2002 SME Annual Meeting
Feb. 25 - 27, Phoenix, Arizona

Preprint 02-037

SILICA DUST SOURCES IN UNDERGROUND METAL/NONMETAL MINES - TWO CASE STUDIES

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ABSTRACT

NIOSH's Pittsburgh Research Laboratory is currently involved in research to identify silica dust generation in underground metal/nonmetal mines. The ultimate goal of this research is to develop control technologies to reduce worker exposure to respirable silica dust. Commodities and job classifications with the highest silica dust exposure have been identified through analysis of the Mine Safety and Health Administration (MSHA) compliance dust sampling database. Dust surveys were conducted in an underground limestone and gold mine to investigate silica dust sources, generation levels, and controls being used. A summary of the mining operations, sampling procedures, resulting data, and suggested methods to improve the dust control will be provided.

INTRODUCTION

Chronic overexposure to respirable silica dust (particle diameter < 10 microns) leads to the progressive lung disease known as silicosis. Historically, overexposure to respirable silica dust in the mining industry has been well documented through MSHA compliance sampling for select occupations. United States Bureau of Mines (USBM) research addressing silica dust sources and worker exposure had mainly focused on surface and underground coal mining and surface processing operations for the nonmetal mining industry. Numerous studies were conducted which have lead to the development of improved control technologies for reducing silica exposure in high-risk occupations in these operations. However, studies addressing silica dust occurrence and exposure in underground metal/nonmetal mines had not been a high priority in the USBM dust control research program.

When the health and safety research functions of the USBM were transferred into the National Institute for Occupational Safety and Health (NIOSH), a strategic planning effort was conducted to identify areas of need that warranted new or continued research efforts. MSHA compliance sampling results from 1993 through 1998 for the metal/nonmetal operations indicated that the percent of samples exceeding the Permissible Exposure Limit (PEL) for underground mines, surface mines, and processing plants/mills was 15%, 19%, and 18%, respectively (MSHA, 1993-1998). This data suggests that although underground mines are a smaller segment of the metal/nonmetal operations, the silica exposure hazard for underground miners is approximately the same as that for surface mines and mills. Consequently, a research project was initiated to address worker exposure and silica dust control for the more than 10,000 miners currently employed in over 300 underground metal/nonmetal mines (MSHA, 2000).

Compliance with the respirable silica standard in metal/nonmetal mines is determined by MSHA using the following procedure. An inspector usually selects a worker to be sampled based on the historical sampling record of the mine or occupations at high risk. The respirable sample is collected on a 37 mm PVC filter after the dust has passed through a 10 mm Dorr-Oliver cyclone preclassifier at a flow rate of 1.7 L/min. Samples are collected for the entire shift. Filters with at least 0.1 mg of weight are analyzed using X-ray diffraction (XRD) (NIOSH, 1994b) for quartz, cristobalite, and tridymite, the three main components of silica dust. Samples with greater than 1% silica are considered compliance samples and the Permissible Exposure Limit (PEL) is determined by the following formula:

$$\text{PEL} = \frac{10}{\%\ \text{silica} + 2}$$

The PEL is expressed as a concentration of respirable dust in milligrams per cubic meter. A citation is issued when the dust concentration is greater than 1.2 times the PEL.

MSHA maintains an underground metal/nonmetal dust sampling database which has detailed silica exposure information concerning commodities, occupations, mines, geographic locations, number of samples taken, and the percentages of samples over the PEL. A study of silica exposure for metal/nonmetal miners from 1988 to 1992 (Watts and Parker, 1995) found that some of the occupations with a high percentage of MSHA inspector samples exceeding the PEL included commodities in underground metal and stone mines. During this period for some commodities, such as silver and copper, more than 50% of the samples exceeded the PEL. Occupations at greatest risk of overexposure included crusher operators, jackleg/stoper drill operators, and scoop-tram operators.

A more recent analysis of the MSHA compliance dust sampling database from 1993 to 1998 (MSHA, 1993-1998) shows that for underground stone and metal mines 15 and 17 percent of the samples exceed the PEL for respirable quartz, respectively. This data was sorted to identify occupations within the commodities with the highest incidence of overexposure. Initial analysis has shown that in the stone industry, most silica overexposures have historically occurred in the crushed limestone commodity. The occupations most at risk include truck drivers, crusher operators, front-end loader operators, and rotary drill operators. On average, 20 to 25% of the samples from these occupations exceed the PEL. In the metal industry, gold ore has the most quartz overexposures. Occupations most at risk include front-end loader operators, truck drivers, and rotary drill operators.

To address these issues, NIOSH's Pittsburgh Research Laboratory is currently involved in research to identify silica dust generation in underground metal/nonmetal mines. The ultimate goal of this research is to develop control technologies to reduce worker exposure to respirable silica dust. Dust surveys were conducted at two mines, a crushed limestone mine located in Pennsylvania and a gold mine located in Nevada. In the case of the limestone mine, a dust survey was conducted at an underground dump/crusher facility to quantify dust levels before the potential installation of an improved ventilation system designed to reduce dust at the location. In the case of the gold mine, a survey was conducted on trucks drivers to determine which activity during the haulage cycle generated the greatest potential for exposing the operator to silica dust.

