Study to Assess Respirable Dust Exposures in Underground U.S. Coal Mines

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In 1991 the Mine Safety and Health Administration conducted a special program to assess occupational exposures to respirable coal mine dust in underground coal mines. Priority was given to longwall mining operations, mines with a history of having a problem controlling dust to the applicable standard, and a representative number of all other mines. Measurements were obtained on approximately 720 mechanized mining units (MMUs) representing 615 mines. Respirable dust measurements were obtained on at least five occupations on each MMU. Extensive data were also gathered at the time measurements were obtained on the amount of material extracted and procedures in place to control dust. This article presents the results of occupational exposure measurements and discusses the influence of production and methods used to control dust on occupational exposures. TOMB, T.F.; PELUSO, R.G.; GERO, A.J.; SEILER, J.P.: STUDY TO ASSESS RESPIRABLE DUST EXPOSURES IN UNDERGROUND U.S. COAL MINES. APPL. OCCUP. ENVIRON. HYG. 13(1):62–72; 1998. PUBLISHED 1998 BY AIH.

The Federal Coal Mine Health and Safety Act of 1969[1] (amended in 1977[2]) established mandatory dust standards for U.S. underground and surface coal mines. Effective June 30, 1970, the average concentration of respirable dust in the active workings of underground coal mines was to be maintained at or below 3.0 mg/m^3. On December 30, 1972, the 3.0 mg/m^3 mandated dust standard was reduced to 2.0 mg/m^3. On June 26, 1972, the 2.0 mg/m^3 standard also became effective for surface work areas of underground coal mines and for surface coal mines. The act further stipulated that the 2.0 mg/m^3 mandated standard was to be reduced whenever the quartz content in the respirable dust was greater than 5 percent. The adjusted standard is determined by dividing the percentage of quartz in the respirable dust into the number 10. So long as the adjusted dust standard is not exceeded, maximum exposure to quartz is limited to 100 μg/m^3.

The reference dust sampling instrument for measuring respirable dust concentrations with respect to the mandated standard is the Isleworth type 113A (MRE)[3] gravimetric dust sampler. However, respirable dust measurements in U.S. coal mines are made using a personal sampling device that uses a 10-mm nylon cyclone, operated at a flow rate of 2.0 L/min, to separate the dust sampled into two fractions: a respirable fraction and a nonrespirable fraction. Because the size fraction of the particles penetrating the 10-mm nylon cyclone is different from the size fraction penetrating the four-channel horizontal elutriator used on the MRE sampler, measurements obtained with the personal sampling device are multiplied by a constant factor[4] (1.38) to obtain an equivalent MRE concentration. Therefore, a concentration of approximately 72.5 μg/m^3 measured with a personal sampler operating at 2.0 L/min is equivalent to a concentration of 100 μg/m^3 as measured with the MRE sampler. The sampling and analytical procedure recommended by the National Institute for Occupational Safety and Health (NIOSH)[5] specifies sampling with a personal sampling device equipped with a 10-mm nylon cyclone, operated at 1.7 L/min. In comparison to the NIOSH recommended exposure limit (REL) of 50 μg/m^3 for quartz, a concentration of 100 μg/m^3 obtained with the MRE sampler is equivalent to a concentration of 85 μg/m^3 obtained using the procedure specified by NIOSH.

Operators of underground coal mines are required to describe the methods being used to control dust in a ventilation, methane, and respirable dust control plan.[6] The plan, submitted to the Mine Safety and Health Administration's (MSHA's) local official for approval, is evaluated annually. This evaluation consists of a mine inspector measuring the respirable dust exposure of at least five occupations working on the operation. If no individual sample is greater than the established standard for the operation, the plan submitted by the mine operator for controlling dust is approved for use. If the average of the five measurements exceeds the established standard, the plan is rejected. If the average is less than or equal to the standard, but any of the five individual measurements shows a concentration greater than the established standard, up to 4 days of additional sampling are required to determine the validity of the procedures being used to control the dust level to the applicable standard. The number of days of additional sampling performed depends on how near the average concentration, determined from measurements obtained on successive days, is to the established standard. During subsequent inspections (performed quarterly) of the mine, compliance with the methods specified in the plan is checked.

On July 15, 1991, the assistant secretary of labor directed that a special inspection program be conducted in a representative number of the country's mining operations. The objectives of the program were to:

1. obtain information with respect to occupational exposures to respirable dust in the nation's underground mining operations;
2. determine the effectiveness of methods being used to control dust; and
3. assess the knowledge of mining personnel with respect to the hazards associated with exposure to respirable coal mine dust and with respect to the programs in place to control dust in their mines.

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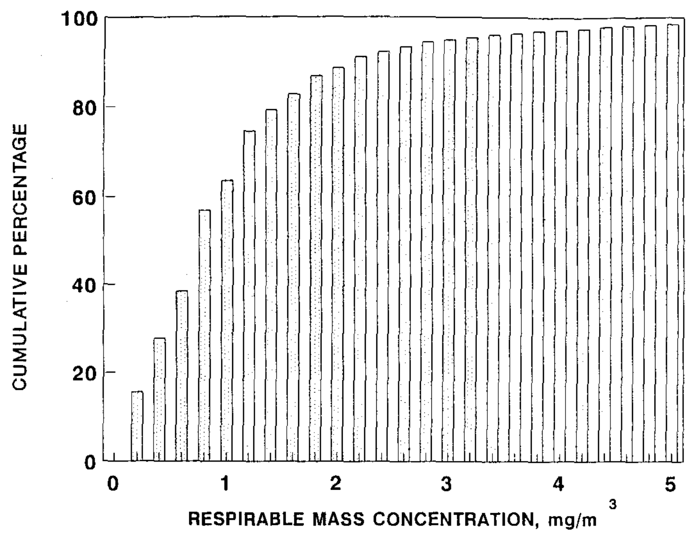

FIGURE 1. Cumulative frequency distribution of occupational exposures to respirable dust.

