CHAPTER 5.—CONTROLLING RESPIRABLE SILICA DUST AT SURFACE MINES

By John A. Organiscak[1]

Overexposure to airborne respirable crystalline silica dust (referred to here as “silica dust”) can cause silicosis, a serious and potentially fatal lung disease. Mining continues to have some of the highest incidences of worker-related silicosis, and the mining machine operator is the occupation most commonly associated with the disease [NIOSH 2003]. In particular, some of the most severe cases of silicosis have been observed in surface mine rock drillers [NIOSH 1992]. A voluntary surface coal miner lung screening study conducted in Pennsylvania in 1996 found that silicosis was directly related to age and years of drilling experience [CDC 2000].

U.S. mine workers continue to be at risk of exposure to excessive levels of silica dust. The percentage of Mine Safety and Health Administration (MSHA) dust samples during 2004–2008 that exceeded the applicable or reduced respirable dust standard because of the presence of silica were: 12% for sand and gravel mines, 13% for stone mines, 18% for nonmetal mines, 21% for metal operations, and 11% for coal mines [MSHA 2009]. At surface mining operations, occupations most frequently exceeding the applicable respirable dust standard are usually operators of mechanized equipment such as drills, bulldozers, scrapers, front-end loaders, haul trucks, and crushers.

This chapter summarizes the current state of the art of dust controls for surface mines. Surface mining operations present dynamic and highly variable silica dust sources. Most of the dust generated at surface mines is produced by mobile earth-moving equipment such as drills, bulldozers, trucks, and front-end loaders excavating silica-bearing rock and minerals. Four practical areas of engineering controls to mitigate surface mine worker exposure to all airborne dusts, including silica, are drill dust collection systems, enclosed cab filtration systems, controlling dust on unpaved haulage roads, and controlling dust at the primary hopper dump.

Many surface mine dust control problems can be visually observed and diagnosed. Visible airborne dust emissions generated from a particular surface mine process usually indicate that respirable silica dust can be present and potentially become a worker exposure problem. Visual dust emissions affecting nearby workers indicates that an engineering control is needed or an existing control needs maintenance. Investigating possible causes of visual dust emissions when using an engineering control often can uncover the reason for its poor dust control effectiveness. Frequent visual inspections of engineering control systems can identify needed maintenance to optimize their dust control effectiveness. Area dust sampling should be conducted, in conjunction with personal sampling, to quantify potential dust sources and examine their contribution to the worker dust exposure problem.

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DRILL DUST COLLECTION SYSTEMS

Drill dust is generated by compressed air (bailing airflow) flushing the drill cuttings from the hole. Dry or water-based dust collection systems are available for controlling this drill dust. Dry dust collection systems are the most common type of dust control incorporated into the drilling machine by original equipment manufacturers because of their ability to be operated in freezing temperatures. A typical dry dust collection system is shown in Figure 5-1. It is composed 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. Ninety percent of dust emissions with this type of system are attributed to drill deck shroud leakage, drill stem bushing leakage, and dust collector dump discharge. Wet suppression is another drill dust collection method and involves injecting water into the bailing airflow traveling down the drill stem. The process of the bailing airflow, water droplets, and cuttings mixing together captures the airborne dust as they travel back up the hole. However, wet suppression is infrequently used because of operational problems in cold climates, lack of a readily accessible water supply, and shorter bit life. Studies by the U.S. Bureau of Mines and NIOSH have shown the practical aspects of optimizing these dust collection systems. These are discussed below for each dust collection method.

