# Analysis of Quartz Exposure Data Obtained from Underground and Surface Coal Mining Operations

*T.F. Tomb, A.J. Gero, and J. Kogut*

Mine Safety and Health Administration, Pittsburgh, Pennsylvania 15236

The Mine Safety and Health Administration (MSHA) yearly performs quartz analysis on approximately 9000 respirable coal mine dust samples collected for various occupations in U.S. coal mines. All occupational quartz exposure data gathered by MSHA since 1985 have been compiled and analyzed to characterize current occupational exposures to quartz; to determine if the quartz percentages of samples collected for different occupations have changed during the period 1985 through 1992; and to study the intramine variability associated with quartz sample percentages of selected occupations. Analysis of the occupational data shows that regardless of the type of coal extraction process used, there are a substantial number of occupational samples that contain greater than 5 percent quartz and show quartz exposures that exceed 100 $\mu g/m^3$. In underground mining operations, approximately 30 percent of the samples collected at the continuous-miner operator and continuous-miner helper occupations on continuous-mining operations, and at the roof bolting occupations on both conventional and continuous-mining operations, had quartz exposures exceeding 100 $\mu g/m^3$. The analysis also shows that the quartz percentages of the continuous-miner operator and cutting machine operator occupations and roof bolter (DA) have increased by 0.12 to 0.19 percent quartz per year. Analysis of the data to study intramine variability showed that the percentages of quartz in samples collected on the different sections of a multisection mine were very similar. For surface mines, the occupational data show that approximately 60 percent of the samples collected at the highwall drill operator, highwall drill helper, bulldozer operator, and refuse/backfill truck driver occupations had quartz concentrations greater than 100 $\mu g/m^3$. The average quartz percentage of three of the four occupations studied was found to decrease over the period studied. Only the average quartz percentage of the highwall drill operator showed an increase. TOMB, T.F.; GERO, A.J.; KOGUT, J.: ANALYSIS OF QUARTZ EXPOSURE DATA OBTAINED FROM UNDERGROUND AND SURFACE COAL MINING OPERATIONS. APPL. OCCUP. ENVIRON. HYG. 10(12):1019–1026; 1995.

The allowable respirable coal mine dust standard for underground and surface coal mine environments in the United States is 2 $mg/m^3$ of air when the quartz content of the respirable coal mine dust is 5 percent or less. However, the Code of Federal Regulations[1] requires that when the respirable coal mine dust in the mine atmosphere contains more than 5 percent quartz, the standard shall be reduced to a value determined by dividing the percentage of quartz into the number 10. Dust samples used to monitor compliance with the standard are collected with a sampler using a 10-mm nylon cyclone operated at 2.0 L/min. The concentration of coal mine dust determined from the sample is multiplied by an empirically determined constant[2] to obtain a concentration equivalent to that which would be measured with a Casella type 113A gravimetric dust sampler, developed by the Mining Research Establishment of Great Britain[3] (MRE). The adjustment to the dust standard when quartz is present is intended to limit the quartz concentration to 100 $\mu g/m^3$ of air (MRE equivalent concentration). This concentration is approximately equivalent to an environmental concentration of 85 $\mu g/m^3$ determined using an approved respirable coal mine dust sampler operating at 1.7 L/min, the sampling method recommended by the National Institute for Occupational Safety and Health (NIOSH).[4] (The equivalent concentration value with the NIOSH method was derived from the fact that the same mass of dust is collected at both flow rates[5,6] and simple calculations accounting for adjustment to the MRE equivalent concentration and the concentrations calculated from the collected mass at the two flow rates.)

In 1985 the Mine Safety and Health Administration (MSHA) revised its program[7] of adjusting the respirable coal mine dust standard based on the analysis of one sample collected by an inspector to using the average of up to three samples that are collected by both an inspector and a mine operator. For underground mining operations, samples have typically been collected on the designated occupation (DO), the occupation on a mechanized mining unit (MMU) determined to have the highest respirable coal mine dust exposure, and at the roof bolting operation. For surface mining operations or surface work areas of underground mines, the samples have been collected for occupations that have been specifically designated by the local MSHA official and are referred to as designated work position (DWP) samples. DWP samples represent areas or occupations that have been shown to exceed 1 $mg/m^3$ of respirable coal mine dust or where there is evidence of excessive quartz exposure. Samples with sufficient weight gain (≥0.45 mg) are analyzed for quartz content using infrared spectrophotometry.[8]

In 1988 MSHA initiated a special program to analyze respirable coal mine dust samples collected by inspectors at occupations other than the DO, roof bolter, and DWP for quartz content. Each month a number of samples representing different occupations were analyzed for quartz content. The results of these analyses have been used to characterize occupational quartz exposures in the coal mining industry. Because these samples were not used for enforcement purposes, the minimum weight gain for them was 0.3 mg.

