Field assessment of control techniques and long-term dust variability for surface coal mine rock drills and bulldozers

J.A.Organiscak & S.J.Page
National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, Pittsburgh, PA, USA

ABSTRACT: Airborne respirable dust surveys were conducted at six surface coal mines to investigate the effectiveness of dust control methods used on rotary rock drills and bulldozers. Dust controls commonly used on drills include a dry dust collection system, exhausting from a shrouded area around the collared hole, and an enclosed drill operator cab, filtering airborne dust from the cab. Bulldozers are also typically equipped with an enclosed operator cab as a dust control measure. Airborne respirable dust sampling was conducted near each equipment's source of generation and inside its enclosed cab. Silica analysis was performed on the dust samples to determine the percent silica content in the dust generated at the six mining operations. An additional eight-month follow-up of dust sampling was also conducted in the enclosed operator cabs of several rock drills and bulldozers. Data were analyzed for long-term variability of accepted control methods to abate dust and silica levels.

The highwall rock drill was the major and most variable dust source as compared to the bulldozer, generating dust levels, on average, one order of magnitude higher than dust levels of the bulldozer. Four of the six drills surveyed had dust containment and capture problems at the shrouded drill table above the hole. Repairs or modifications to three of the drill dust collection systems were shown to reduce dust levels by more that 50% next to the shrouded drill table. The enclosed operator cabs provided more than 90% and more than 40% lower dust levels than at the dust source for the drill and bulldozer, respectively. Long-term sampling of several of these highwall drills and bulldozers showed that the dust levels in the drill cabs were frequently higher than 0.2 mg/m^3 and more variable than in the bulldozers. The bulldozer dust levels were frequently below 0.2 mg/m^3. Future research should focus on improving some of the deficiencies present in the drill's primary dust collection system, and developing quality control methods to ensure the integrity of enclosed cab protection for equipment operators.

1 INTRODUCTION

Overexposure to airborne respirable crystalline silica dust can cause serious or fatal respiratory disease. Although mortality rates attributed to silicosis have dramatically dropped in the general U.S. population (for ages 15 and over) from 7.9 deaths per million people in 1968 to 1.3 deaths per million people in 1992, eight states still have notably higher silicosis-related mortality rates as compared to the general U. S. population (NIOSH, 1996). The eight states with silicosis-related mortality rates above 3 deaths per million people for 1991-1992 are Vermont, Pennsylvania, Ohio, West Virginia, Wisconsin, Utah, Colorado, and New Mexico (NIOSH, 1996). These states are associated with a long history of mining and mineral processing activities. The most frequent occupation (16.0%) recorded on silicosis-related death certificates between 1991-1992 was mining machine operators, with coal mining being the first (9.5%) and metal mining being the third (8.6%) most frequently associated industries (NIOSH, 1996). Therefore, mine worker exposure to silica dust continues to be an ongoing occupational health concern.

Exposure of surface coal mine rock drillers to respirable crystalline silica is of particular concern. In a 1992 NIOSH Alert on silicosis in rock drillers, the National Institute for Occupational Safety and Health (NIOSH) reported 23 individual cases of advanced silicosis (acute, accelerated, and chronic) ranging in workers from 25 to 60 years of age, with drilling tenures ranging between 3 and 20 years (NIOSH, 1992). Most of the cases involved drill operators in their 30's and 40's, clearly indicating that high silica-exposure levels are associated with their occupation (NIOSH, 1992). A more recent lung x-ray surveillance study of a 664-volunteer population of surface coal miners revealed that the prevalence of silicosis-like abnormalities was 9% (Stauffer et al., 1998). The two most significant factors associated with these silicosis-like abnormalities were increasing age and years of drilling experience.