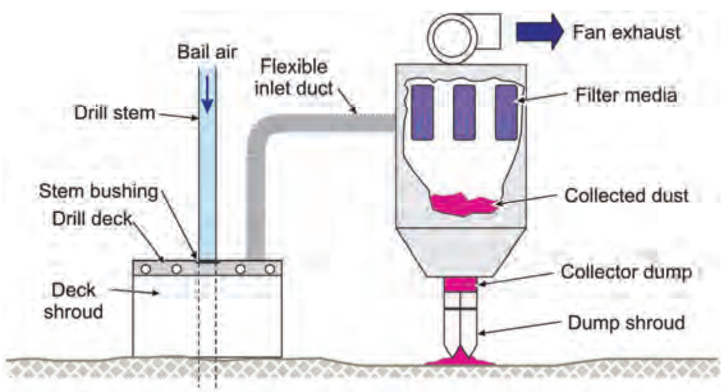

Figure 5-1.—Typical dry dust collection system used on surface drills.

Dry Dust Collector System

- **Maintain a tight drill deck shroud enclosure with the ground.** Dust emissions are significantly reduced around the drill deck shroud by maintaining the ground-to-shroud gap height below 8 in [NIOSH 2005; USBM 1987]. This can be accomplished by better vertical positioning of the drill table shroud by the operator to minimize the ground-to-shroud gap. Dust levels were significantly reduced from 21.4 to 2.5 mg/m^3 next to the drill deck shroud when the drill operator changed the drill setup procedure to minimize this gap [Organiscak and Page 1999]. Also, the ground-to-shroud gap can be more tightly closed 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 [NIOSH 1998, 2005]. Finally, a shroud constructed in sections with vertical gaps along sections or corners can also be a source of shroud leakage. Overlapping sections of shroud material reduce gaps and leakage. One conceptual shroud design for a rectangular drill table is construction with corner sections and overlapping side sections of shroud material [Page and Organiscak 1995].

- **Maintain a collector-to-bailing airflow ratio of at least 3:1.** Dust emissions are significantly decreased around the shroud at or above a 3:1 collector-to-bailing airflow ratio [NIOSH 2005]. Dust collector airflow reductions under the shroud are generally caused by restrictions and/or leakages in the system. Loaded filters and material in the ductwork are likely causes of restrictions, whereas damaged ductwork and holes are likely causes of leakage in the system. Thus, inspection and maintenance of the dust collection system are vital to achieving and maintaining optimal collector operation and airflow.
- **Maintain a good drill stem seal with the drill table.** A rubber drill stem bushing (see Figure 5-1) restricts bailing airflow from blowing dust and cuttings through the drill deck and therefore needs to be replaced after mechanical wear. An alternative sealing method involves using a nonmechanical compressed air ring seal manifold under the drill deck. This manifold consists of a donut-shaped pipe with closely spaced holes on the inside perimeter that discharges air jets in a radial pattern at the drill stem. The high-velocity air jets block the gap between the drill stem and deck, reducing respirable dust leakage through the drill deck by 41%–70% [Page 1991].
- **Shroud the collector dump discharge close to the ground.** Dumping dust from the collector discharge several feet above ground level can disperse significant amounts of airborne respirable dust. Dust emission reductions of greater than 63% were measured by the collector discharge dump after installing an extended shroud near ground level (Figure 5-1) [Reed et al. 2004; USBM 1995]. These shrouds can be fabricated quickly by wrapping brattice cloth around the perimeter of the collector discharge dump and securing it to the discharge dump with a hose clamp.
- **Maintain the dust collector as specified by manufacturer.** Collector system components should be frequently inspected and damaged components repaired or replaced. A 51% dust emission reduction was measured at one drill after a broken collector fan belt was replaced, while another drill showed a reduction of 83% after the torn deck shroud was replaced [Organiscak and Page 1999].

Wet Suppression

- **Add small amounts of water into the bailing air until the visible dust cloud has been significantly reduced.** Drill dust emissions are significantly reduced by increasing the water flow rate from 0.2 to 0.6 gal/min [USBM 1987]. A needle valve and water flow meter installed on the water supply line provides adjustable control for wet suppression systems. However, adding excessive water down the hole can cause operational problems with no appreciable improvement in dust control.