SAMPLING INSTRUMENTS

Two types of dust sampling instruments were used in these studies. The first type and primary dust measuring instrument was the gravimetric sampler operated at 1.7 L/min with the 10 mm Dorr-Oliver cyclone and a 37 mm PVC filter. The pumps featured automatic compensation for changes in temperature and altitude, but calibration was checked at the mine site using a primary standard to within plus or minus 2.5%. The filters were weighed before and after sampling to calculate overall respirable dust concentrations (which includes all dust types and particulate) based on the sampling rate and time. The filters were then analyzed using XRD to determine the silica weight, so that the silica concentrations could be calculated.

The second type of sampling instrument was the MIE personal DataRAM (pDR). The instrument was operated in the active mode to monitor respirable dust. Before entering the unit, dust in classified using a 10 mm Dorr-Oliver cyclone and a pump operated at flow rate of 1.7 L/min. The pDR measures and records the concentration of respirable airborne dust (which again includes all dust types and particulate) using a light scattering technique. Light-scattering instruments offer only a relative measure of concentrations but provide a continuous record of dust levels so that concentrations can be evaluated over any time interval during the sampling period.

LIMESTONE MINE - SAMPLING AT A DUMP/CRUSHER

Sampling Strategy

Approximately 50% of all underground limestone mines have their crushers located underground (NIOSH, 1999**)** which can be a major source of silica as well as nuisance dust. In this particular case study, the mine is considering different methods of controlling dust at their underground crusher using either a push-pull ventilation system or a fan-powered dust collector. NIOSH and mine personnel agreed to complete a dust study to quantify dust levels being generated by the current operation. This would be accomplished by area sampling at key locations around the crusher to determine the dust levels generated from the dumping and crushing operations and to identify potential zones of high dust concentration.

Current dust controls for this study consisted of a 37.1 kw (50 hp) blowing fan positioned inby the crusher (as shown in figure 1) which attempts to blow dust away from the crusher and down the belt entry into the return airway.

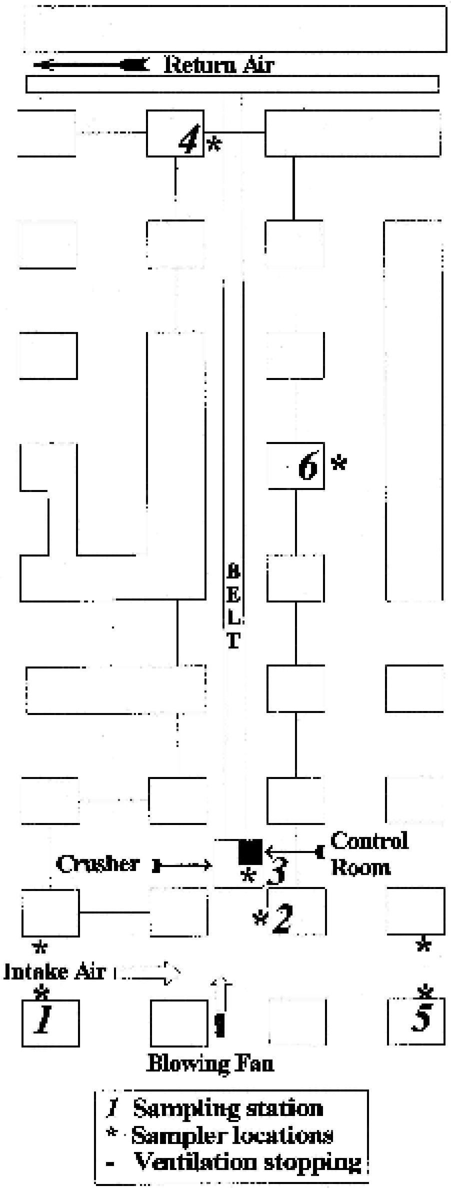

Figure 1. Location of the 37.1kw blowing fan and sampling stations at the crusher area.

Table 1. Dust Samplers Utilized in the Limestone Mine Survey

		Sampling Instruments		
Site	Location	Gravimetric	pDR	Comment
1	Intake	4	1	2 grav samplers on each rib, pDR on one rib
2	Dump	3	1	all samplers on rib upwind of dump site
3	Crusher	3	1	samplers at control booth above crusher
4	Belt	3	1	inby open mandoor in stopping at return
5	Return	4	1	2 grav samplers on each rib, pDR on one rib
6	Entry PP	2	0	on rib in entry parallel to belt entry

Table 2. Production and Air Velocity Measured During Sampling

Shift Number	1	2	3
Number of trucks	129	128	107
Measured tonnage, metric tons (short tons)	4624 (5098)	4711 (5194)	4214 (4647)
Average air velocity, m/s (fpm)	2.8 (565)	2.6 (506)	2.3 (460)

The crusher is a 222.6 kw (300 hp) jaw type rated at 907 t/h (1000 stph) The belt entry is isolated from the main developments using both permanent and curtain stoppings in crosscuts along its entire length of approximately 152 m (500 ft). A spray bar system was used at the dump location to control dust during the truck dumping operation. The crusher operator was located in an enclosed booth that was equipped with a pressurization and filtration system. Any personnel entering or working in the vicinity of the crusher were required to wear personal protective equipment.