In July 1991 MSHA revised its underground respirable coal mine dust enforcement program. Part of that revision included the analysis of all respirable coal mine dust samples that were collected on an MMU during an inspection for quartz content. The samples collected during an inspection included five samples for various occupations (including the DO) plus an intake air sample. All samples were collected on the same day. Intake air samples typically did not have enough mass (at least 0.45 mg) for quartz analysis. Since initiation of the revised program, approximately 32,000 samples representing 65 different occupations have been analyzed for quartz content.

The MSHA compliance monitoring system has been called "one of the largest data sets in existence."[9] While this description was applied to the dust monitoring data, it is also true for the quartz data set. A number of studies[10–13] have explored different aspects of dust and quartz exposures using these data sets. The analysis of the data presented in this study updates some of these aspects and adds others which were not previously investigated. All quartz exposure data gathered by MSHA between 1985 and 1992 have been compiled and analyzed to:

1. characterize current occupational exposures to quartz in the surface and underground coal mining industry;
2. determine if the quartz percentages of samples collected for different occupations have changed over time; and
3. study the variability associated with quartz sample percentages of DOs and the roof bolter occupation on different MMUs within the same mine over a 5-year period.

## Data Analysis

Data for all samples analyzed for quartz content during the period 1985 through 1992 were compiled. The data were separated by date, mine and entity identification, and method of mining (surface or underground). The data compiled for underground mining operations were further classified by the type of mining performed (conventional, continuous, or longwall). A complete description of the three mining types can be found elsewhere.[14] In addition, the percentage of samples for each occupation that contained greater than 5 percent quartz and greater than 100 $\mu g/m^3$ (MRE equivalent) quartz was determined.

To evaluate if occupational sample percentages have changed over time, occupational data obtained during the period 1985 through 1992 were compiled and average quartz percentages for each year within this period were determined for selected occupations. The data were plotted to establish trends over time and analyzed using regression analysis to determine if noted trends were statistically significant. The period chosen for the trend analysis and the selection of occupations were based on having samples from a sufficient number of operations in order to estimate an annual quartz percentage. However, for some occupations of interest, such as the longwall shearer operator, jacksetter, and continuous-miner operator helper, there were fewer than 100 samples per year.

Variability associated with quartz percentages of DOs and the roof bolter occupation working on different MMUs within the same mine was evaluated by comparing measurements obtained over a 5-year period in 22 multisection (three or more MMUs) mines. Twenty-two mines represent approximately 15 percent of the multisection mines with three or more MMUs. The mines were selected based on the analysis for quartz content of at least three samples which were collected at the DO of each MMU in the mine. Additional criteria were the number of MMUs with at least three samples on the DO and the number of roof bolter samples analyzed from each MMU. All of the mines chosen had at least four MMUs meeting the criteria for DO samples, and all but two mines had at least two MMUs with no fewer than three roof bolter samples analyzed. The data for each occupation were statistically analyzed using a two-factor, nested analysis of variance model of the form

$$\mathrm{PctQrtzT}_{ijk} = \mu + \beta(\mathrm{time}) + \alpha_i + \delta_{ij} + \varepsilon_{ijk}$$

where:

$\mu$ = overall mean
$\beta$ = coefficient of time effect
time = number of years
PctQrtzT = $10\,[\arcsin(\mathrm{PctQrtz}^{1/2}/10)]$
$\alpha_i$ = fixed mine effect
$\delta_{ij}$ = random MMU effect for jth MMU in ith mine
$\varepsilon_{ijk}$ = residual error for kth measurement in jth MMU of the ith mine

In addition to the rigorous statistical analysis, the data were informally analyzed. For the informal analysis, the mean and standard deviation of the mean quartz percentages of the MMUs for each mine were calculated. For each mine the percentage of MMUs having a mean quartz percentage within one standard deviation of the mine's mean quartz percentage was calculated. In addition, the standard deviations characterizing the inter-MMU variability associated with each mine were compared.