- **Minimizing water flow to a rolling cutter bit can increase bit life.** Wet drilling with rolling cutter bits can cause premature bit wear. A drill stem water separator installed upstream of a rolling cutter bit can increase bit life without adverse affects on dust control [Listak and Reed 2007; USBM 1988]. The water separator is a bit stabilizer with an internal cyclonic or impaction water droplet classifier, removing most of the water from the bailing airflow before it is flushed through the drill bit. The water removed by the internal separator is released through external holes in the bit stabilizer (Figure 5-2).

Figure 5-2.—Water separator discharging water before it reaches the drill bit.

ENCLOSED CAB FILTRATION SYSTEMS

Enclosed cab filtration systems are one of the mainstay engineering controls for reducing mobile equipment operators' exposure to airborne dust 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. Surface mining dust surveys conducted by NIOSH on drills and bulldozers have shown that enclosed cabs can effectively control the operator's dust exposure, but cab performance can vary [Organiscak and Page 1999]. The enclosed cab protection factors (outside ÷ inside dust concentrations) measured on rotary drills ranged from 2.5 to 84, and those measured on bulldozers ranged from 0 to 45. NIOSH also conducted field studies of upgrading older equipment cabs to improve their dust control effectiveness. These studies involved retrofitting older enclosed cabs with air-conditioning, heating, and air filtration systems to show the effectiveness of upgrading older mine equipment cabs. During these retrofits, any reasonably repairable cracks, gaps, or openings were sealed with silicone and closed cell foam tape. Varying degrees of enclosure integrity were achieved. Table 5-1 shows the results in ascending order of performance achieved with these retrofitted installations. In addition, NIOSH conducted controlled laboratory experiments to examine the key design factors of enclosed cab dust filtration systems. The key performance factors for effective enclosed cab dust filtration systems are summarized below.

Table 5-1.—Respirable dust sampling results of enclosed cab field studies

Cab evaluation	Reference	Cab pressure, in w.g.	Wind velocity equivalent,[1] mph	Average inside cab dust level, mg/m^3	Average outside cab dust level, mg/m^3	Protection factor, out / in
Rotary drill	Organiscak et al. [2003a]	ND	0	0.08	0.22	2.8
Haul truck	Chekan and Colinet [2003]	0.01	4.5	0.32	1.01	3.2
Front-end loader	Organiscak et al. [2003a]	0.015	5.6	0.03	0.30	10.0
Rotary drill	Cecala et al. [2003]	0.20–0.40	20.3–28.7	0.05	2.80	56.0
Rotary drill	Cecala et al. [2005]	0.07–0.12	12.0–15.7	0.07	6.25	89.3

ND None detected.
[1]Wind velocity equivalent = (4000 $\sqrt{\Delta p_{cab}}$) fpm × 0.11364 mph/fpm @ standard air temperature and pressure.

Key Performance Factors for Enclosed Cab Filtration Systems

- **Ensure good cab enclosure integrity to achieve positive pressurization against wind penetration into the enclosure.** As shown in Table 5-1, significant improvements in cab protection factors were achieved in the field studies when cab pressures exceeded 0.01 in w.g. This corresponded to wind velocity equivalents (an indicator of cab wind velocity resistance) greater than 4.5 mph. The cab enclosures with greater than 0.01 in w.g. pressure were of close-fitted construction, and their integrity could be readily improved by sealing cab enclosure cracks, gaps, or openings with silicone and closed cell foam tape. The loosely fitted cab construction on one of the drills and the truck were difficult to seal, which limited the amount of cab pressure that could be attained.

- **Use high-efficiency respirable dust filters on the intake air supply into the cab.** Filter efficiency performance specifications used in the field were 95% or greater on respirable-sized dusts [Chekan and Colinet 2003; Cecala et al. 2003, 2005; Organiscak et al. 2003a]. Laboratory experiments showed an order of magnitude increase in cab protection factors when using a 99% efficient filter versus a 38% efficient filter on respirable-sized particles [NIOSH 2007].