Table 1 identifies the types of dust samplers that were positioned at each sampling location, while figure 1 illustrates the relative location of these sampling stations

Samples were collected for three consecutive days with an average sampling time of about five hours per shift. Other information related to dust production and migration were collected each day during the sampling period. During this time, the number of trucks that dumped and the tonnage processed through the crusher were recorded. In addition, anemometer readings were taken at a doorway at the end of the belt entry leading to the return to monitor airflow from the crusher to the return airway. This information is given in table 2 and shows consistent values for all three sampling days.

Results

Figures 2 and 3 summarize the average concentrations for the 3 sampling days for the respirable dust and silica dust, respectively. In figure 2, the respirable dust concentration is most likely composed of three main components: inert limestone dust or calcite, diesel particulate, and silica. Filters were sent to an independent laboratory for XRD silica analysis, which included quartz, cristobalite, and tridymite. The analysis only found quartz mineral on the filter. Figure 3 shows the concentrations of quartz at the six locations around the crusher.

For each sampling location, the mean and 95% confidence interval were calculated. The graphs in figures 2 and 3 plot the mean concentration and the upper and lower confidence limit (UCL and LCL) for each sampling location. In examining all locations, the following is notable for each:

Site 1- Intake: This station had respirable and silica concentrations of 0.42 and 0.06 mg/m^3, respectively. These dust levels were the lowest observed from all locations and indicates that very little if any dust is migrating from the crusher back into the main developments on the intake side.

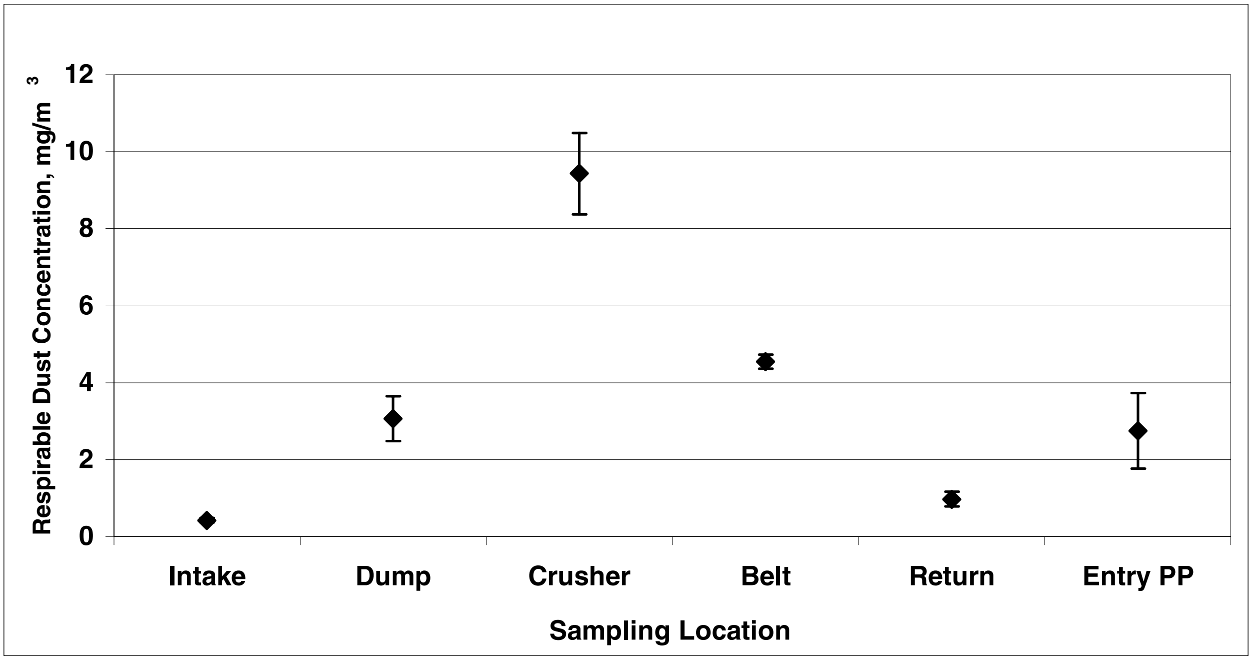

Figure 2. Respirable dust concentrations at the six locations around the crusher.