## Discussion

### *Occupational Quartz Data Compiled by Mining Type*

The compilation of quartz data by type of mining for underground occupations is shown in Tables 1 to 3. Shown on the tables are the number of samples analyzed for each occupation, the percentage of samples that contained greater than 5 percent quartz, and the percentage of samples having a quartz concentration greater than 100 $\mu g/m^3$. Data for two time periods are shown: 1985 through 1992, and July 1991 through 1992. The period beginning July 1991 was chosen because this was the date MSHA initiated analysis of all enforcement samples with sufficient mass for quartz content, giving the broadest distribution of information regarding quartz content across different occupations. Only the data for the latter period will be discussed in detail, since this provides the most up-to-date information on current occupational exposure levels.

The data in Table 1, for conventional mining operations, show that the percentage of quartz was greater than 5 percent for approximately 10 percent of the samples representative of most of the occupations noted. A similar percentage of samples exceeded a quartz concentration of 100 $\mu g/m^3$. The percentage of roof bolter samples with greater than 5 percent quartz

TABLE 1. Occupational Quartz Exposures in Underground Conventional Mining Operations

| | 1985 through 1992 | | | July 1991 through 1992 | | |
|---|---|---|---|---|---|---|
| | | Percentage of Samples | | | Percentage of Samples | |
| Occupation | Number of Samples | >5% | >100 μg/m³ | Number of Samples | >5% | >100 μg/m³ |
| Roof bolter single head | 1051 | 40* | 33 | 140 | 37* | 32 |
| Roof bolter (DA) | 169 | 33* | 25 | 40 | 42* | 33 |
| Coal drill operator | 395 | 14 | 8 | 116 | 12 | 8 |
| Scoop car operator | 301 | 12 | 6 | 151 | 11 | 9 |
| Cutting machine operator DO | 1068 | 7 | 10 | 187 | 10 | 12 |
| Shuttle car operator | 104 | 9 | 3 | 20 | 12 | 4 |
| Loading machine operator | 80 | 7 | 6 | 39 | 9 | 7 |

*Fifteen to 20 percent of samples had quartz percentages greater than 10 percent.

(40%) was significantly higher than for other occupations. For the roof bolting occupation on conventional mining operations, the percentage (32%) of samples that exceeded 100 $\mu g/m^3$ also was similar to the percentage with more than 5 percent quartz. Quartz exposures were found to exceed 200 $\mu g/m^3$ approximately 15 percent of the time for the roof bolting occupation. Approximately 30 percent of the samples that exceeded 100 $\mu g/m^3$ had a low quartz percentage (less than 6%), but the dust concentration was so high that the quartz standard was exceeded.

For continuous-mining operations (Table 2), the percentage of occupational samples with greater than 5 percent quartz is considerably higher than that shown for occupations on conventional mining operations. Approximately 40 percent of the samples collected for the continuous-miner operator and continuous-miner operator helper occupations and 20 percent of the samples for the other occupations had quartz percentages that exceeded 5 percent. This is approximately twice that obtained for most occupations on conventional operations. The percentage of roof bolter samples (55%) with greater than 5 percent quartz was again significantly higher than for other occupations. In general, those occupations that had a significant percentage of samples with greater than 5 percent quartz also had a significant number of samples that represented respirable quartz exposures greater than 100 $\mu g/m^3$. The percentage exceeding 100 $\mu g/m^3$ was approximately half that exceeding 5 percent for most occupations. Quartz exposures were found to exceed 200 $\mu g/m^3$ approximately 15 percent of the time for the roof bolting occupation and the continuous-miner operator occupation. Approximately 15 percent of the samples collected on continuous-mining MMUs which exceeded 100 $\mu g/m^3$ had less than 6 percent quartz.

On longwall mining operations (Table 3), approximately 20 percent of the samples had greater than 5 percent quartz, approximately twice the percentage of samples for conventional mining operations and two-thirds that of the DO on