- **Use an efficient respirable dust recirculation filter.** All of the cab field demonstrations used recirculation filters that were 95% efficient or better in removing respirable-sized dusts [Chekan and Colinet 2003; Cecala et al. 2003, 2005; Organiscak et al. 2003a]. Laboratory experiments showed an order of magnitude increase in cab protection factors when using an 85%–94.9% efficient filter compared to no recirculation filter [NIOSH 2007]. Laboratory testing also showed that when using a recirculation filter, the time for interior cab concentration to decrease and reach stability after the door had been opened and closed was cut by more than half.

- **Minimize dust sources in the cab.** Use good housekeeping practices, and move heater outlets that blow across soiled cab floors. Dust levels were shown to increase from 0.03 to 0.26 mg/m^3 by turning on a floor heater inside the cab [Cecala et al. 2005]. The floor heater was removed and cab heating was discharged down from the ceiling HVAC system, reducing dust entrainment in the cab during colder winter months. Another method of reducing entrainment of dust from a soiled cab floor is placing a gritless (without sand added) sweeping compound on the floor during the working shift. Most commercial sweeping compounds have petroleum-based oils or wax added to the cellulose material. It must be noted, however, that people sensitized to petroleum distillates could have allergic reactions to these sweeping compounds if used in enclosed cabs. A few companies offer non-petroleum-based sweeping compounds that use either a natural oil or chemical additive for dust adhesion [NIOSH 2001]. It is also recommended to cover the floor with rubber matting instead of carpeting for easy cleaning. More frequent cleaning of heavily soiled floors by the operator may be a more straightforward alternative to using sweeping compounds to minimize this type of dust entrainment.

- **Keep doors closed during equipment operation.** On one drill operation, the respirable dust concentrations inside the cab averaged 0.09 mg/m^3 with the door closed and 0.81 mg/m^3 when the door was briefly opened to add drill steels [Cecala et al. 2007]. Although this occurred after drilling stopped and the visible dust dissipated, opening the door, even briefly, produced a ninefold increase in respirable dust concentrations inside the cab during the many drill steel changes made over a working shift.

CONTROLLING HAULAGE ROAD DUST

Off-road haul trucks used in the mining industry typically contribute most of the total dust emissions at a mine site. Although most of the airborne dust generated from unpaved haulage roads is nonrespirable, up to 20% is in the respirable size range [Organiscak and Reed 2004]. The most common method of haul road dust control is surface wetting with water. Figure 5-3 shows the effectiveness of road wetting with water on airborne respirable dust generation measured next to an unpaved haul road. The road was wetted in the morning and dried out in the afternoon. Although the road treatment methods have been shown to be very effective, their application generally involves continual maintenance due to road degradation from traffic, dry climatic conditions, and material spillage on the road. Road dust generation then can be inevitable at times during the mining operation until controls are applied. Given their mobility, trucks have the potential to expose other downwind mine workers to respirable dust, as well as other truck drivers on the haul road. NIOSH has recently studied the size characteristics, concentrations, and spatial variation of airborne dust generated along unpaved mine haulage roads to examine the potential human health and safety impacts of this dust source and is examining other avenues of truck dust mitigation. Techniques for controlling haulage road dust are summarized below.