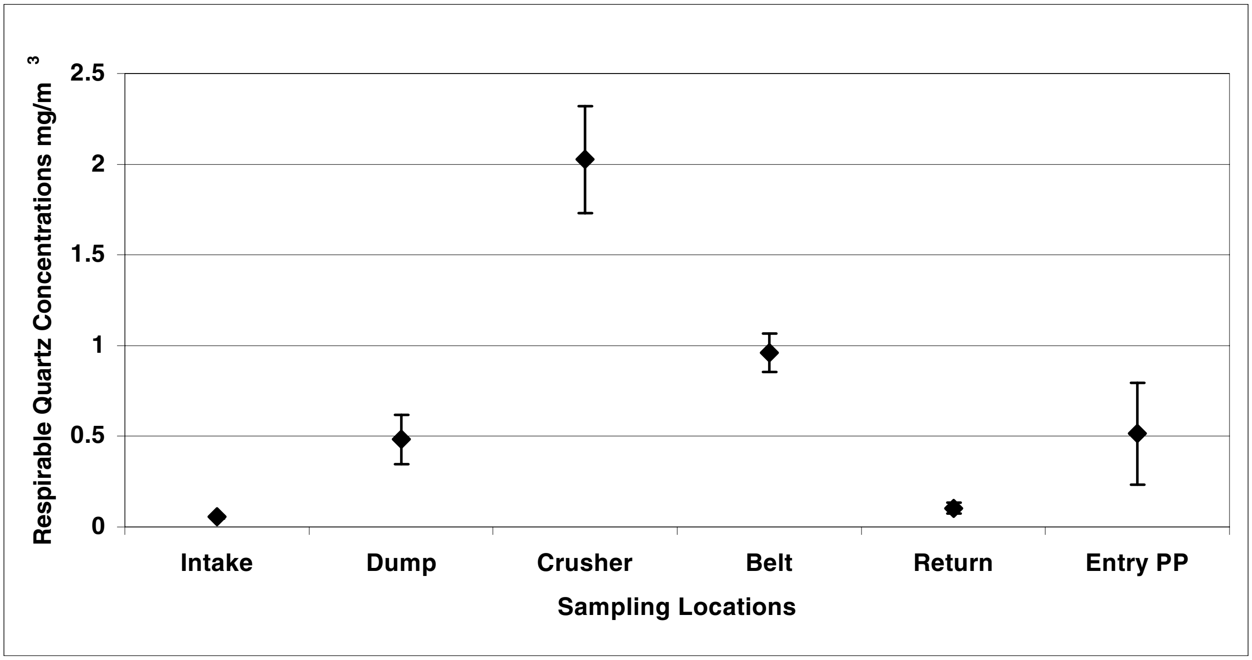

Figure 3. Respirable quartz concentrations at the six locations around the crusher.

Site 2 - Dump: When compared to the crusher and belt, this station has low respirable and silica concentrations. This suggests that the 37.1 kw (50 hp) fan is preventing dust rollback from the crusher as the trucks dump.

Site 3 - Crusher: This location had the highest concentrations of both respirable and silica dust. Of interest, is the fact that respirable concentrations increase threefold from the dump to the crusher location, a distance of roughly 18.2 m (60 ft). This indicates that the current fan is preventing dust migration back from the crusher, but lacks the ability to effectively move it away from the crusher. Observation from inside the operator's booth showed that during the dumping cycle a large plume of dust was created but the low air movement allowed the dust to remain around the crusher for an extended period of time. Stratification or layering of the air may be causing this effect as the fan is suspending the dust above the crusher, but is ineffectual in removing it.

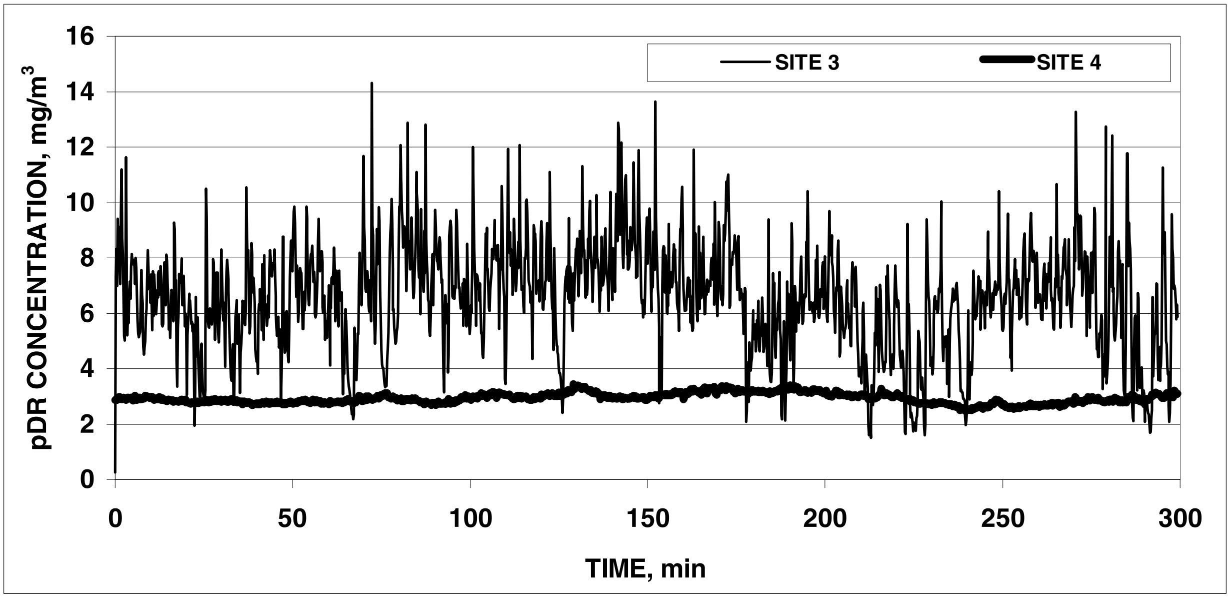

Figure 4. Comparison of dust patterns from pDRs at site 3 (crusher) and site 4 (belt).