Approximately 720 mechanized mining units (coal-getting operations) were included in the program. Emphasis was placed on mines that demonstrated irregularities in their sampling program, operations employing longwall mining methods, and mines that had been targeted for special health emphasis programs. The major differences between the assistant secretary's special inspection program and the customary annual plan approval program were:

1. Sampling by an inspector would be conducted on only one day.
2. To comply with the intent of the 1977 act (i.e., "that each operator shall continuously maintain the average concentration of respirable dust in the mine atmosphere during each shift to which each miner in the active workings of such mine is exposed" below the applicable dust standard for that operation) noncompliance was determined on a single respirable dust measurement as well as on the average of five occupational measurements. For a noncompliance determination to be made on a single measurement, values were calculated, based on measurement precision, that, when exceeded, would provide greater than 95 percent confidence that the applicable standard had been exceeded. For an applicable standard of 2.0 mg/m^3, the value calculated for a noncompliance determination was 2.5 mg/m^3.
3. During the inspection, individual miner interviews were conducted to obtain information relative to the miners' knowledge of the MSHA's respirable dust enforcement program and procedures applicable to the control of dust in the mine environment.

This article presents a review of the respirable dust and quartz exposure data for different occupations that were obtained during the assistant secretary's special inspection program and discusses the status of compliance with the 2.0 mg/m^3 respirable dust standard and the influence of ventilation, sprayed water, production, and dust avoidance techniques on environmental respirable dust levels.

Data Compilation and Analysis

Occupational Exposure Data

At each working section where a special inspection was conducted, full-shift respirable dust samples were collected on five different occupations. Of the five occupations sampled, one was to be the designated occupation (DO) and one the roof bolter (if a roof bolting operation was part of the mining operation). For regulatory purposes, the DO is defined as that occupation on a working section which previous sampling has shown to have the highest respirable dust exposure. (If it is shown that the exposure of the DO is below the applicable standard, other occupations on the section are assumed to be protected as well.) A sample was also collected of the intake air being used to ventilate the working section. During the special inspection program, approximately 4000 samples representative of 52 occupations were obtained.

All of the samples collected were analyzed gravimetrically and the equivalent MRE respirable mass concentration was determined. Samples with sufficient weight gain were also quantitatively analyzed for quartz content using infrared spectroscopy.[7] For this study, the minimum weight gain required was 0.3 mg. Over 90 percent of the occupational samples were analyzed for quartz content. Figures 1 and 2 show, respectively, the cumulative frequency distribution of the respirable mass concentration determinations for the occupational measurements and the cumulative frequency distribution of the quartz determinations (as a percentage of the respirable mass) obtained from analysis of the occupational samples. The data in Figure 1 show that approximately 11 percent of the occupational measurements were above 2.0 mg/m^3; the data in Figure 2 show that approximately 30 percent of the samples analyzed for quartz content contained greater than 5 percent quartz. As previously discussed, mining operations that have greater than 5 percent quartz in their respirable dust are required to have their respirable dust standard lowered.

A compilation of the respirable dust exposure data by mining type is shown in Tables 1 through 4. Shown in the

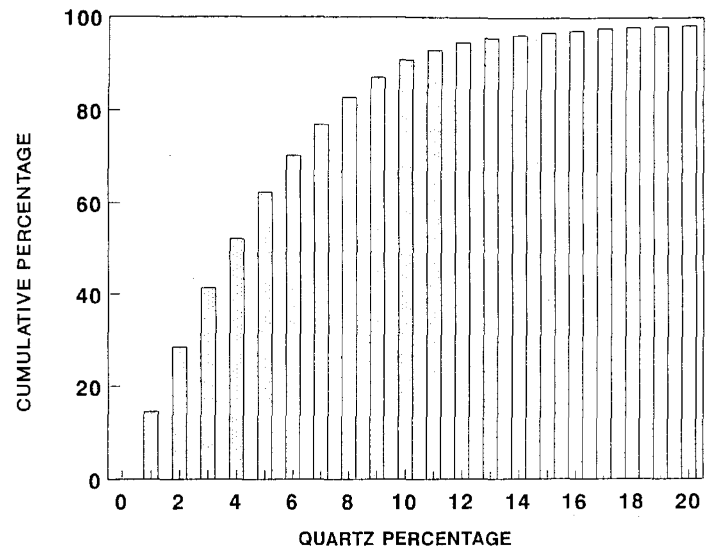

FIGURE 2. Cumulative frequency distribution of the quartz content of respirable dust samples.

respective tables are the number of samples collected on each of the occupations sampled, the average concentration representative of the exposure for that occupation, the percentage of measurements that exceeded 2.0 mg/m^3, and the percentage of time the measurement would result in a noncompliance determination because the calculated single sample value was exceeded.

The data in Table 1 for longwall mining operations show that approximately 25 percent of the measurements obtained on the DO were greater than 2.0 mg/m^3, and that approximately half of these measurements exceeded 2.5 mg/m^3. The data in Table 1 also show that the number of times (24) the exposure of the jack setter occupation (shield setter) exceeded 2.0 mg/m^3 was greater than the number of times (21) the DO exceeded 2.0 mg/m^3. Analysis of the individual occupational longwall exposure data showed that approximately 50 percent of the time an occupation other than the DO was exposed to the highest concentration of respirable dust. This indicates that measurements obtained on the DO may not ensure that other occupations are being protected. However, since multiple samples on the same occupation were not collected, insufficient data were available to establish if another occupation was consistently exposed to higher concentrations, indicating that the designation of the DO was inappropriate. A schematic of a typical longwall operation is shown in Figure 3.