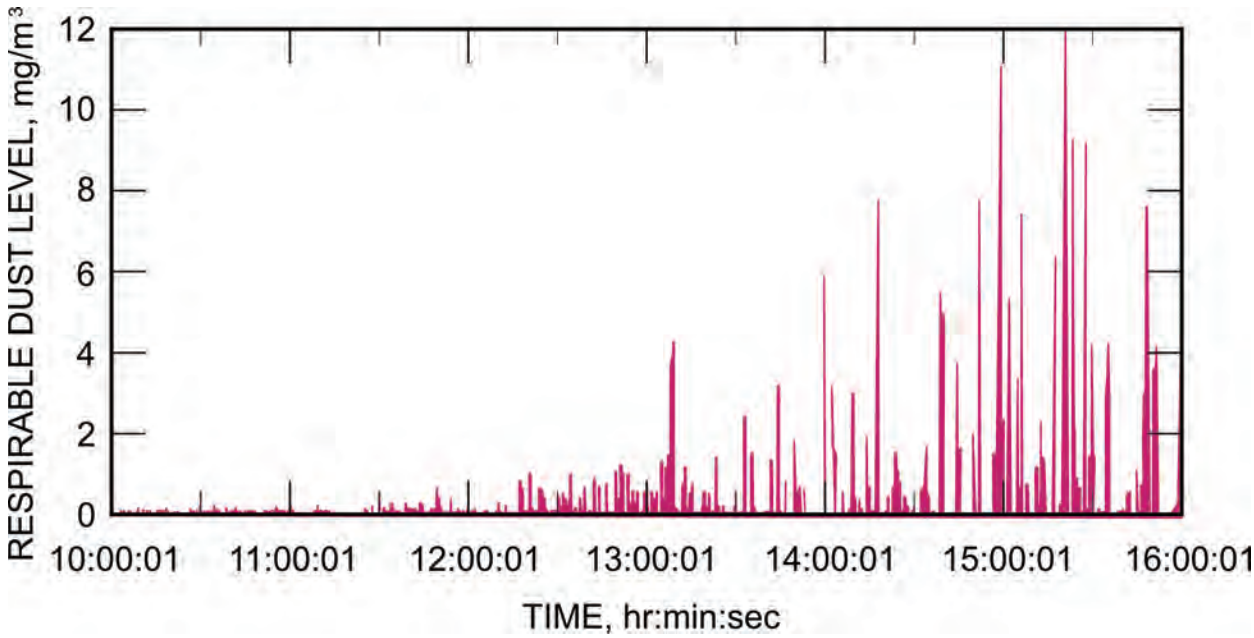

Figure 5-3.–Increase in dust when a wet haul road dries.

Methods for Controlling Haulage Road Dust Exposures

- **Treatment of unpaved road surfaces.** Figure 5-3 shows the effectiveness of road wetting with water on respirable dust liberation next to the haul road and its time-frame of effectiveness at this mine [Organiscak and Reed 2004]. Other haulage road treatments include adding hygroscopic salts, surfactants, soil cements, bitumens, and films (polymers) to the road surface, which can extend the time of effectiveness between treatments up to several weeks [Organiscak et al. 2003b; Olson and Veith 1987].

- **Increase the distance between vehicles traveling the haul road.** Research has shown that airborne dust concentrations generated from haulage roads rapidly decreased and approached ambient air dust levels 100 ft from the road [Organiscak and Reed 2004]. This road dust dissipation and dilution provides an opportunity to use administrative and mine planning controls to reduce worker dust exposure. If a trailing haul truck was not allowed to follow within 20 sec of a leading truck, the resulting distance between trucks allowed generated dust to dissipate. This led to more than a 40% reduction in respirable dust exposure to the following truck [Reed and Organiscak 2005]. Finally, advantageous road layout and traffic patterns can be designed into the mine plan to isolate the dust sources from other workers [Organiscak and Reed 2004].

CONTROLLING DUST AT THE PRIMARY HOPPER DUMP

The mined product is normally loaded into haul trucks from the surface mine pit and driven to the primary crusher location. This product is either dumped directly from the haul truck into the primary hopper feeding a crusher or dumped into a stockpile. If it is stockpiled, a front-end loader then takes the mined product and dumps it into the primary hopper. In either case during this dumping process, a dust cloud can billow out of the hopper and roll back under the truck bed or front-end loader bucket. Dust in the mined product is released from the large volume of material being dumped in a short period of time, which quickly displaces the air in the hopper and transports the airborne dust released from dumping. If the equipment operators dumping the mined product into the hopper have an effective enclosed cab filtration system (as described earlier), their exposure to this dust would be reduced. However, if other mine personnel such as crusher operators and/or maintenance workers work near this primary dump, they can be exposed to this airborne dust. Several effective control methods are available and include enclosing the hopper dump and using water sprays to suppress and contain the dust from rolling back out of the enclosure.