Site 4 - Belt: Both the respirable and silica dust concentrations at the belt location are half of the levels at the crusher, at a distance of approximately 152 m (500 ft). The pDR concentration graphs from the belt were characterized by very consistent levels of dust throughout the sampling period when compared to the pDR graphs from other locations, which usually showed spiked traces of high and low concentrations. The pDR graphs in figure 4 illustrate the difference in dust patterns between the two sampling stations for a typical day of sampling. Since the dust is well diluted and uniform when it reaches the end of the belt this indicates that the fan air is slowly moving the air down the entry, but not very efficiently.

Site 5 - Return: This location behaved much the same as the intake location with low respirable and silica concentrations showing that very little dust is migrating from the dump/crusher back into the main developments on the return side of the crusher. Once again, these samples suggest that the fan is preventing dust rollback from the crusher toward the intake entry.

Site 6 - Entry PP: Dust levels were nearly three times higher than at the return sampling location. This indicates that dust leakage is occurring through the line curtains along the belt entry and this dust has the potential to be carried toward the working faces.

LIMESTONE MINE - CONCLUSIONS

This baseline survey was conducted to evaluate dust generation and migration around an underground crusher during normal production activities. Dust concentrations around the crusher and down the belt entry were higher than desired and could be reduced with improved dust capture. The current fan location is performing a function by clearing dust at the dump and keeping it from recirculating back to the main developments. Either a push-pull system with two auxiliary fans or a fan-powered dust collector is being considered and should provide an effective approach for reducing dust levels. The push-pull system would require a second fan to be placed outby the crusher in the belt entry with exhaust tubing placed as close to the crusher as possible to maximize dust capture. Tubing will then be attached to the blowing side of the fan to transport captured dust directly to the return airway. The second alternative would involve the installation of a fan powered dust collector with filtration system to remove airborne dust and discharge clean air. Either system would increase dust capture at the crusher, thus lowering dust levels at the crusher and in the belt entry. Additionally, less dust would leak through the stoppings into Entry PP.