Figures 4 through 6 show different configurations used for continuous mining operations. Data obtained on continuous mining operations (room and pillar) were divided into two categories: data from operations that limit mining advance to 6.1 m (20 ft) before taking measures to support the roof (Table 2), and data from operations that have been granted permission to mine to depths greater than 6.1 m (referred to as deep-cut mining) before supporting the roof (Table 3). A schematic illustrating the deep-cut method of mining is shown in Figure 6. Operations that mine to depths greater than 6.1 m before supporting the roof typically employ inertial dust collectors (scrubbers) on the mining machine and use remote control to operate the machine. The remote control enables the continuous miner operator (the DO) to be positioned in clean air that is being used to ventilate the working place, and the scrubber reduces the amount of dust exiting the working place. Therefore, the DO's exposure on these operations would be expected to be less than the DO's exposure on operations limiting mining advance to 6.1 m. Comparison of the data in Tables 2 and 3 confirms this expectation. The percentage of occupational exposures exceeding 2.0 mg/m^3 was 7 percent

TABLE 1. Occupational Exposures Obtained on Longwall Mining Operations

Occupation	Number of Samples	Average (mg/m^3)	Percent Greater Than 2.0 mg/m^3	Percent Greater Than 2.5 mg/m^3
Longwall operator (tailgate side)*	83	1.7	25	12
Longwall operator (headgate side)	50	1.5	16	8
Jack setter	160	1.4	15	5
Headgate operator	76	0.7	1	1
Mechanic	34	0.7	0	0

*Usually the DO.

TABLE 2. Occupational Exposures on Continuous Mining Operations Not Advancing Greater Than 20 Feet

Occupation	Number of Samples	Average (mg/m^3)	Percent Greater Than 2.0 mg/m^3	Percent Greater Than 2.5 mg/m^3
Continuous miner operator[A]	350	1.6	21	14
Continuous miner helper	142	1.4	23	13
Roof bolter (twin head) intake side	101	1.0	7	3
Other roof bolter[B]	356	1.3	18	11
Roof bolter helper	32	1.4	22	9
Section foreman	40	0.9	10	8
Electrician	20	0.5	0	0
Shuttle car operator (standard side)	295	0.7	5	4
Shuttle car operator (off standard side)	204	0.8	6	3
Scoop car operator	91	0.8	8	5
Tractor operator/motorman	31	0.4	0	0
Mobile bridge operator	39	0.9	10	8
Utility man	62	0.6	2	0

[A]Usually the DO.
[B]Includes twin head (return side), single head, and designated area.

greater on operations limiting mining advance to 6.1 m. Also, on operations limiting mining advance to 6.1 m, the percentage of time the DO's exposure exceeded 2.5 mg/m^3 was higher by a factor of two. From an industry standpoint, this 7 percent difference is significant because there are approximately 1.8 times more continuous mining operations that limit

TABLE 3. Occupational Exposures on Continuous Mining Operations Advancing Greater Than 20 Feet

Occupation	Number of Samples	Average (mg/m^3)	Percent Greater Than 2.0 mg/m^3	Percent Greater Than 2.5 mg/m^3
Continuous miner operator[A]	170	1.2	14	8
Continuous miner helper	90	1.1	7	6
Roof bolter (twin head) intake side	63	1.0	8	6
Other roof bolter[B]	190	1.0	7	5
Section foreman	23	0.7	4	4
Shuttle car operator (standard side)	187	0.9	6	3
Shuttle car operator (off standard side)	67	0.8	4	3
Scoop car operator	33	0.8	3	0
Mobile bridge operator	34	0.8	3	0

[A]Usually the DO.
[B]Includes twin head (return side), single head, and designated area.

TABLE 4. Occupational Exposures Obtained on Conventional Mining Operations

Occupation	Number of Samples	Average (mg/m^3)	Percent Greater Than 2.0 mg/m^3	Percent Greater Than 2.5 mg/m^3
Coal drill operator	64	1.1	14	6
Cutting machine operator*	70	1.9	27	23
Loading machine operator	27	1.6	26	15
Roof bolter (single head)	90	1.3	17	11
Scoop car operator	92	1.1	12	9

*Usually the DO.

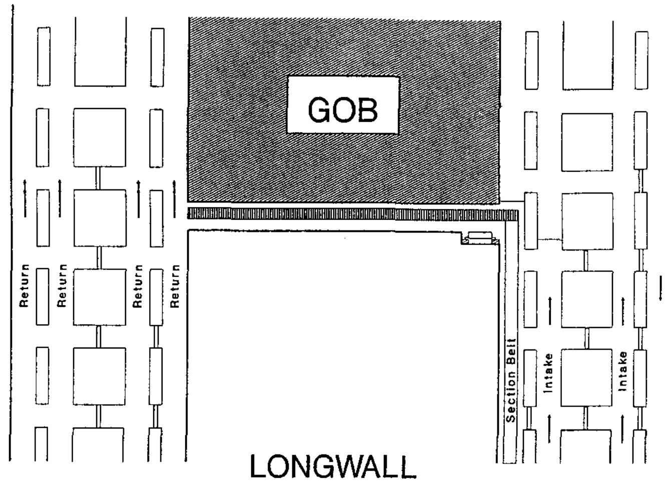

FIGURE 3. Schematic of typical longwall mining operations.

their advance to 6.1 m before installing roof supports than operations advancing to depths greater than 6.1 m.