Key Factors for Controlling Dust From the Primary Dump

- **Enclose the primary hopper dump.** Walls can be constructed around the primary dump location to form an enclosure that must be custom-designed to accommodate the dump vehicles being used. Walls can be either stationary (rigid) or removable (flexible material or curtains) based on maintenance access within parts of the enclosure. Staging curtains, also called stilling curtains, can be used in the enclosure to provide physical barriers that break up the natural tendency for dust to billow out of the primary dump hopper when a large volume of product is dumped in a very short time period (see Figure 5-4) [Weakly 2000]. Another option to restrict the dust from escaping the enclosure is using panels of flexible plastic stripping on the dump side of the enclosure. This plastic stripping employs an overlapping sequence that provides a very effective seal and resists damage if contacted by the bucket of the front-end loader or the bed of the haul truck during dumping. Finally, a local exhaust ventilation system can be used to filter the dust-laden air from the enclosed hopper area. This would be most appropriate when the primary dump is at a location where the dust could enter an adjoining structure or impact outside miners. Since hoppers are usually large, a significant amount of airflow would be required to create a negative pressure sufficient enough to contain the dust cloud. This approach would be a more expensive alternative than using wet suppression [Rodgers et al. 1978].

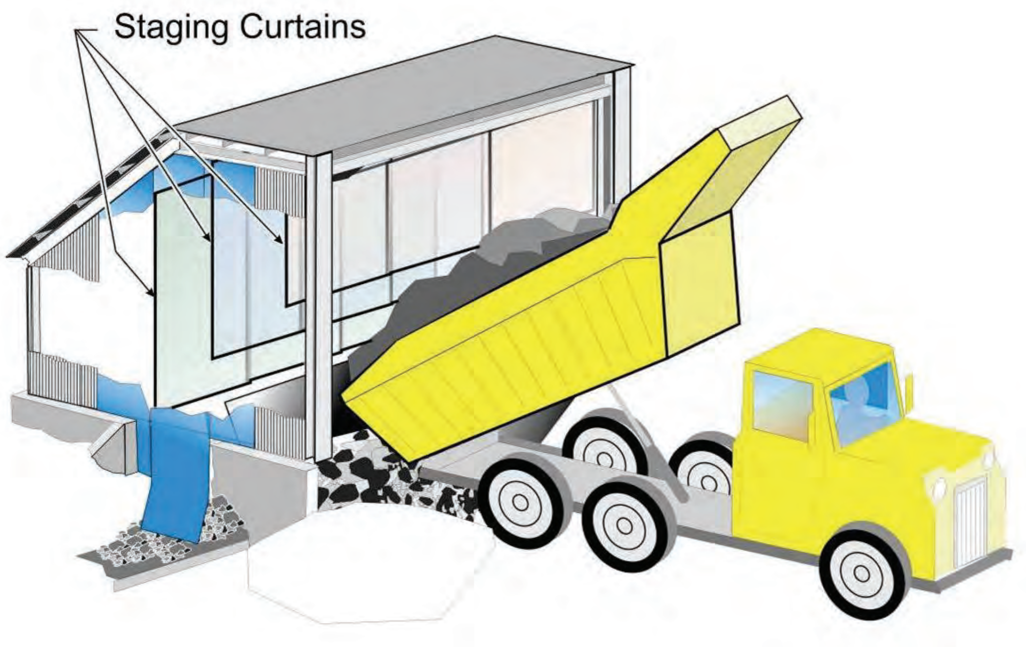

Figure 5-4.—Staging curtains used to prevent dust from billowing out of enclosure.

