

# Assessment of occupational silica exposures on continuous mining operations

G.V.R. Goodman, J.M. Listak and J.A. Organiscak

Mining engineers, Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, Pennsylvania

## Abstract

*Data on dust-control practices, mining conditions and occupational exposures were gathered for approximately 80 underground continuous mining units. Despite silica contents on dust samples in excess of 5%, nearly forty units successfully maintained silica concentrations at or below 100 µg/m<sup>3</sup> on a majority of occupational dust samples, while the remainder had difficulty maintaining this level. These two sample sets were termed Group A operations and Group B operations, respectively. This data was compared to identify causes of high occupational silica dust exposures. Analyses of dust-control parameters and geologies revealed only minor differences between these two groups. However, subsequent comparisons of face ventilation design showed considerable differences in silica exposure and silica content between Group A and Group B at the continuous mining machine and roof bolter operator occupations. These differences were minimal when using exhaust curtain ventilation with a dust scrubber. This face ventilation system can benefit operations having difficulty controlling silica dust exposure and silica dust content. The collected data also showed that occupational samples from Group B operations possessed generally higher silica exposures and silica content than similar samples from Group A. The single head roof bolter (helper) possessed among the highest silica exposures and silica contents in both groups.*

## Introduction

The Federal Coal Mine Health and Safety Act limits the respirable dust exposure of mine workers to a time weighted average of 2.0 mg/m<sup>3</sup> for a working shift (Code of Federal Regulations Title 30, Parts 70 and 75). If the respirable dust sample contains more than 5% silica by weight, the dust standard is reduced according to the formula  $10 \div (\% \text{ silica})$ . This maintains silica dust levels at or below 100 µg/m<sup>3</sup> for all dust samples.

The process of adjusting the respirable dust standard is discussed by others, including Jankowski and Niewiadomski (1987), Ainsworth et al. (1995) and Tomb et al. (1995), and is based on the silica content of dust samples collected by coal mine operators and by Mine Safety and Health Administration (MSHA) coal mine inspectors. Such sampling is conducted for eight hours at 2.0 L/min using a 10-mm nylon cyclone preseparator. On continuous mining operations, samples analyzed for silica content are typically collected at mining machine operator and roof bolter operator occupations.

Mining machine operator samples (typically the dustiest occupation at each production unit) are used to adjust the respirable dust standard for the entire mining unit with the understanding that the reduced standard will protect all other occupations. However, because of a variety of factors (Colinet et al., 1985), silica dust levels at roof-bolter occupations often can exceed silica levels found at the continuous mining machine. To provide additional protection, MSHA may require more frequent sampling of roof-bolter occupations by the mine operator.

A number of studies have defined trends in silica dust exposures for the underground coal mining industry (Ainsworth

et al., 1995; Tomb et al., 1995). These analyses revealed that, for the period from July 1991 through 1992, more than 40% of the continuous mining machine operator and machine helper samples exceeded 5% silica. Between 25% and 30% of the operator and helper samples exceeded 100 µg/m<sup>3</sup> for respirable silica. For this same period, roughly 50% to 70% of the roof-bolter operator and helper samples exceeded 5% silica, and 30% to 40% of the samples exceeded 100 µg/m<sup>3</sup>.

## Data collection

Two groups of continuous mining operations were compared to identify potential causes of high occupational silica dust exposures. One group, despite high silica dust contents on the dust filters, successfully controlled occupational exposures. The second group could not control these exposures. Information on dust-control practices, mining conditions and occupational exposures was gathered and compared for operations in each of these two groups.

Due to the large number of underground coal mining operations represented in the database and the need to gather dust plan and MSHA exposure data from each operation, only a very small subset of these operations could be considered for the study. For this reason, several restrictions were placed on the selection of a particular mining operation.

Only operations in southern West Virginia, southwestern Virginia, northeastern Kentucky and southeastern Kentucky were considered. Prior to the start of this study, MSHA suggested that these areas be considered due to the high prevalence of silica exposures.