The data on Tables 2 and 3 also show that on operations limiting mining advance to 6.1 m, the percentage of roof bolter (single-head) exposures exceeding 2.0 and 2.5 mg/m^3, respectively, is approximately the same as that of the DO. This is different than what was obtained for operations mining to depths greater than 6.1 m. On these operations, the percentage of roof bolter exposures exceeding 2.0 mg/m^3 was approximately 40 percent less than that obtained for the DO. A possible explanation for this difference could be that on operations mining to depths greater than 6.1 m, the cleaned air (because of the use of the dust collector) exiting the working place is being used to ventilate the roof bolting operation.

The data obtained for occupational exposures on conventional mining operations (Table 4) show that approximately 27 and 23 percent of the exposures measured on the cutting machine operator (the DO) were greater than 2.0 and 2.5 mg/m^3, respectively. The data obtained on conventional mining operations also show that, in general, the percentage of occupational exposures that exceeded 2.0 and 2.5 mg/m^3 was greater than for either the longwall or continuous methods of mining.

Tables 5 through 7 show the compilation of quartz exposure data. The compilation shows the percentage of measurements, by occupation for each method of mining, that had quartz percentages that exceeded 5 percent quartz, and the percentages of measurements that, respectively, exceeded 50 μg/m^3 (the NIOSH REL), 100 μg/m^3 MRE equivalent (the MSHA standard), and 150 μg/m^3 MRE equivalent concentration. Also shown are the percentages of samples that represented respirable dust concentrations less than or equal to 2.0 mg/m^3 MRE equivalent concentration, but which contained greater than 100 μg/m^3 MRE equivalent concentration of quartz. Data representative of longwall mining operations (Table 5) show that for the longwall operators (shearer operator) and jack setters approximately 15 percent of the measurements had a quartz percentage greater than 5 percent. About the same fraction of samples exceeded 100 μg/m^3 MRE equivalent quartz concentration, while about twice as many exceeded the NIOSH REL. Of the samples collected on these occupations which indicated respirable coal mine dust concentrations below the 2.0 mg/m^3 standard, only 6 percent exceeded 100 μg/m^3 MRE equivalent quartz concentration. These results indicate that, if the coal mine dust standard is met, only a small number of overexposures will occur.

The data representative of continuous mining operations (Table 6) show that a significant number of samples obtained on the continuous miner operator, the continuous miner operator helper, roof bolter, and roof bolter helper occupations had quartz percentages that exceeded 5 percent. Approximately 40 percent of the samples obtained on the continuous miner and his or her helper contained greater than 5 percent quartz, and more than 55 percent of the samples for those occupations involved in the roof bolting operation contained greater than 5 percent quartz. For these occupations, the percentage of samples exceeding the NIOSH REL is similar to the percentage above 5 percent, while the fraction exceeding 100 μg/m^3 MRE equivalent quartz concentration is approximately half as high. Particularly for the roof bolting occupations, the percentage of samples below the 2.0 mg/m^3 MRE equivalent coal mine respirable dust standard but above the MSHA quartz dust standard is similar to the overall percentage exceeding the quartz standard, indicating that meeting the 2.0 mg/m^3 dust standard will not ensure control of quartz exposure for these workers. In many cases, special measures to control exposure to the quartz aerosol are required to protect these employees.

The data representative of operations employing conventional mining methods are shown in Table 7. These data show that approximately 10 percent of the samples collected on all occupations except the roof bolter had a quartz content greater than 5 percent. For the roof bolter occupation, 37 percent of the samples collected had quartz contents greater than 5 percent. For all of these occupations, the percentage of samples indicating a quartz concentration above the NIOSH REL is at least as high as, and for most considerably higher than, the percentage above 5 percent quartz. The percentage of samples showing a quartz concentration above 100 μg/m^3 MRE equivalent is similar to the fraction above 5 percent; however,