TABLE 2. Occupational Quartz Exposures in Underground Continuous-Mining Operations

| | 1985 through 1992 | | | July 1991 through 1992 | | |
|---|---|---|---|---|---|---|
| | | Percentage of Samples | | | Percentage of Samples | |
| Occupation | Number of Samples | >5% | >100 μg/m³ | Number of Samples | >5% | >100 μg/m³ |
| Roof bolter single head | 4127* | 56 | 42 | 546* | 61 | 30 |
| Roof bolter (DA) | 3143* | 52 | 32 | 1067* | 61 | 39 |
| Roof bolter twin intake | 1460* | 47 | 30 | 361* | 52 | 30 |
| Roof bolter twin return | 2051* | 48 | 33 | 366* | 48 | 33 |
| Roof bolter helper single | 192* | 55 | 34 | 60* | 68 | 40 |
| Continuous miner operator DO | 10,849* | 37 | 29 | 2245* | 42 | 30 |
| Continuous miner helper | 1386* | 37 | 33 | 561* | 41 | 25 |
| Scoop car operator | 356 | 31 | 18 | 224 | 31 | 19 |
| Shuttle car operator | 2451 | 25 | 13 | 1431 | 25 | 11 |
| Roof bolter mounted return | 269 | 18 | 13 | 44 | 11 | 9 |
| Utility man | 177 | 19 | 12 | 136 | 21 | 14 |
| Roof bolter mounted intake | 191 | 13 | 10 | 42 | 12 | 7 |
| Mobile bridge operator | 213 | 29 | 13 | 164 | 28 | 13 |
| Section foreman | 183 | 17 | 8 | 132 | 19 | 9 |
| Electrician | 41 | 20 | 7 | 37 | 19 | 8 |
| Tractor operator/motorman | 70 | 26 | 7 | 51 | 24 | 6 |
| Mechanic | 61 | 23 | 12 | 31 | 23 | 13 |

*Fifteen to 20 percent of samples had quartz percentages greater than 10 percent.

TABLE 3. Occupational Quartz Exposures in Longwall Mining Operations

| Occupation | 1985 through 1992 | | | July 1991 through 1992 | | |
|---|---|---|---|---|---|---|
| | Number of Samples | Percentage of Samples | | Number of Samples | Percentage of Samples | |
| | | >5% | >100 μg/m³ | | >5% | >100 μg/m³ |
| Tailgate operator | 50 | 16 | 18 | <20 | — | — |
| Longwall shearer operator (tailgate) DO | 762 | 20 | 23 | 261 | 20 | 20 |
| Jacksetter | 813 | 19 | 18 | 384 | 19 | 16 |
| Return side face worker DO | 27 | 33 | 50 | 20 | 25 | 35 |
| Longwall shearer operator (headgate) | 234 | 12 | 13 | 146 | 14 | 19 |
| Headgate operator | 210 | 7 | 2 | 154 | 6 | 3 |
| Section foreman | 59 | 6 | 4 | 46 | 4 | 4 |
| Mechanic | 66 | 5 | 2 | 58 | 5 | 2 |

continuous-mining operations. Unlike conventional and continuous mining, no occupation stands out as having a significantly higher quartz exposure than the norm. The number of samples that represented exposures greater than 100 $\mu g/m^3$ was approximately the same as the percentage that contained greater than 5 percent quartz; however, nearly 40 percent of these samples had less than 6 percent quartz.

These data show that, based on samples collected for occupations which are typically the DO, a significant number (approximately 30%) of underground MMUs would be expected to be on a reduced respirable coal mine dust standard requiring more stringent control of dust levels to avoid overexposure to quartz. They also show that at the time the operations represented by these data were sampled for compliance with the respirable coal mine dust standard, approximately 25 percent of the miners were exposed to quartz concentrations greater than 100 $\mu g/m^3$.

Tables 4 and 5 show the compilation of quartz data for surface coal mines and surface facilities of underground mines. The data in Table 4 are representative of those occupations that are specifically designated by MSHA for operator sampling, while the data in Table 5 are representative of other occupations selected and sampled by MSHA enforcement personnel. The occupations shown in Table 5 are referred to as nondesignated work position (NDWP) samples. As the data show in both Tables 4 and 5, the percentage of samples that contain more than 5 percent quartz for surface occupations is significantly higher than for underground occupations. Approximately 70 percent of the DWP samples collected at the highwall drill operator, highwall drill helper, bulldozer operator, and refuse/backfill truck driver occupations contained greater than 5 percent quartz. Of the samples collected for these occupations, approximately 60 percent represented occupations whose exposures were greater than 100 $\mu g/m^3$. NDWP samples collected for these occupations, as well as for the scraper operator and blaster/shooter/shotfirer occupations, had percentages of samples that had greater than 5 percent quartz and more than 100 $\mu g/m^3$, similar to those obtained for the DWP occupations. Only four percent of the samples collected at surface operations exceeding 100 $\mu g/m^3$ had a low quartz percentage.