The Mine Safety and Health Administration (MSHA) permissible dust exposure for coal mine workers is a shift average of 2.0 mg of airborne respirable coal mine dust per cubic meter of air (2.0 mg/m^3 as defined by the Mining Research Establishment (MRE) Criteria (U. S. Code of Federal Regulations, 1998). If the airborne respirable dust (ARD) sample contains more than 5% crystalline silica, the dust standard is reduced to the quotient of 10 divided by the percentage of silica in the dust, limiting the respirable crystalline silica exposure to a maximum of 100 μg/m^3 (MRE equivalent) for the working shift. Compliance with this respirable dust standard is expected to significantly reduce a worker's risk of occupational lung disease throughout an average life expectancy.

MSHA's dust enforcement program includes both inspector and coal mine operator dust sampling. MSHA's surface coal mine dust program focuses its sampling efforts at designated work positions (DWP's). These are particular areas or occupations that have been historically shown to either exceed 1 mg/m^3 of respirable dust or have high silica exposure. The local MSHA official has the authority to classify DWP's based on an operation's dust sampling history or to classify non-designated work positions (NDWP's) based on a history of competent dust abatement. The most frequently sampled and classified DWP's at surface coal mines are highwall drill and bulldozer operators. MSHA dust exposure data from 1985 to 1992 showed that the percentage of the highwall drill dust samples (taken from DWP's) having greater than 5% silica and exceeding the 100 μg/m^3 silica limit were 81% and 77%, respectively (Tomb et al., 1995). Bulldozer operator dust samples (taken from DWP's) having greater than 5% silica and exceeding the 100 μg/m³ silica limit were 68% and 60%, respectively (Tomb et al., 1995).

A special MSHA inspector sampling survey of non-designated work positions (NDWP's) at surface coal mines showed very similar silica dust level results for the highwall drill operator and somewhat lower silica dust level results for the bulldozer operator as compared to the DWP sampling data. The percentage of NDWP highwall drill operator samples having greater than 5% silica content and exceeding the 100 μg/m³ silica limit were 81% and 75%, respectively (Tomb et al., 1995). The NDWP bulldozer operator samples having greater than 5% silica content and exceeding the 100 μg/m³ silica limit were 56% and 47%, respectively (Tomb et al., 1995). Therefore, MSHA data suggest that overexposure to silica dust is an ongoing surface coal mine dust problem for highwall drill and bulldozer operators.

Dust controls commonly used on highwall drills include a dry dust collection system, exhausting from a shrouded area around the collared hole, and an enclosed drill operator cab, filtering airborne dust from the cab air. Bulldozers also use an enclosed operator cab as a dust control measure. Field assessment of these dust control practices was conducted to examine their dust abatement strengths and weaknesses. Six highwall drilling machines and five bulldozers were evaluated for their dust control effectiveness at six surface coal mines. Three of the drills and two of the bulldozers were sampled weekly over an eight-month period to determine the mitigated long-term dust level variability inside the operator cab. Silica analysis was also performed on the dust samples to determine the amount of silica dust generated from these mining operations. This paper describes these field studies, analyzes their results, and identifies any deficiencies found in the dust control practices used.

2 FIELD STUDY SAMPLING PROCEDURES

Field assessments of highwall drills and bulldozers included airborne respirable dust (ARD) sampling with documentation of dust control practices utilized. Area ARD sampling was conducted near each equipment's source of dust generation and inside its enclosed cab to examine the effectiveness of the dust control practices used. Four personal gravimetric dust samplers were located inside the dust plume escaping the drill shroud and inside the enclosed cab. Four personal gravimetric dust samplers were located above the bulldozer tracks on both sides of the cab and inside the enclosed cab of the bulldozer. Each personal sampler utilized a 10-mm Dorr-Oliver nylon cyclone classifier[1], operating at 2.0 liters/min. The respirable dust was deposited on a MSA 37-mm coal dust filter cassette. All the dust concentrations measured by these personal samplers adhere to the Atomic Energy Commission (AEC) criteria for respirable dust and are not reported as MRE equivalent concentrations (U. S. Code of Federal Regulations, 1998).