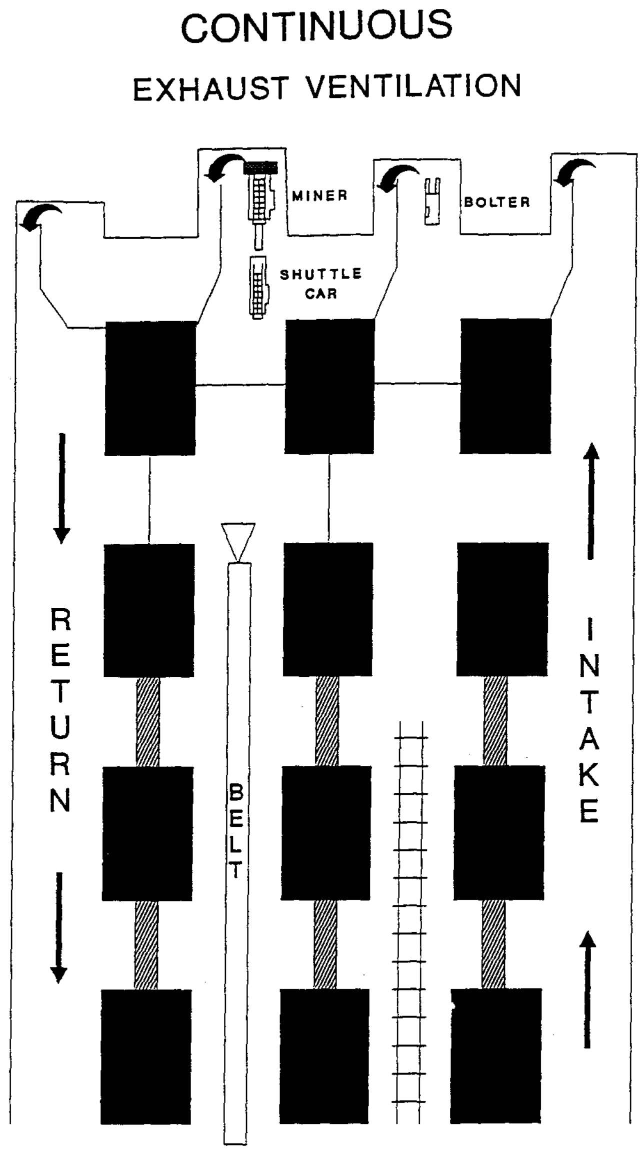

FIGURE 4. Schematic of typical continuous mining operation using an exhausting ventilation system.

among those samples that do not exceed the 2.0 mg/m^3 coal mine dust concentration limit, the percentage above 100 μg/m^3 is much lower. Except for roof bolters, meeting the respirable dust standard provides adequate protection from overexposure to quartz for almost all workers.

Effect of Production on DO Exposure

As previously discussed, one of the primary objectives was to obtain information relative to procedures being utilized to control dust. Data obtained showed that the primary methods being used to control dust included the application of sprayed water during the cutting process and air to ventilate the working place. Air ventilating the working place was used to dilute dust generated during the mining process or to capture the dust and direct its removal from the working place. The utilization of remote control mining equipment was also being used on approximately 32 percent of the continuous mining operations. Utilization of this technology provided for increased efficiency of the mining process and allowed personnel operating the mining machine to position themselves in clean (intake) air. The utilization of remote control as well as dust avoidance (control of work practice) techniques, such as keeping jack setters upwind of the shearer during the cutting pass, were also used on many longwall mining operations to control occupational exposures to respirable dust.

Figures 7 and 8 show the effect of production on the DO's exposure on continuous mining operations employing exhausting and blowing face ventilation systems, respectively. On all of these operations, machine advance was limited to 6.1 m before action was taken to support the roof (i.e., no operations employing deep-cut mining). The data shown in Figure 7 for operations employing exhausting face ventilation systems were categorized into two groups: operations where the line curtain was maintained to within 3.1 m (10 ft) of the face and the

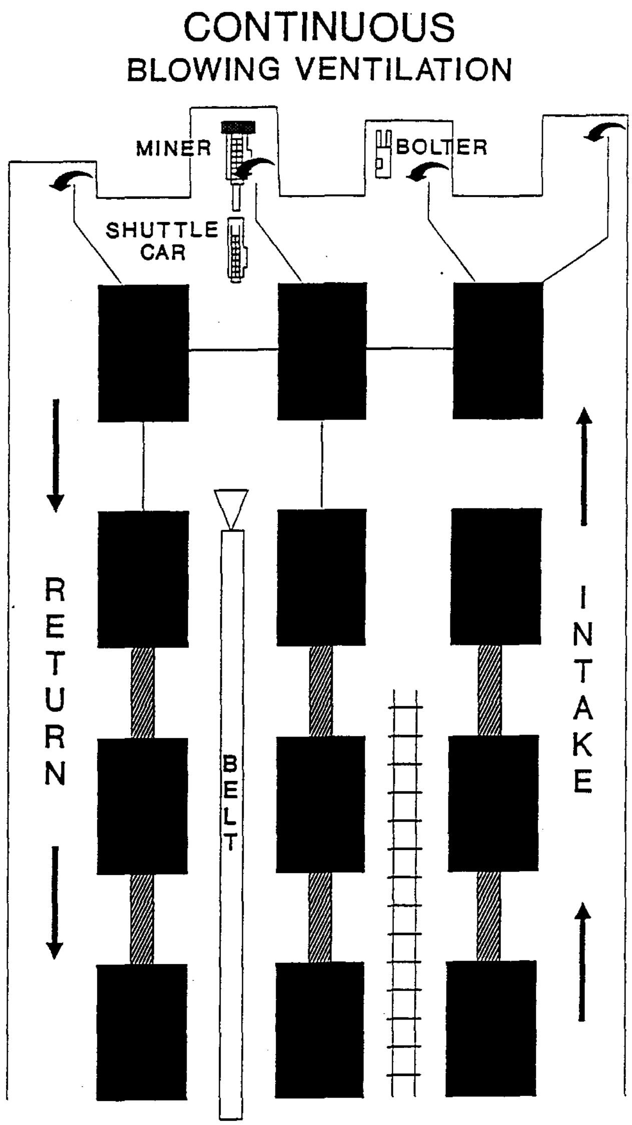

FIGURE 5. Schematic of typical continuous mining operation using a blowing ventilation system.

velocity of the air in the entry to the face was equal to or greater than 0.31 m/s (60 ft/min) and operations where the curtain was greater than 3.1 m from the face and the velocity of air in the entry to the face was less than 0.31 m/s. As the data in Figure 7 show, on operations employing exhausting face ventilation systems, exposure of the DO does not appear to be related to the amount of material produced. The data also show that for exhausting systems that maintain the line curtain to within 3.1 m of the face and the velocity of the air in the entry to the face at or above 0.31 m/s, the percentage of measurements below 2.0 mg/m^3 was 30 percent greater than when these conditions were not maintained. It was observed that for those operations that did not maintain the curtain to within 3.1 m of the face and the velocity of the air to the face greater than 0.31 m/s, and on which the DO measurement was greater than 2.0 mg/m^3, air velocity to the face was at least 0.24 m/s (47 ft/min). This corroborates previous work[8] that has demonstrated that for an exhausting face ventilation system, it is most important to maintain the intake to the system as close to the working face as possible.