- **Use water sprays to suppress the dust in the enclosure.** Water sprays directed at the mined product dumped into the hopper will wet the material and suppress some of the airborne dust generated. A good starting point is to add 1% moisture by weight [Quilliam 1974]. This percentage can be adjusted based on the improvement gained from additional moisture versus any consequences from adding too much. Since continuous use of water sprays during long periods of idle time between dumping can have adverse operational effects, activate the water sprays during the actual dump cycle through the use of a photo cell or a mechanical switching device. A delay timer can also be used in this application so that the sprays continue to operate and suppress dust for a short time period after the dump vehicle has moved away.

- **Prevent the dust from rolling back under the dump vehicle.** A tire-stop water spray system is recommended to reduce the dust liberated due to rollback under the dumping mechanism. A tire stop or Jersey barrier should be positioned at the most forward point of dumping for the primary hopper. A water spray system should be attached to the back side of this tire stop to knock down and force the dust that would otherwise roll back under the dumping mechanism into the hopper. In addition, a shield should be placed over this water spray manifold to protect it from damage from falling material (Figure 5-5). Finally, a system should also be incorporated that allows the water sprays to be activated only during the actual dumping process, as previously discussed.

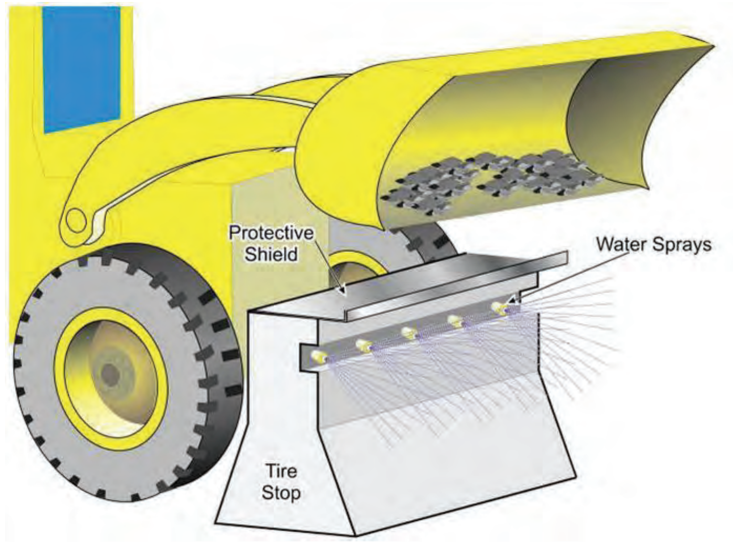

Figure 5-5.—Tire-stop water spray system reduces dust rollback under the dumping vehicle.

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Best Practices for Dust Control in Coal Mining

Department of Health and Human Services
Centers for Disease Control and Prevention
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Best Practices for Dust Control in Coal Mining

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TABLES

ACRONYMS AND ABBREVIATIONS USED IN THIS REPORT

CWHSP	Coal Workers' Health Surveillance Program
CWP	Coal workers' pneumoconiosis
DO	designated occupation
HVAC	heating, ventilation, and air conditioning
IARC	International Agency for Research on Cancer
ILO	International Labour Office
MSHA	Mine Safety and Health Administration
NIOSH	National Institute for Occupational Safety and Health
PDM	personal dust monitor
pDR	personal DataRAM
PEL	permissible exposure limit
PMF	progressive massive fibrosis
TEOM	tapered-element oscillating microbalance

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cfm	cubic foot per minute
cm	centimeter
fpm	foot per minute
ft	foot
ft/min	foot per minute
gpm	gallon per minute
hr	hour
in	inch
in w.g.	inch water gauge
kPa	kilopascal
lpm	liter per minute
m/sec	meter per second
mg/m^3	milligram per cubic meter
mm	millimeter
mph	miles per hour
$\mu g/m^3$	microgram per cubic meter
psi	pound-force per square inch
sec	second

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