For this study, two groups of operations were identified in each area. The first group contained those operations with a

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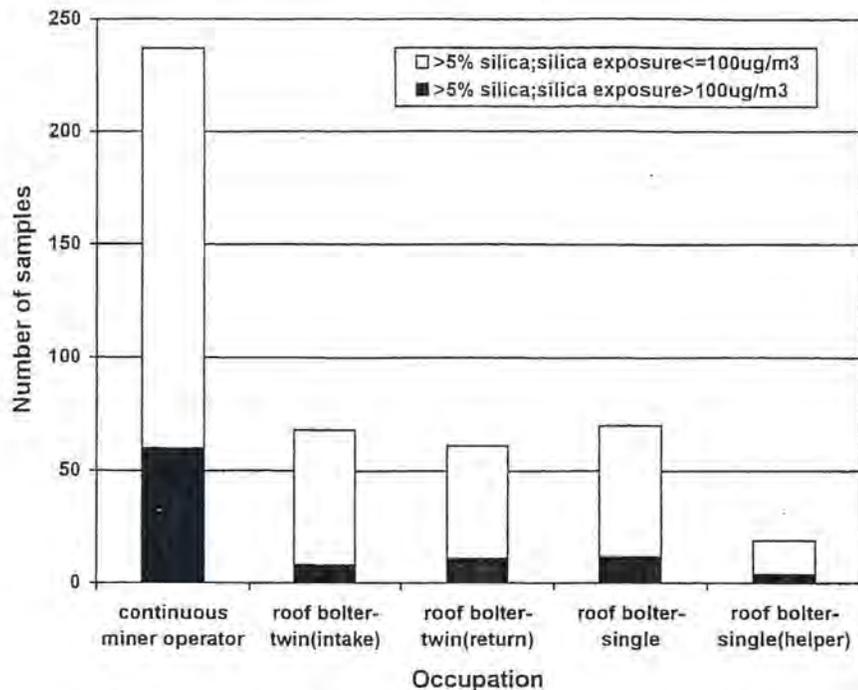


Figure 1 — Distribution of occupational silica exposures (Group A operations).

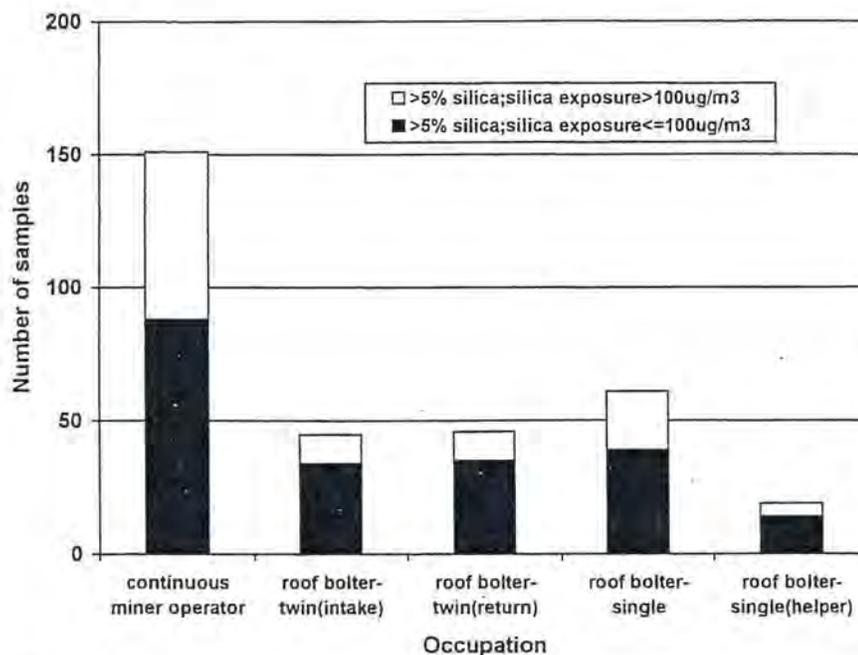


Figure 2 — Distribution of occupational silica exposures (Group B operations).

majority of samples exceeding 5% silica and having silica dust concentrations less than or equal to  $100 \mu\text{g}/\text{m}^3$  (Group A operations). The second group contained those operations with a majority of samples exceeding 5% silica and having silica dust concentrations greater than  $100 \mu\text{g}/\text{m}^3$  (Group B operations). Initially, 80 operations were considered in this study, 40 operations that were able to maintain respirable silica dust levels on a majority of compliance samples at or below  $100 \mu\text{g}/\text{m}^3$  and 40 operations that were unable to maintain a majority of samples below this level.

When this survey began, October 1997 compliance sampling data was the most current available from MSHA. These operations were selected based on the results of MSHA

compliance sampling at the continuous mining machine operator and roof bolter operator occupations for the period January 1997 to October 1997 (Mine Safety and Health Administration, 1999). To keep this information as current as possible, pre-1997 sampling data was not used.