The data in Figure 8 for operations employing a blowing face ventilation system also show that exposure of the DO does not appear to be related to the amount of material mined. However, the quantity of air used to ventilate the face is not the primary factor that governed the exposure of the DO. This is because operations using a blowing face ventilation system typically position the end of the line curtain or tubing so that the mining machine operator is positioned in clean air. However, it should be noted that for these operations, the exposure of the DO exceeded 2.0 mg/m^3 approximately 30 percent of the time, indicating that the location of the mining machine operator was not being maintained in clean air.

Analysis of the data for longwall mining operations shows that occupational exposures to respirable dust appear to be related to the amount of air supplied to the working place and to the amount of material mined. This can be observed from

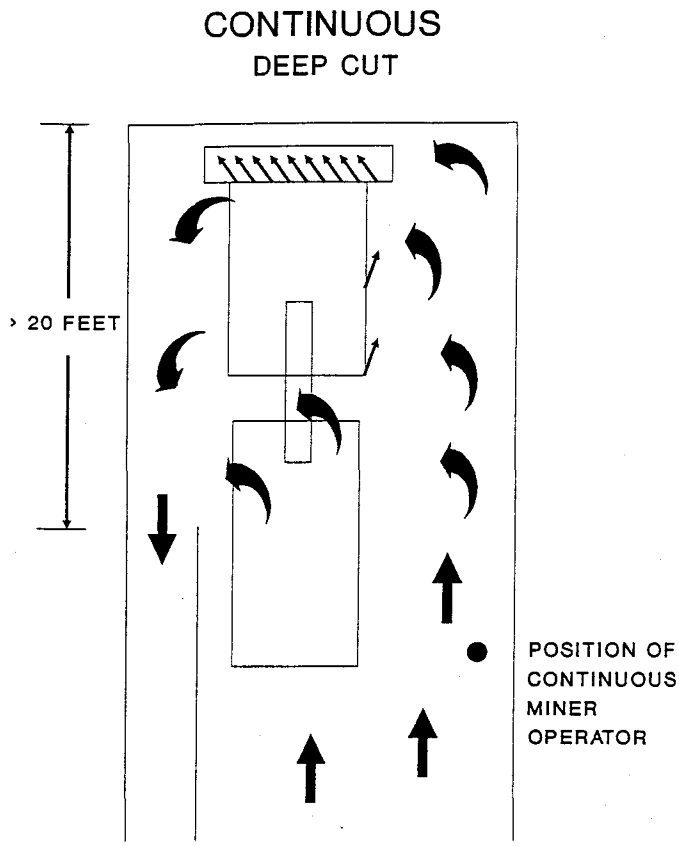

FIGURE 6. Schematic of typical continuous mining operation using an exhausting ventilation system and the deep-cut mining method.

the data presented in Figure 9. These data show that occupational exposures on longwall mining operations that supply approximately 0.4 m^3 of air per minute (approximately 15 ft^3/min) per ton of material mined were less than 2.0 mg/m^3.

As previously discussed, sprayed water is also critical to the control of dust. While information collected during the special inspections included data on the number of sprays, their operating pressure, and application to control dust, no information was obtained on water quantity. Therefore, no rigorous analysis of the effectiveness of different water application systems could be made. However, analysis of the data did show that all mines were using sprayed water to assist in controlling dust generated during the mining and material transporting processes.

Summary

Between July 15 and October 30, 1991, a special study was conducted in U.S. underground coal mines to evaluate the MSHA mandated health enforcement programs. As part of that evaluation, occupational exposures to respirable coal mine dust and quartz were measured. Information was also gathered on methods being used to control dust, and the data were analyzed to determine their influence as well as the influence of production on occupational respirable dust exposures.

TABLE 5. Results of Quartz Analyses of Samples Obtained on Longwall Mining Operations

Occupation	Number of Samples Analyzed	Percentage of Samples Greater Than 5%	50 $\mu g/m^3$	100 $\mu g/m^3$ (MRE)	150 $\mu g/m^3$ (MRE)	100 $\mu g/m^3$* (MRE)
Longwall operator (tailgate side)	80	15	33	18	9	7
Longwall operator (headgate side)	47	13	30	19	11	8
Jack setter	155	16	27	12	4	5
Headgate operator	72	4	3	0	0	0
Mechanic	34	6	6	0	0	0

*Of those samples with a respirable dust concentration ≤2 mg/m^3.

TABLE 6. Results of Quartz Analyses of Samples Obtained on Continuous Mining Operations

Occupation	Number of Samples Analyzed	Percentage of Samples Greater Than				
		5%	50 μg/m³	100 μg/m³ (MRE)	150 μg/m³ (MRE)	100 μg/m³* (MRE)
Continuous miner operator	489	38	41	22	16	11
Continuous miner helper	226	39	39	23	15	11
Roof bolter (twin head) intake side	161	47	39	23	11	18
Other roof bolter	512	59	51	35	22	33
Roof bolter helper	36	64	56	44	31	34
Section foreman	60	20	15	8	5	6
Electrician	21	14	10	0	0	0
Shuttle car operator (standard side)	451	22	17	8	5	4
Shuttle car operator (off standard side)	253	24	15	9	6	5
Scoop car operator	114	26	9	0	0	0
Tractor operator/motorman	34	26	9	0	0	0
Mobile bridge operator	69	28	25	7	4	3
Utility man	70	21	14	6	0	0

*Of those samples with a respirable dust concentration ≤2 mg/m³.