Dust sampling was conducted during most of the working shift, but sampler times were less for some locations having high dust concentrations. The dust samplers were run continuously for about 7 hours inside the operator cabs and outside the bulldozer cabs where dust concentrations were expected to be less than 1 mg/m³. Since dust concentrations in the dust plume near the drill shroud were notably higher than at the other sampling locations, sampling times were commonly between 3 and 6 hours for this location. Sampling times were varied in an effort to keep the amount of the respirable dust mass collected within the recommended range for silica analysis, as discussed below.

The dust mass from the cassette filters was analyzed for crystalline silica by MSHA's P-7 infrared spectrophotometer method (MSHA, 1989). The P-7 procedure was found to be a NIOSH-classified B method of less than 25% error within the true value in a single laboratory (Anderson, 1983). Preparation of dust samples for testing involves low-temperature ashing of the filter cassettes and re-depositing the residue mass (ash) on another filter for infrared analysis. The tested and recommended net dust mass collected on a coal mine filter cassette for the P-7 method is between 0.5 and 2 mg with a minimum silica mass of 25 μg (Anderson, 1983). Because the P-7 method testing had at least twice as much or more combustible coal dust mass than noncombustible mineral matter deposited on the cassette filters (Anderson, 1983), this method is expected to provide similar precision for a dust mass as low as 0.25 mg of essentially noncombustible mineral matter with 25 μg of silica. Surface coal mine dust generated from highwall drills and bulldozers during overburden removal is expected to have little or no combustible coal dust, so the silica content (percent) in the ARD measurements is reported for at least 0.25 mg of dust mass and 25 μg of silica. Many of the cassette filters did not have 0.25 mg of dust mass, so multiple filters from the same sampling location were composited for silica analysis. Some dust levels were so low that even the composite filter mass did not meet the authors' minimum reportable range. Also, silica analysis for some filter cassettes with high weight gains was not conducted because numerous splits of the sample would be required to obtain a dust mass in the recommended mass range for this analytical technique.

Supplemental airborne dust sampling was also conducted with instantaneous dust monitors. A MiniRAM instantaneous dust instrument connected to a Metrosonics 331 data logger was operated in the operator's cab to examine real-time dust level variation during the shift. The MiniRAM measures respirable dust by light-scattering techniques and was operated in the passive sampling mode (Organiscak et al., 1986). The Metrosonics 331 data logger records analog output from instruments and is downloaded to a personal computer for data analysis (Cecala et al., 1988). These instantaneous dust data are expressed in relative MiniRAM units to identify corresponding dust-level changes to particular operational events during the shift.

During these field surveys, the make and model of equipment and dust control methods being used were documented. This documentation included identification of equipment sampled, classification of control methods used, and inspection of the controls' operating status. Because actual dust control operating parameters were difficult to measure in the field, their specified capacities are reported. Dust collector and cab airflow parameters were especially difficult to measure because of numerous elbows and area changes in the duct work. The only reliable measurements made during the surveys were bailing airflow on some of the drills. Bailing airflow is compressed airflow directed at the bit in order to remove cuttings from the hole. This airflow was measured with a calibrated limited orifice flow device placed on the drill steel with the bit removed. Because the drill had to be taken out of production and the bit removed to install the instrument, opportunities to acquire this measurement on all drills were limited. However, measurements were made on one of each drill make, and

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[1]Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