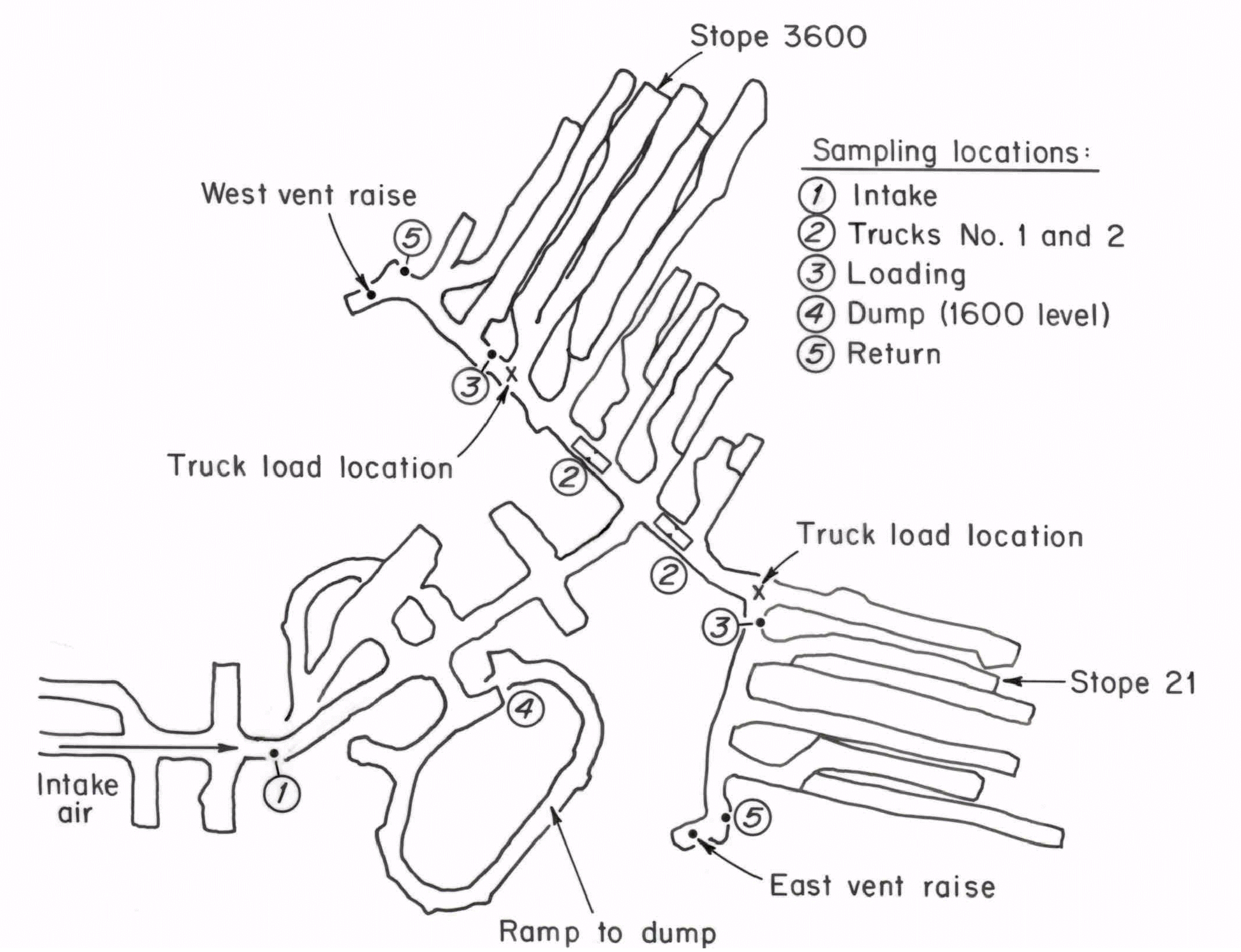

Figure 5. Location of sampling stations on 1750 level.

GOLD MINE - SAMPLING TRUCKS DURING THE HAULAGE CYCLE

Sampling Strategy

Analysis of MSHA compliance dust sampling data has shown that truck drivers are at high risk for silica exposure (MSHA, 1993-1998). The goal of this dust survey was to monitor truck drivers through the loading, tramming, and dumping cycle to profile their dust exposure during these different operations. This was accomplished by positioning a dust instrument package on two different trucks near the operators cab. A time study for each instrumented truck was conducted to document times spent during the shift for four separate operations; loading, tramming full, dumping, and tramming empty. The study provided information to analyze three primary concerns: 1) truck drivers dust exposure during the different operations; 2) the amount of silica dust generated by these operations; and 3) dust exposures for truck drivers working in dry versus wet stopes. A total of six sites were selected for area sampling and are shown in figure 5. Two were located on the trucks, one at the primary dump, and the remaining three within the stopes. The samplers used at each sampling locations are identified in table 3.

Samples were collected for three consecutive days with an average sampling time of about five hours per shift. Other information related to dust production and migration were collected each day during the sampling period. During this time, the total number of trucks that loaded and dumped and the estimated tonnages were recorded. A time study which logged the loading, tramming, and dumping times for the two instrumented trucks was also conducted. The condition of the muck, whether wet or dry, was also noted for each day. Anemometer readings were taken daily at two locations on the intake drift. Table 4 summarizes this information.

Results of Gravimetric Samplers

Gravimetric samplers were located at all six location but only the filters at the dump location, load location, and on the two trucks were analyzed for silica. The total filter weight is most likely composed of three main components: inert dust from the host rock, diesel particulate, and silica. Filters were sent to an independent laboratory for XRD silica analysis, which included quartz, cristobalite, and tridymite. The analysis only found quartz mineral on the filter.

Table 3. Dust Samplers Utilized in the Gold Mine Survey

Site	Location	Sampling Instruments		Comment
		Gravimetric	pDR	
1	Intake	2	1	samplers on rib outby truck haulage route
2	Trucks	4	2	2 gravimetric and 1 pDR at cab on each truck
3	Loading	2	1	samplers on rib 6.1 m (20 ft) downwind of the loading point
4	Dump	2	1	samplers on rib outby dump point
5	Return	2	1	samplers near return air vent raise

Table 4. Production and Airflow Measured During Sampling

Day	Trucks 1 and 2		All Trucks		Muck	Intake Location 1		Intake Location 2	
	No.	Metric Tons (ShortTons)	No.	Metric Tons (Short Tons)		Velocity m/s (fpm)	Quantity cms (cfm)	Velocity m/s (fpm)	Quantity cms (cfm)
1	15	299 (330)	25	498 (550)	Dry	3.6 (695)	105.9 (224,485)	1.3 (245)	37.3 (79,135)
2	9	179 (198)	20	439 (484)	Dry	2.1 (415)	63.2 (134,045)	0.84 (165)	25.1 (53,295)
3	24	479 (528)	45	1027 (1,133)	Wet	2.9 (565)	86.1 (182,495)	1.9 (385)	58.6 (124,355)

Table 5 summarizes average values obtained at each location during the three days of sampling.

Several notable observations can be made from this data. First, the intake location has very low dust levels indicating that the air coming into the stope is very clean. Second, both the respirable and quartz concentrations at the trucks, loading, and return locations are very similar indicating consistent ventilation patterns in the stopes. Third, the dump location had respirable and quartz concentration values almost three times higher than the stopes. This difference is attributed to the dump being at a different level with different ventilation patterns and the muck being dumped quicker compared to being loaded in the stopes, thus generating more dust. However, additional differences in dust levels over the three days of sampling are apparent. Analysis comparing the impact of tonnage mined each day and the condition on the muck (wet or dry) will be discussed.