Analysis of the occupational exposure data showed that approximately 89 percent of the occupational exposures were less than 2.0 mg/m³. However, approximately 18 percent of the face occupations associated with the shearing and jack setting processes on longwall mining operations, 21 percent of the continuous miner operators, helpers, and roof bolters on continuous mining operations employing an exhausting face ventilation system, and 26 percent of the loading and cutting machine operators on conventional mining operations had exposures greater than 2.0 mg/m³. This indicates that while a very high percentage (approximately 89 percent) of underground mining personnel have exposures below the 2.0 mg/m³ mandated respirable dust standard, a high percentage of the occupations directly associated with the coal-getting processes have exposures above 2.0 mg/m³. It should be noted that no attempt was made in this study to evaluate exposures with respect to reduced dust standards. If occupational exposures were compared with the actual standards established for their respective work places, the percentages would be greater than those established for exposures exceeding a 2.0 mg/m³ standard.

Analysis of the quartz exposure data obtained on longwall mining operations showed that approximately 15 percent of the samples collected on the shearer operator and jack setter occupations contained greater than 5 percent quartz. This was significantly lower than that obtained on continuous mining operations. On continuous mining operations, approximately 40 percent of the samples collected on the continuous miner operator and his or her helper and approximately 60 percent of the samples collected on personnel involved in the roof bolting operations contained greater than 5 percent quartz. Approximately 8 percent of the samples collected on the cutting and loading machine operators of conventional mining operations contained greater than 5 percent quartz; however, approximately 40 percent of the samples collected on personnel performing the roof bolting operation on these operations contained greater than 5 percent quartz.

The pattern of quartz overexposures relative to the MSHA quartz standard of 100 μg/m³ MRE equivalent concentration is similar to the pattern of samples over 5 percent quartz. The proportion of such samples is considerably higher on continuous mining operations than on either longwall or conventional mining operations. For the latter two mining methods, adherence to the coal mine respirable dust standard of 2.0

TABLE 7. Results of Quartz Analyses of Samples Obtained on Conventional Mining Operations

Occupation	Number of Samples Analyzed	Percentage of Samples Greater Than				
		5%	50 μg/m³	100 μg/m³ (MRE)	150 μg/m³ (MRE)	100 μg/m³* (MRE)
Coal drill operator	58	12	12	10	9	4
Cutting machine operator	67	7	27	12	9	4
Loading machine operator	26	8	15	8	8	0
Roof bolter (single head)	84	37	40	26	17	13
Scoop car operator	91	9	16	5	3	1

*Of those samples with a respirable dust concentration ≤2 mg/m³.

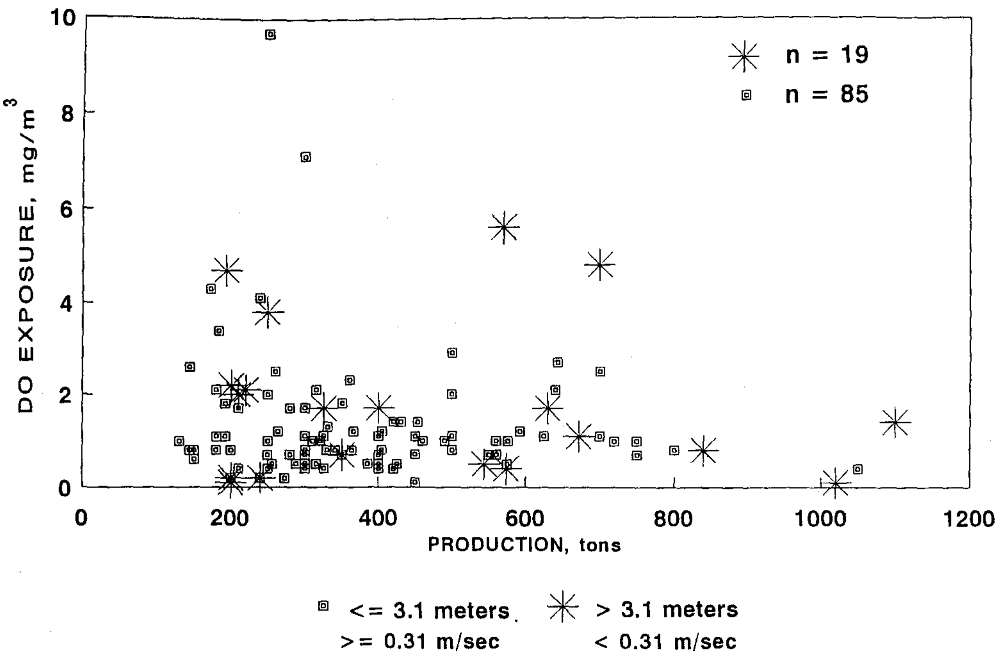

FIGURE 7. Effect of brattice distance from the face and mean entry air velocity on the DO's exposure.

mg/m^3 results in a low proportion of samples showing overexposure to the quartz standard (except for roof bolter samples). This is consistent with the larger fraction of samples showing a high quartz percentage on continuous mining operations and roof bolting occupations.

Analysis of the production and dust control data showed that occupational exposures on longwall mining operations appeared to be related to the amount of material produced per shift and to the amount of air supplied to the face. The analysis also showed that on 96 percent of the longwall operations supplying at least 0.4 m^3 of air per minute per ton of material mined, occupational exposures were maintained below 2.0 mg/m^3.