During visits to the various MSHA field offices, it was discovered that some operations were no longer producing. Because current exposure data was not available for these operations, they were dropped from further consideration. As a result, the study examined 39 underground coal-mining operations in Group A and 36 operations in Group B. These operations were selected from a population of nearly 700 in these geographic areas.

Information on approved dust-control practices is part of the dust-control plan established for each underground coal operation. Considerable detail on dust-control parameter levels, mining conditions (rock thickness and coal thickness), plus corresponding occupational exposures were found in reports filed by MSHA coal mine inspectors after sampling at an operation. Because equivalent detail was not available with mine operator compliance samples, only MSHA compliance sampling data was used. Unfortunately, this likely introduced some variability into future analyses.

MSHA field offices were visited and data gathered on approved dust-control practices for each of the selected underground mining operations in that district. Mine inspector reports for these operations dating from January 1997 to an approximate end date of June 1998 to October 1998 (end dates differed because the districts were not visited in the same month) were reviewed to obtain actual dust-control parameter levels and mining conditions. The corresponding occupational exposures to respirable silica dust also were gathered (Figs. 1 and 2).

The information representing operations in Group A was compared to that representing operations in Group B to identify any similarities and differences

in dust control parameter levels and mining conditions. Although, by definition, occupational silica exposures at Group B operations exceeded those at Group A operations, this work established potential influences of dust-control parameter level or mining conditions on exposure levels.

### Evaluation of general characteristics

General characteristics for Group A operations and Group B operations are given in Table 1. These include daily tonnage produced, coal thickness mined and rock thickness mined during sampling by the MSHA mine inspector. Also given are values for various dust-control parameters (face ventilation air quantity, scrubber air quantity, water spray count on the

**Table 1 — Characteristics for operations in two sample groups.**

Characteristics	Group A operations					Group B operations				
	Number of samples	Range of values	50 <sup>th</sup> percentile value	75 <sup>th</sup> percentile value	90 <sup>th</sup> percentile value	Number of samples	Range of values	50 <sup>th</sup> percentile value	75 <sup>th</sup> percentile value	90 <sup>th</sup> percentile value
Production (st)	384	96-2,700	600	950	1393	226	85-2,520	572	1,023	1,527
Coal thickness cut (in.)	318	4-108	48	58	69	162	0-126	42	52	69
Rock thickness cut (in.)	336	0- 60	8	14	24	162	0-96	8	14	21
Dust plan face ventilation airflow (cfm)	336	3,000-9,700	4500	6,000	6,500	206	2,500-10,000	4,500	6,000	7,500
Measured face ventilation airflow (cfm)	325	1,080-49,500	6462	9,000	13,640	203	2,024-45,360	6,500	8,188	11,824
Dust plan scrubber airflow (cfm)	222	3,400-9,700	4500	6,200	7,300	105	2,500-8,500	5,000	5,500	6,100
Measured scrubber airflow (cfm)	133	3,000-11,600	5034	6,552	8,067	53	2,580-13,099	5,600	7,074	8,437
Dust plan spray count on mining machine	319	16-50	26	30	35	201	14-40	23	30	35
Measured spray count on mining machine	313	18-50	27	30	36	188	14-58	25	33	39
Dust plan water spray pressure (psi)	315	50-200	89	90	100	199	50-120	60	80	92
Measured water spray pressure (psi)	313	50-280	90	100	125	195	50-260	85	100	113

Dust plan values are levels specified in the dust control plan of that operation.  
 Measured values are those measured by the coal mine inspector prior to or during MSHA sampling.  
 Face ventilation airflow is the amount of air flowing to the continuous mining machine.  
 Spray count is the number of sprays on the mining machine. In both groups, hollow and full cone sprays placed on cutting boom for dust control purposes. Venturi/fan sprays placed along machine frame in air moving capacities.  
 cfm = cubic feet per minute; psi = pounds per square inch

continuous mining machine, and water pressure on this machine) specified in the approved dust-control plan of each operation and measured by the coal mine inspector during occupational sampling.

The range of values is given for each characteristic. In addition, 50<sup>th</sup>, 75<sup>th</sup> and 90<sup>th</sup> percentile values provide a means for categorizing the distribution of data for each characteristic. Differences in sample size between Group A and B operations are attributed to the number of operations in each group and the extent of sampling at each operation.