Figure 6 shows the relationship between quartz generation and the condition of the stope being loaded that day. On the first and second days of sampling, the condition of the muck in the stope was considered dry, on the third day the muck was much wetter. One method to show this relationship is to graph tonnage produced versus the actual quartz weight on the filter, rather than the quartz percentage. The reason being is that the percentage value can be influenced by other dust and particulate on the total filter mass. Figure 6 graphs the total tonnage loaded each day for instrumented trucks 1 and 2 versus the average weight of quartz on the filter for trucks 1 and 2 combined for each day. As shown in the figure, the tonnage on the last day was about 40% more than the first two days, yet the quartz generated by a wet muck was approximately 28 % less than that produced by a dry muck.

Results of pDR Samplers

To further quantify the different dust sources and the condition of the muck (dry or wet) for truck drivers, the haulage cycle was divided into four separate activities: loading, tramming full, dumping, and tramming empty. The pDR samplers were set to log the concentrations at 10 second intervals providing approximately 1,800 data points for five hours of sampling. From the time studies conducted on the trucks, the dust concentrations during each activity were determined by correlating loading, tramming and dump times with those times and concentrations recorded on the pDR's.

Table 5. Respirable and Quartz Dust Concentrations

Sampling Location	Respirable Dust mg/m^3	Quartz Dust mg	Quartz Dust mg/m^3
Intake	0.06	na	na
Truck 1	0.27	0.021	0.040
Truck 2	0.33	0.022	0.045
Loading	0.39	0.043	0.094
Dump	0.85	0.080	0.179
Return	0.32	na	na

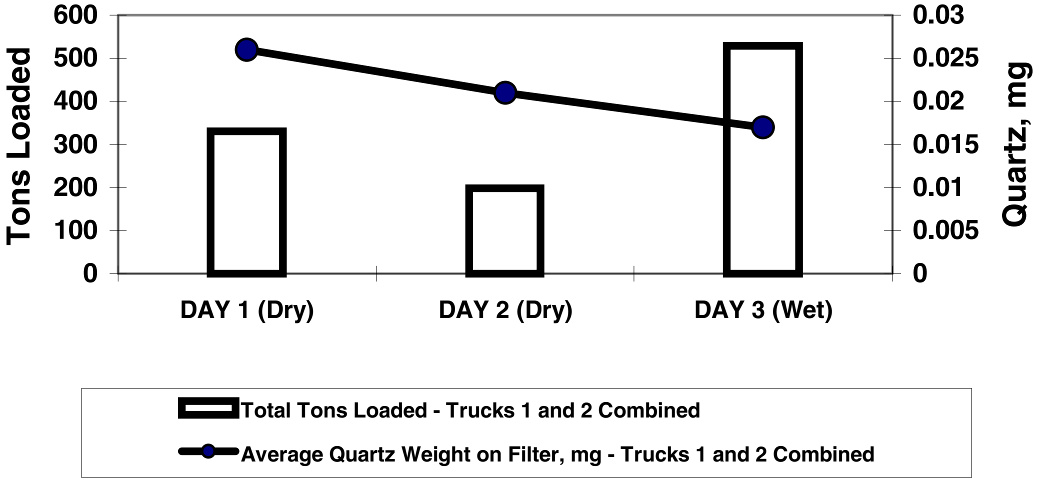

Figure 6. Quartz generation versus condition of stope.

Figure 7 compares the results of the pDR concentrations between dry muck averaged for day 1 and day 2 and the wet muck on day 3. The impact of water on dust levels for truck drivers is especially evident for the loading and dump operations where a 32% and 35% reduction in dust occurs, respectively. Differences in dust levels for the tramming full and empty are not as significant, with concentration ranging from 0.10 to 0.20 mg/m^3. Since the concentrations are actually higher when tramming empty from dumping the wet muck, the condition of the tram roads that day and whether they were wet or dry may be the most likely factor.

Figure 8 shows the time weighted average that each dust source contributes to the entire loading, tramming, and dumping cycle. This pie chart combines the pDR data for both trucks for all three days. Time weighted averaging is a commonly used method to determine dust exposure during activities of different time durations and dust concentrations. This method is more representative of dust exposure during the cycle than using just the concentration data. Multiplying the survey average time by the survey average concentration gives the time weighted average for that activity. The percent contribution of each dust source can then be determined.

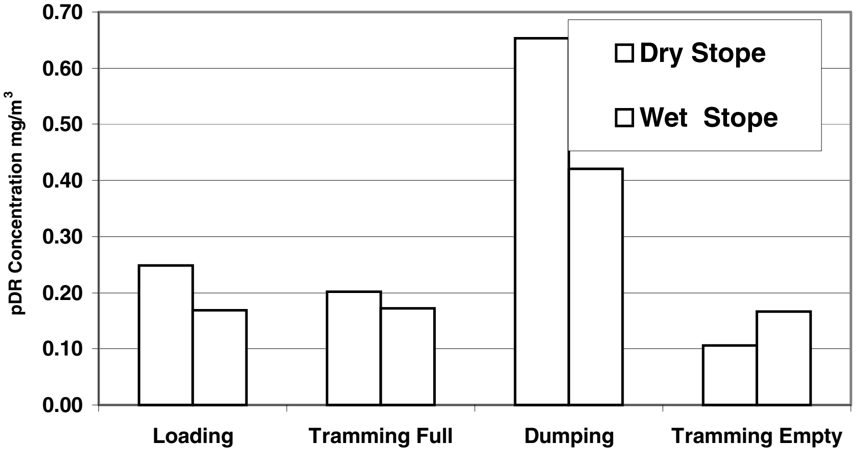

Figure 7. Impact of water on truck dust levels.