Table 1 - Surface Mine Equipment Studied

Mine Equipment	*Make/Model	General Description	Dust Controls
Drill No. 1	Drill Tech/ D40K	• Truck-mounted drill • 6.75" diameter hole • ≈ #400 cfm bailing airflow	• ≈ #1,200 cfm dry collector • Enclosed weather cab, no air cleaning system
Drill No. 2 & 3	Ingersol-Rand/ DM50E	• Track-mounted drill • 6.75" diameter hole • ≈ †500 cfm bailing airflow	• ≈ 3,000 cfm dry collector • Enclosed cab with air cleaning system
Drill No. 4 & 5	ReedDrill/ SK45i	• Track-mounted drill • 7.875" diameter hole • ≈ †750 cfm bailing airflow	• ≈ 3,000 cfm dry collector • Enclosed cab with air cleaning system
Drill No. 6	ReedDrill/ SK50i	• Track-mounted drill • 7.875" diameter hole • ≈ 750 cfm bailing airflow	• ≈ 3,000 cfm dry collector • Enclosed cab with air cleaning system
Dozer No. 1, 4, 5, & 6	Caterpillar/ D10N	• Elevated track-drive sprocket • U-shaped dozer blade	• Enclosed cab with air cleaning system
Dozer No. 2	Caterpillar/ D9H	• U-shaped dozer blade	• Enclosed cab with air cleaning system
Dozer No. 3	Caterpillar/ D11N	• Elevated track-drive sprocket • U-shaped dozer blade	• Enclosed cab with air cleaning system

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#Measurement made on this equipment model.
†Measurement made on one of these same models.

these measurements were assumed to be similar for alike drills.

Frequent visual inspections of the dust control practices were made during the shift and any operational problems with these practices were documented. Several critical problems were observed with the primary dry dust collection systems used on some of the highwall drills. Efforts were made to rectify these operational problems during the shift or between shifts, and additional gravimetric dust samplings were conducted to measure the net effect of the control improvement near the source of generation. The instantaneous dust levels measured inside the cabs were useful for identifying the significance of equipment operator practices that allowed dust into the cabs.

Additional intermittent long-term dust sampling was conducted in the operator cabs of three drills and two bulldozers to examine the variability of accepted control methods designed to abate dust levels. At several mine sites, airborne respirable dust sampling was conducted one day each week over an 8-month period in the enclosed operator cab of a highwall drill and bulldozer. Four personal dust samplers (described earlier) were placed in each cab and were operated for nearly 7 hours or more during the sampling shift. Dust samples were analyzed for silica by the P7 method as described earlier. Because this study was conducted with a small coal mine operator, only select pieces of equipment were being used during each week at the operator's different mine sites. Usually coal loading occurred at one mine site while overburden removal occurred at the other mine site. Only the highwall drill and bulldozer involved with overburden removal at either mine sight could be sampled. Therefore, variability data were collected for several pieces of equipment, sampled at various intermittent time intervals. Visual inspection of the dust control practices and recording of climatic conditions were also documented for each sampling shift.

3 DUST CONTROL ASSESSMENT RESULTS

Dust control field assessments were completed on six highwall drills and five bulldozers. Two coal mining companies were cooperative in providing access to their equipment at six different surface coal mining sites. These six surface mines were located in the Appalachian mountains of West Virginia, Kentucky, and Tennessee. All the mines used the truck haulback strip mining method, where front end loaders load the blasted overburden into trucks to be hauled and dumped onto the other side of the existing pit. Bulldozers are used to push the overburden into the previously mined-out pit.

Table 1 shows the equipment surveyed and the control practices used for each piece of equipment. The highwall drills and bulldozers sampled usually operated remotely from each other and were not considered to be contributing dust sources to one other. The highwall drills forced compressed air through the drill stem and bit (bailing air) to flush the cuttings and dust out of the collared hole. Dry dust collection systems were used on the drills to capture the dust from underneath the shrouded drill table. These drills also used enclosed cabs to provide the operator additional protection from the drill dust. All the drills except drill no. 1 had positive air filtration systems conditioning the enclosed cab. All the bulldozers also had enclosed cabs with air filtration systems. These cab filtration systems re-circulated and filtered most of the inside cab air with some additional make-up air drawn in through an inlet filter.