This data shows small differences in dust-control parameters and mining conditions (coal thickness and rock thickness) for operations in Groups A and B. Minor differences were evident, with Group B producing roughly 10% more at the 75<sup>th</sup> and 90<sup>th</sup> percentile levels than Group A. Ranges of coal and rock thicknesses were greater for Group B operations than Group A operations. Distributions of dust plan and measured face ventilation airflows were similar for operations in Groups A and B. Group A operations generally had greater scrubber airflow quantities specified in their dust plans, although Group B operations possessed the greater scrubber airflows when measured. Water spray count and spray pressure were consistent between the two groups, with most operations placing hollow or full cone sprays on the cutting boom for dust suppression. Other spray designs, such as venturi and fan, were located along the body of the mining machine, and these were likely to induce additional airflow in this region.

Although data were available on rock thickness, little information was available on the composition of rock being

cut. Previous work (Taylor et al., 1986; Organiscak and Jankowski, 1990) showed that the silica content in the roof, floor or parting material could influence the amount of respirable silica generated during the mining process.

Previous work showed that a number of factors could potentially impact occupational silica dust exposures and silica dust contents in underground coal mining. Dust-control practices such as ventilation airflow, flooded-bed dust scrubber air quantity, water spray quantity and pressure, and water spray configuration influence silica dust exposures (Jankowski and Niewiadomski, 1987). When evaluating the collected data, silica exposures were assumed as indicators of dust control effectiveness on that mining unit.

Work practices affect silica content, for instance, using a modified cutting scheme to avoid grinding of parting rock (Jankowski and Niewiadomski, 1987), avoiding the use of worn cutting bits (Organiscak et al., 1995), minimizing the time the roof bolter works downwind of the continuous mining machine (Colinet et al., 1985) and maintaining dust control systems. Geologic conditions at the mining unit (such as rock parting type, thickness and silica content) affect silica content (Taylor et al., 1986; Organiscak et al., 1990). For these analyses, silica contents were assumed as indicators of work practices and/or geologic conditions on the mining unit.

### Assessments of face ventilation

Reviews of coal mine inspector reports detailed the types of face ventilation systems used at each operation in Groups A and B (Table 2). Four basic types of face-ventilation systems were noted. The first was an exhaust-ventilation curtain with

**Table 2** — Distributions of occupational silica contents and continuous mining machine operator occupations for various face-ventilation schemes (50<sup>th</sup>, 75<sup>th</sup> and 90<sup>th</sup> percentiles).

Ventilation scheme	Group	Number of samples	Range of silica exposure, $\mu\text{g}/\text{m}^3$	
Exhaust curtain with scrubber	A	59	16-312	
	B	31	1-532	
Exhaust curtain with directional spray designs	A	57	2-260	
	B <sup>1</sup>	31	20-946	
Combination curtain scheme	A	62	3-549	
	B <sup>2</sup>	55	8-1,149	

0 100 200 300  
Silica exposure ( $\mu\text{g}/\text{m}^3$ )

Ventilation scheme	Group	Number of samples	Range of silica contents, %	
Exhaust curtain with scrubber	A	59	1-17	
	B	31	0-16	
Exhaust curtain with directional spray designs	A	57	0-14	
	B	31	2-25	
Combination curtain scheme	A	62	0-23	
	B	55	3-34	

0 10 20 30  
Silica content (%)

<sup>1</sup> 90<sup>th</sup> percentile silica exposure = 490  $\mu\text{g}/\text{m}^3$   
<sup>2</sup> 90<sup>th</sup> percentile silica exposure = 470  $\mu\text{g}/\text{m}^3$

values. Exhaust curtain with scrubber led to the lowest 50<sup>th</sup>, 75<sup>th</sup>, and 90<sup>th</sup> percentile values among Group B operations. Silica contents were much less for Group A operations than for Group B operations, although the contents did not exhibit much variation between ventilation schemes.

These data suggest that dust control effectiveness for Group A operations was superior to that for Group B operations for all face ventilation schemes. The difference was not as great when using exhaust curtain with a scrubber. The high silica contents in Group B show that this group of operations, compared to those in Group A, suffered from poor work practices and/or geologic conditions.

The data show that differences in Group A and Group B silica exposures were less when using exhaust curtain face ventilation with a dust scrubber. Using either exhaust curtain ventilation with directional sprays or combination curtain ventilation, Group B operations were less able to effectively control occupational exposures.