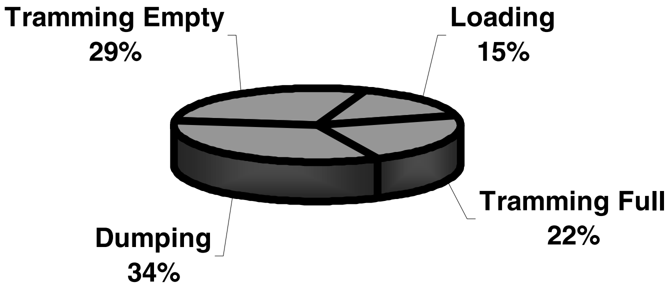

Figure 8. Time-weighted-average dust source contributions for trucks 1 and 2 combined.

As shown in figure 8, the primary dust source for truck drivers is the dump which accounts for 34% of a truck drivers exposure. This is in agreement with figure 7 which shows the highest concentration of dust also occurs during this activity whether the stope is wet or dry. The next highest source occurs when the trucks are tramming with 29% occurring when empty and 22% when full. Finally, loading accounts for 15% of the total dust during the cycle.

GOLD MINE - CONCLUSIONS

The purpose of this study was to identify major dust sources for truck drivers and quantify dust generation from these sources. Dust results show three primary findings:

1. The three days of sampling on the trucks produced data which quantified the quartz found near the truck drivers' cab during a typical working shift. This is illustrated by the summary data in table 5 which shows an average silica exposure for the three days of sampling of 0.040 and 0.045 mg/m^3 for trucks 1 and 2, respectively.

2. A major source of dust exposure for the truck drivers was unloading the truck at the dump (figure 8). The data from the pDR's positioned on the trucks as well as gravimetric sampling results at the dump confirm that the dump is a high source of dust. Respirable dust from the loading operation had the lowest contribution of dust exposure indicating that there is little roll back of dust during loading.

3. The benefit of keeping the muck wet to reduce quartz generation was evident in this study. This relationship is depicted in figures 6 and 7. Figure 6 graphs the quartz weight (from the gravimetric samplers on the trucks) versus tons loaded during the shift. As shown in the figure, the tonnage on the last day was about 40% more than the first two days, yet the quartz generated by wet muck was approximately 28 % less than that produced by dry muck. Figure 7 graphs the results from the pDR data and shows that the impact of water on dust levels for truck drivers is especially evident during the loading and dump activities where a 32% and 35% reduction in dust occurs respectively when the muck is wet.

DISCUSSION

Gravimetric and instantaneous dust samplers were utilized to isolate and quantify dust generation from different sources and at multiple sampling locations in an underground limestone mine and an underground gold mine. This sampling indicated that significant quantities of silica dust can be generated in these operations and that improved controls are warranted. Ventilating air and water have been the primary dust control technologies applied throughout the mining industry. It appears that improved application of these controls at these mines would reduce dust levels.

At the limestone mine, significant amounts of dust were generated at the underground crusher by the dumping and crushing operations. An auxiliary fan was installed in a blowing mode to direct intake air over the haul trucks toward the crusher. It appears that this fan prevented dust rollback into the intake entry but did not quickly remove dust from the crusher. Sampling also indicated that dust leakage was occurring through the belt entry stoppings. The mine is considering two options to reduce dust levels at this location. The first option is a push-pull ventilation system where a second fan will be positioned outby the crusher and operated in an exhaust mode. Ventilation tubing will also be installed with this fan to capture dust at the crusher and carry it directly into the main return entry. The second option is the installation of a fan-powered dust collector. The collector will be positioned to capture dust-laden air at the crusher, filter dust out of the air, then discharge clean air down the belt entry. Installation of either system should substantially reduce dust around the crusher and reduce dust leakage from the belt entry.

At the gold mine, dumping at the crusher also was a major source of dust generation. Ventilation was provided at the dump site, which flowed from the haulage entry into the crusher area. This ventilation provided protection for the truck driver during the dump cycle but forced dust toward the crusher operator. Fortunately, the crusher operator was located in a booth with fresh air supplied to the booth. Sampling results also indicated that wet muck liberated far less dust than when the muck was dry. Normal operating procedures at the mine did require wetting of the muck pile prior to loading. Unfortunately, the long-hole-open-stoping method of mining made wetting the muck difficult at times. However, these results illustrate the benefit of this procedure and methods to improve the application of water to the muck pile should be pursued.

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