Table 2 shows the ARD survey data for the two coal companies, six surface mines, and the various pieces of equipment studied. As these data show, the highwall drills generated significantly more ARD than the bulldozers. During four of the sampling days the primary dust collection system on drills 1, 2, 3, and 5 were observed to be malfunctioning, generating some of the highest respirable dust concentrations during these surveys. The collector fan on drill 1 was found not to be operating because the drive belts were either broken or slipped off the drive pulleys. Drill 3 had a badly damaged collector shroud with about one-fourth of the shroud material missing. Drills 2 and 5 had dust escaping underneath the shroud due to sloped and uneven ground conditions. Drill 2 was operated at the edge of the drill bench during a good portion of the shift, making it difficult to seal the area under the shroud.

The dust control problems were rectified on drills 1 and 3

Table 2 - Dust Control Assessment Data

Mine Co.	Mine	Sampling Date	Rotary Rock Drill			Bulldozer		
			Drill No.	Shroud Dust mg/m³ (% SiO_2)	Cab Dust mg/m³ (% SiO_2)	Dozer No.	Outside Dust mg/m³ (% SiO_2)	Cab Dust mg/m³ (% SiO_2)
I	A	11/19/97	*1	10.65 (48.5)	0.29 (42.9)	1	NS	NS
		12/4/97	1	1.43 (45.7)	0.54 (29.3)	1	0.28 (52.7)	0.11 (38.8)
		12/10/97	1	1.14 (49.0)	0.20 (29.5)	1	0.07 (NS)	0.00 (NS)
		12/17/97	*2	14.07 (NS)	1.21 (33.1)	1	0.13 (38.4)	0.14 (24.9)
	B	11/18/97	*3	14.80 (12.3)	0.57 (13.2)	3	NS	NS
		11/20/97	3	2.52 (11.3)	0.09 (NS)	3	NS	NS
	C	6/3/98	3	NS	NS	3	0.23 (47.6)	0.22 (15.1)
		6/10/98	#3,A2	4.56 (42.1)	0.53 (27.3)	3	0.02 (NS)	0.14 (3.8)
		7/29/98	3	4.82 (NS)	0.15 (21.4)	3	0.46 (41.8)	0.14 (8.6)
		8/5/98	3	0.92 (37.4)	0.07 (NS)	3	0.39 (63.2)	0.11 (18.6)
II	D	7/14/98	4	1.64 (16.7)	0.10 (NS)	4	0.52 (40.0)	0.06 (NS)
	E	7/15/98	*5	5.90 (28.9)	0.07 (NS)	5	0.09 (NS)	0.00 (NS)
	F	7/16/98	6	1.04 (27.2)	0.06 (NS)	6	0.45 (24.5)	0.01 (NS)

*****Primary dust controls observed to not be operating properly on the drill during a portion or all of the shift.*
#Dust sampling was conducted initially at drill 3 and continued for the same drill operator who move to drill 2 at mine A.
NS - *No sample was collected or silica percentage was not reported because of low or high sample weights.*

Table 3 Drill Dust Collector System Improvements

Drill No.	Dust Collector Improvements	Pre-Dust Levels mg/m³ (%SiO_2)	Post -Dust Levels mg/m³ (%SiO_2)	% Dust Level Reduction
*1	Put drive belt back on dust collector fan	12.03 (49.1)	5.93 (46.6)	51%
#3	Replaced torn drill shroud, ~ 1/4 of shroud was missing	14.80 (12.3)	2.52 (11.3)	83%
†5	Reduced shroud-to-ground gap, better vertical positioning	21.43 (42.5)	2.47 (25.9)	88%

**The collector improvement and the different dust level measurements occurred during the same shift.*
#The collector improvement and the different dust level measurements occurred between separate shifts.
†The collector improvement and the different dust level measurements occurred during the same shift while drilling at notably different locations on the bench. The pre-dust level sampling was made while the drill was finishing a row of holes in the consolidated overburden at the furthest distance away from the pit edge. Most of the post-dust level sampling was made while drilling holes in unconsolidated (highly fractured) overburden at the pit edge portion of the bench.

through collector system repairs and corrected on drill 5 through lower vertical drill positioning to close the gap between the collector shroud and ground. The pre- and post-dust levels were measured for the collector improvements on drills 1 and 5 during the same shift, while these measurements were made during separate shifts for drill no. 3. Table 3 shows the ARD results obtained for these dust control improvements (Note: drills 1 and 5 shroud dust levels reported in Table 2 are represented by time-weighted averages of the pre- and post-sampling periods measured during the same shift). Fifty-one to 88% reductions in drill dust generated were realized because of these changes.