Operations having difficulty controlling silica dust exposures can benefit from using exhaust-curtain ventilation with a dust scrubber. This system avoids potential problems associated with dust-control schemes using blowing-face curtains or directed sprays. Firstly, face ventilation using an exhaust curtain and a flooded-bed dust scrubber is not affected as much by high intake air velocities as is the one using a blowing-curtain ventilation. Past work showed that high air velocities at the mouth of a blowing curtain

dust control provided by a machine-mounted flooded-bed dust scrubber. The second was an exhaust-ventilation curtain with water sprays arranged in either a sprayfan or other directional face-spray design. The third type was a combination system using intake curtains to ventilate faces on one side of the section belt entry and exhaust curtains to ventilate faces on the other side. This system reduced the number of drive-through check curtains between each face and the feeder-breaker in the belt entry. A flooded-bed dust scrubber provided dust control in this scheme. The final type was an intake or blowing-ventilation curtain with a flooded-bed scrubber for dust control. However, this face-ventilation scheme was not widely represented in the accumulated data and, for this reason, was not evaluated further.

The data shows that all face ventilation designs were equally represented in Group A operations, while Group B operations used combination curtain face ventilation by nearly two-to-one margin over other ventilation schemes. Group A silica exposures generally were much less for all face-ventilation schemes with the exception of the exhaust curtain with dust scrubber. In this case, the 90<sup>th</sup> percentile values were similar for both groups of operations. Although 50<sup>th</sup> and 75<sup>th</sup> percentile silica-exposure levels were similar among the three face-ventilation schemes for Group A, combination curtain ventilation resulted in the lowest 90<sup>th</sup> percentile exposure

could reduce capture of respirable dust by blowing the dust cloud around the mining machine (Schultz and Fields, 1999). Secondly, positioning of the mining machine operator is not as critical to controlling this person's occupational exposure. The operator has some latitude in movement as long as this person remains outby the curtain mouth. When using blowing curtain ventilation, however, the operator must remain within the curtain mouth to control occupational dust exposures (Goodman and Listak, 1999). Thirdly, exhaust curtain ventilation with a dust scrubber does not produce high dust levels around the mining machine, as can occur when using directed sprays. These high dust levels also can affect occupational exposures of the roof-bolter operator if working downwind of the mining machine.

### Assessments of occupational exposures

Data on silica exposures and silica percentages were categorized according to worker occupation for Group A and B operations (Table 3). Much of the exposure data is given for the continuous mining machine operator. The remaining roof-bolter occupations, with exception of the single head roof-bolter (helper), had similar numbers of samples in this study. Silica analyses were conducted for other underground occupations. However, these samples were not very numerous and, consequently, were not reported.

The data shows that silica exposures and silica contents at all occupations were higher for Group B operations than for Group A operations. Variations in exposures and contents suggest that these differences were attributable to changes in dust-control effectiveness, work practices and geologic conditions.

The single head roof bolter (helper) possessed among the highest silica exposures and silica contents in both Group A and Group B operations. This suggests less effective dust controls, inappropriate work practices and poorer geologic conditions at this occupation for Group A and B operations. It is also possible that the bolter helper engaged in activities that put this person at risk for increased exposure to silica. These would include emptying the dust box and cleaning the dust filters.

### Adjusting the respirable dust standard

As stated above, the silica content of the designated occupation (typically the mining machine operator on continuous mining MMUs) is used to adjust the respirable dust standard for the entire MMU. Using the dustiest occupation to adjust the standard insures that the remaining, potentially less-dusty, occupations are adequately protected from overexposures. Group A and B operations were assessed for their abilities to protect other occupations through adjustment of the respirable dust standard using the silica content of the designated occupation. Because of the limited silica analyses conducted on non-roof-bolter occupations, only roof bolter occupations were used as part of this evaluation.

Table 4 shows the results of sampling at the designated occupation and at the RB on the same MMU, on the same shift and on the same day. For Group A operations, 77 occurrences were identified where DO sampling occurred simultaneously with sampling on at least one single head roof-bolter occupation. In 66% of the instances, the silica content of at least one single head roof-bolter sample exceeded that of the DO. However, less than 10% of the samples exceeded the applicable respirable dust standard. Group B operations had a similar percentage of RB samples, with silica contents exceeding those of the DO. In this case, more than 30% of the samples exceeded the applicable respirable dust standard. For twin head roof-bolter operation, nearly three-quarters of the Group A and B samples had higher silica percentages than the corresponding DO samples. Again, less than 10% of the Group A samples exceeded the applicable dust standard, while nearly 40% of the Group B samples exceeded the standard. The levels to which roof bolter silica percentages exceed DO silica percent-

**Table 3** — Distributions of silica exposures and silica contents for various underground continuous mining occupations (50<sup>th</sup>, 75<sup>th</sup> and 90<sup>th</sup> percentiles).

