivalent concentration by multiplying the gravimetric dust concentration by 1.38.

exposures, with miner and bolter operators having reductions of 84% and 80%, respectively. Despite the recent upturn shown in Figure 1, CWP prevalence has also been substantially reduced from levels identified in 1970. The significant reductions in dust exposure and disease have been realized through the combined efforts of: the USBM/NIOSH developing control technologies, MSHA promulgating and enforcing dust standards, mine operators implementing dust controls, and mine workers effectively utilizing these controls.

However, the recent upturn in CWP indicates that more work needs to be done. A comment by Mr. James R. Garvey at the Symposium on Respirable Coal Mine Dust (USBM 1970), which was held on November 3–4, 1969, sheds some guidance on reducing dust exposure among miners:

> The only effective way in which compliance with the standards can be achieved is by controlling the exposure of the miner. He must learn how to do his job with a minimum of exposure to high dust levels, and he must know how to take full advantage of whatever means are available, such as water sprays, ventilation, etc., to keep dust away from his breathing zone. This will not be easy, because the respirable dust with which we are concerned is invisible. The miner must learn how to avoid it without being able to see it or otherwise detect it.

Mr. Garvey's comments on control technologies are still valid today in that multiple controls must be utilized to control dust levels and NIOSH continues to support a strong dust control research program. His last comment provides an opportunity to mention the results of NIOSH research in the area of instrumentation that offers a significant advantage to today's miner in efforts to further prevent CWP. The Personal Dust Monitor (PDM) is a real-time dust sampler that provides the wearer with a running average of their respirable dust exposure from the beginning of the shift (Volkwein et al. 2006). The PDM also displays the percent of the allowable dust standard that has been reached. When miners are wearing this sampling instrument, they will have the ability to monitor their dust exposure while still having the opportunity to influence their subsequent exposure over the remainder of the shift. Ideally, improvements in dust controls can be made that will prevent overexposures from occurring. The PDM is approved for use in underground coal mines by MSHA and became commercially available in July of 2009. Utilization of the PDM along with application of improved control technologies should result in reduced dust exposures for mine workers and further reductions in lung disease among mine workers.

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