Dust leakage from the drill shroud was observed to be the worst dust source problem at most of these drills. However, other dust generation sources were also present on these drills. They include: dust escaping through the drill stem seal at the top of the drilling table; dust entrained from the dumping of collector fines on the mine bench; and dust discharged from the collector's exhaust because of impaired filter capture (Maksimovic and Page, 1985). The dust collectors on drills 1, 2, and 3 had no discharge chutes located near ground level, so the fines were dumped from approximately 4 feet off the ground. Drills 4, 5, and 6 had discharge chutes located about 1 foot off the ground. Dust discharged from the collector exhaust was a rare problem and was only observed on drill 3 during its first two days of sampling. The amounts of dust generated from these multiple sources on the drill were likely included in the dust levels measured next to the drill shroud. However, the shroud leakage was felt to be the most significant dust source, because major dust reductions were realized from improving the dust capture of the shroud.

Although the drills were observed to generate high levels of respirable dust, the dust levels in their operator cabs were significantly lower than near their source of generation. Figure 1 shows the ARD levels next to the collector shroud, ARD levels inside the enclosed cab, and the relative percentage decrease in ARD levels between the shroud and inside the cab for the six drills surveyed. Multiple-shift dust concentrations for several of these drills (see Table 2) are represented as time-weighted averages in the graph. These enclosed operator cabs provided better than a 90 percent reduction in dust levels generated by the drill. These results show that enclosed cabs are a key element in controlling the drill operators' dust levels.

Bulldozers generated significantly less dust than the drills, with low dust levels present inside the operators' cabs. Figure

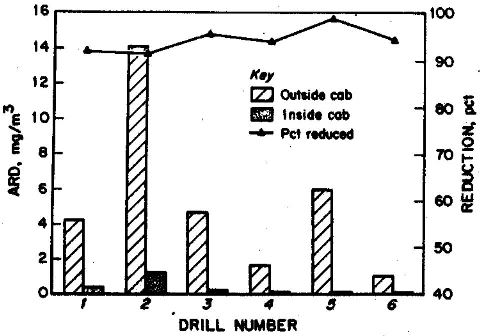

Figure 1. Rotary Drill Dust Summary

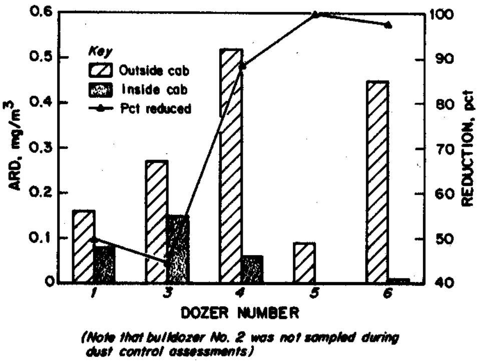

Figure 2. Bulldozer Dust Summary

2 shows the ARD levels above the bulldozer tracks, ARD levels inside the enclosed cab, and the relative percentage decrease in ARD levels between the outside and inside of the cab. Again, multiple-shift dust concentrations for several of these bulldozers (see Table 2) are represented as time-weighted averages in the graph. The dust levels generated by these bulldozers were one order of magnitude lower than the levels generated by the drills. Although the enclosed cabs on the bulldozers provided a more inconsistent percentage reduction in relation to the dust levels generated (between 44 and 100 %), dust levels inside these cabs on average were all below 0.20 mg/m^3. During several of the individual sampling shifts (see Table 2), the dust levels inside the enclosed cab were similar or higher than these measured outside the cab, suggesting that some of the enclosed cab dust may be caused by re-entrainment from within the cab.