Ventilation scheme	Group	Number of samples	Range of silica exposure, $\mu\text{g}/\text{m}^3$	
Continuous mining machine operator	A	321	1-664	
	B	192	1-1,149	
Twin head roof bolter (intake side operator)	A	77	8-340	
	B	52	10-583	
Twin head roof bolter (return side operator)	A	70	10-329	
	B	54	4-653	
Single head roof bolter (operator)	A	36	0-263	
	B <sup>1</sup>	57	1-1,771	
Single head roof bolter (helper)	A	22	7-644	
	B <sup>2</sup>	20	4-740	

0 100 200 300 400  
Silica exposure ( $\mu\text{g}/\text{m}^3$ )

Ventilation scheme	Group	Number of samples	Range of silica contents, %	
Continuous mining machine operator	A	321	0-37	
	B	192	0-34	
Twin head roof bolter (intake side operator)	A	77	1-23	
	B	52	1-74	
Twin head roof bolter (return side operator)	A	70	2-21	
	B	54	0-27	
Single head roof bolter (operator)	A	36	0-35	
	B	57	0-39	
Single head roof bolter (helper)	A	22	1-17	
	B	20	2-21	

0 5 10 15 20 25  
Silica content (%)

<sup>1</sup> 90th percentile silica exposure = 420  $\mu\text{g}/\text{m}^3$   
<sup>2</sup> 90th percentile silica exposure = 410  $\mu\text{g}/\text{m}^3$

ages for single and twin head roof bolters are larger than found in other work (Ainsworth et al., 1995), but may be attributable to the smaller sample sizes used in this study. Although controlling the silica dust content of roof-bolter samples was a problem of similar magnitude for Group A and B operations, control of silica dust exposures at the roof bolter was very dependent upon general dust-control capabilities. This was clearly a problem for Group B operations, where 30% of the single head roof-bolter samples and 40% of the twin head

**Table 4 — Comparisons of roof bolter and designated occupation sampling results.**

Roof bolter type	Group A operations			Group B operations		
	Number of occurrences <sup>1</sup>	Percent of RB samples > DO silica content	Percent of RB samples > applicable dust standard	Number of occurrences <sup>1</sup>	Percent of RB samples > DO silica content	Percent of RB samples > applicable dust standard
Single head	77	66%	<10%	57	63%	33%
Twin head	85	78%	<10%	44	75%	39%

DO = designated occupation  
 RB = roof bolter  
<sup>1</sup>number of times where sampling occurs simultaneously at DO and RB occupations

roof-bolter samples exceeded the applicable dust standard. The impact of effective dust control was evident in Group A operations, where less than 10% of the RB samples exceeded the dust standard.

### Summary

Information on dust-control parameters, mining conditions and corresponding silica exposures was gathered for nearly forty operations that, despite silica content in excess of 5%, were able to maintain silica dust levels in a majority of occupational samples less than or equal to 100 µg/m<sup>3</sup>. Approximately 40 other operations, unable to maintain a majority of occupational samples less than or equal to 100 µg/m<sup>3</sup>, were also identified. These two subsets were termed Group A and Group B operations, respectively.

Evaluations of dust-control parameters and mining conditions generally revealed only minor differences between Group A and Group B operations. Subsequent analyses of face-ventilation design showed that Group B operations suffered from higher silica exposures and contents at continuous mining machine operator occupations. However, these differences were minimized when using exhaust curtain with a dust scrubber. This face-ventilation system is recommended for operations having difficulty controlling occupational silica dust exposures and contents.

Occupational silica exposures and silica contents were higher for Group B operations than Group A operations. In both groups, the single head roof-bolter (helper) occupation possessed among the highest silica exposures and silica contents. It is possible that this occupation was involved in risky activities such as emptying the dust box and cleaning the dust filters.

A final analysis considered the protection given roof-bolting occupations by adjusting the respirable dust standard with the silica percentage of the designated occupation sample. This revealed similar problems between Group A and B operations in controlling silica dust content, although controlling silica exposures was dependent upon general dust-control capabilities.

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