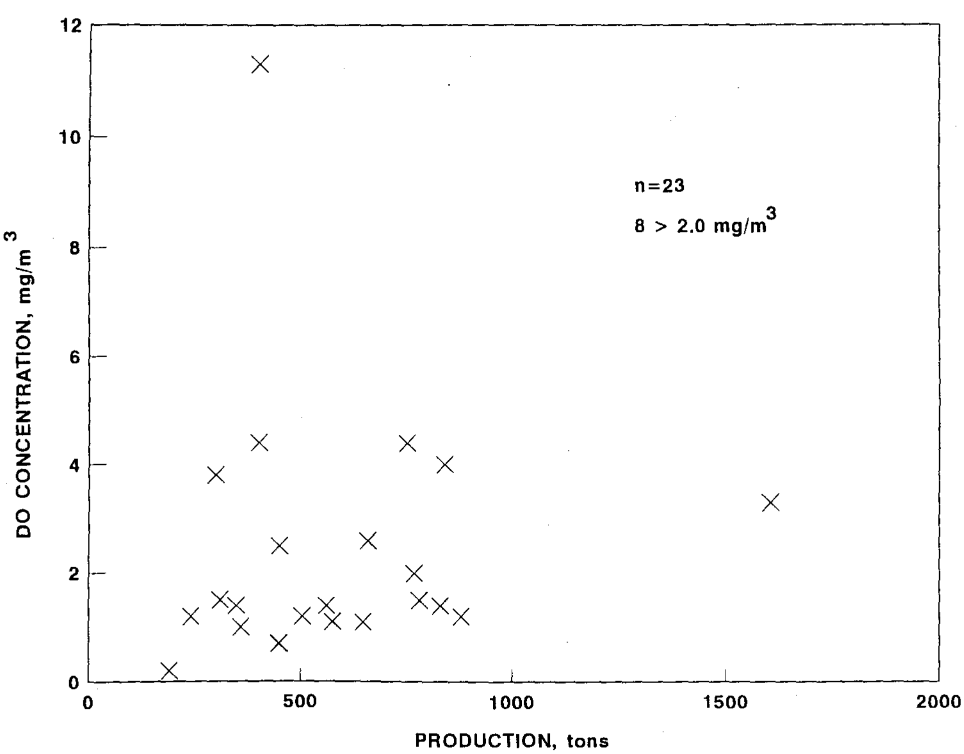

FIGURE 8. Effect of production on the DO's exposure on continuous mining operations using a blowing ventilation system.

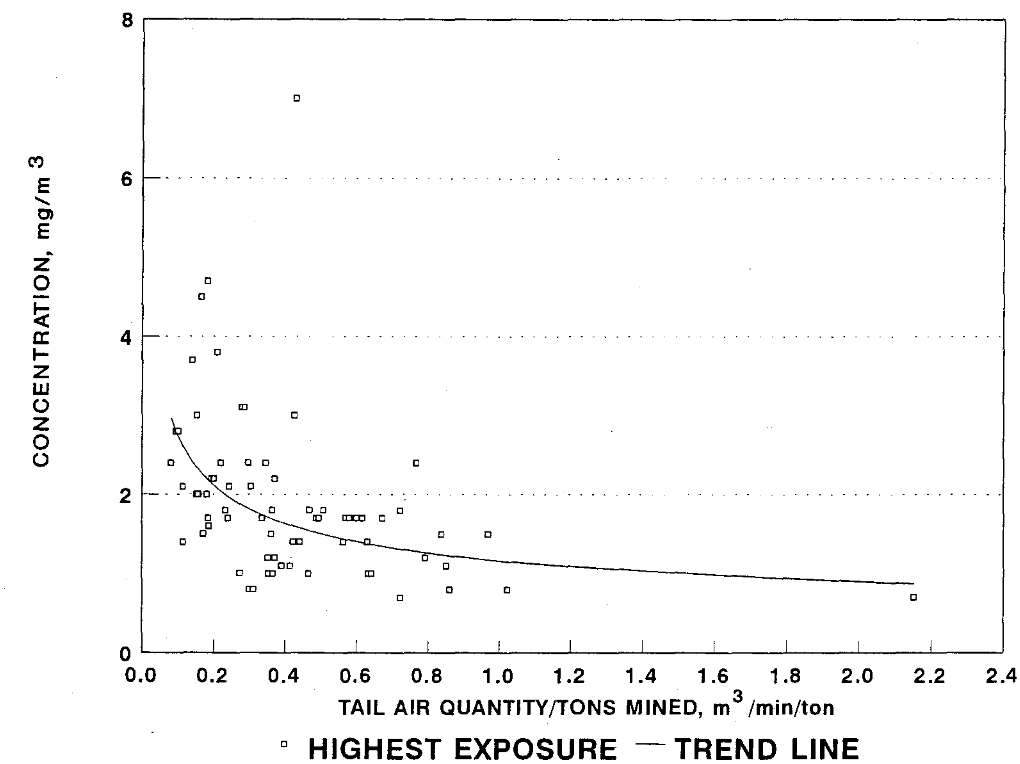

FIGURE 9. Relationship between the ratio of ventilating air and production on occupational exposures on longwall mining operations.

Occupational exposures on continuous and conventional mining operations appeared not to be related to the amount of material produced per shift. Analysis of the data obtained on continuous mining operations showed that, on operations employing an exhausting face ventilation system that maintains the inby end of the ventilation system to within 3.1 m of the face and the velocity of air in the entry ventilating the face at or above 0.31 m/s, 84 percent of the DO exposures were below 2.0 mg/m^3.

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