Typically, the silica content of the ARD during these field surveys was much higher than 5%; therefore, silica dust exposure is a concern for these highwall drill and bulldozer operators. Over two-thirds of the ARD measurements met this study's silica analysis criteria and are reported in Table 2. Most of the nonreportable silica content had ARD sample concentrations less than or equal to 0.1 mg/m^3. The reportable results indicate that nearly three-fourths of the ARD samples had greater than 20% silica content. A higher percentage of silica dust was commonly observed near the dust generation source as compared to the operator's cab.

Figure 3 shows the average percentage of silica content for the subset of jointly reported data inside the operator's cab and at the generation source for the highwall drill and bulldozer. As this graph shows the average silica content of the dust inside the enclosed operator's cab was less than at the generation source, especially for the bulldozer. These differences were significant at the 88% confidence level for

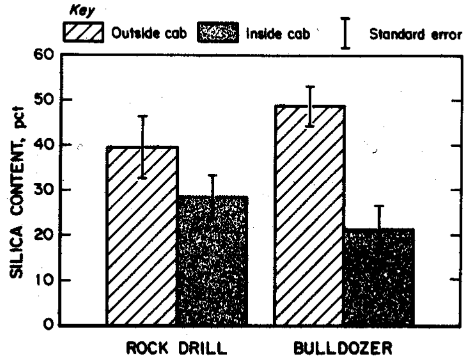

Figure 3. Silica percentages inside and outside the cab

the highwall drill and the 99% confidence level for the bulldozer, for a one-tail t-test statistic. However, this finding was unexpected given that prior highwall drill dust studies have shown that dry or wet control methods reduce the ARD concentrations, but do not notably change the silica content of the dust (Organiscak and Page, 1996; Organiscak et al., 1990). Dust collector reductions achieved at three of the drills during this study showed that silica percentage in the dust remained similar for 2 out of the 3 drills studied (drills 1 and 3 in Table 3). Drill 5 had both the dust levels and silica percentages reduced, but the suspected reason for the silica content reduction in the dust is that drilling took place at two very different areas of the drill bench during these dust measurements (see Table 3). The notable silica content differences observed inside and outside the enclosed cabs during this study are presumed to be due to some of the ARD present inside these cabs was likely generated by another lower-silica dust source from within the cab. Dried mud and/or dirt buildup was observed on the floor in many of the cabs and may have been re-entrained by operator movement and recirculating airflow in the cabs.

These field assessments demonstrate that in order to achieve low equipment operator exposure to silica dust, all the engineering controls require quality upkeep with good operating practices followed. The ARD concentration inside the operator cabs had a significant positive correlation, at the 99% confidence level, with the ARD concentration at the generation source (data from Table 2). This positive ARD correlation explained 54% (correlation squared, r^2) of the dust-level variation between the enclosed operator cab and the generation source. Since both of these dust levels are directly related, all the engineering controls need to be operating effectively to abate operator dust exposure. A particular example of this dust control interrelationship can be seen by examining the data from drill 3 at mine C (shown in Table 2). Dust levels measured next to the shroud and inside the enclosed cab were similarly reduced by 83% due to the repair of the collector shroud between working shifts.

Poor operating practices by the equipment operator could also be detrimental to the cab's protection from high dust levels. Several examples of how operator practices can affect dust levels inside the cab can be seen from MiniRAM data presented in Figure 4. The operator of drill 4 opened the cab door to collar the next hole, sometimes letting notable amounts of dust into the cab. Although the operator shut the cab door during the drilling operation, the air filtration system consistently took about 7 minutes to adequately remove the airborne dust that was let into the cab. The other drill operators (drills 5 and 6) collared the next hole without opening the cab door. Better work practices by these operators helped to maintain lower dust levels in the operator