### *Trend Analysis of Occupational Data*

Figures 1 to 3 show trend plots of the annual average quartz percentage of selected occupations. The trend lines in Figure 1 for continuous-miner operator, continuous-miner operator helper, and shuttle car operator all indicate that the average annual quartz percentage for these occupations has been increasing, and that, in 1992, the average was approximately 1.25 times what it was in 1985. It is also noteworthy that the average quartz percentages for the continuous-miner operator and continuous-miner operator helper samples in 1992 were greater than 5 percent. Although the slope of the trend line for the longwall shearer operator (Figure 2) is similar to those of the occupations discussed above, only in 1989 did the average quartz percentage of the longwall shearer operator exceed 5

TABLE 4. Occupational Exposure of the DWP on Surface Coal Mining Operations (1985–1992)

| Occupation | Number of Samples | Percentage of Samples | |
|---|---|---|---|
| | | >5% | >100 μg/m³ |
| Highwall drill helper | 40 | 88 | 85 |
| Highwall drill operator | 865 | 81 | 77 |
| Bulldozer operator | 575 | 68 | 60 |
| Scraper operator | 39 | 62 | 45 |
| Refuse/backfill truck driver | 347 | 46 | 41 |
| Coal truck driver | 37 | 46 | 44 |
| Highlift operator | 196 | 25 | 26 |
| Oiler/greaser | 33 | 15 | 15 |
| Coal sampler | 41 | 7 | 10 |
| Cleanup man | 157 | 5 | 10 |
| Washer operator | 43 | 9 | 5 |
| Scalper/screen operator | 116 | 5 | 9 |
| Mechanic | 177 | 4 | 4 |
| Laborer/blacksmith | 271 | 4 | 7 |
| Electrician | 45 | 2 | 2 |
| Fine coal plant operator | 262 | 2 | 4 |
| Tipple operator | 181 | 2 | 6 |
| Cleaning plant operator | 168 | 1 | 2 |
| Dryer operator | 48 | 0 | 0 |
| Froth cell operator | 42 | 0 | 0 |

TABLE 5. Occupational Quartz Exposure of the NDWP on Surface Coal Mining Operations (1985–1992)

| Occupation | Number of Samples | Percentage of Samples >5% | Percentage of Samples >100 μg/m³ |
|---|---|---|---|
| Highwall drill helper | 30 | 90 | 79 |
| Highwall drill operator | 815 | 81 | 75 |
| Blaster/shooter/shotfirer | 38 | 71 | 58 |
| Scraper operator | 118 | 63 | 48 |
| Bulldozer operator | 1389 | 56 | 47 |
| Refuse/backfill truck driver | 714 | 40 | 31 |
| Road grader operator | 40 | 32 | 27 |
| Coal truck driver | 90 | 30 | 23 |
| Highlift operator | 914 | 25 | 16 |
| Crusher attendant | 45 | 9 | 9 |
| Oiler/greaser | 60 | 15 | 8 |
| Mechanic | 144 | 7 | 5 |
| Auger operator | 34 | 9 | 12 |
| Laborer/blacksmith | 202 | 8 | 7 |
| Coal sampler | 46 | 4 | 4 |
| Washer operator | 50 | 6 | 4 |
| Scalper/screen operator | 70 | 7 | 9 |
| Welder (shop) | 40 | 2 | 5 |
| Auger helper | 35 | 6 | 3 |
| Tipple operator | 231 | 2 | 1 |
| Utility man | 87 | 7 | 5 |
| Cleaning plant operator | 157 | 3 | 3 |
| Cleanup man | 62 | 3 | 5 |
| Electrician | 52 | 4 | 4 |
| Fine coal plant operator | 99 | 2 | 4 |

percent. The trend line for the jacksetter occupation (also in Figure 2) shows that the average percentage for this occupation has been relatively stable over the period 1985 through 1992. The trend lines for the roof bolter occupation and the roof bolter (DA) samples (Figure 3) also show that the annual quartz percentage for these entities has remained fairly constant for the period 1985 through 1992, and that the average annual quartz percentage of these entities is consistently greater than 6 percent.

Figure 4 shows the trend plots of the annual average quartz percentage of selected surface mining occupations. The occupations selected were the bulldozer operator, highwall drill operator, and refuse truck driver. These are occupations that have been identified as having a very high percentage of samples containing greater than 5 percent quartz and a sufficient number of samples analyzed annually. The trend lines for these occupations show that, for the period depicted, the average quartz percentage for all three of these occupations has been relatively constant. The lines also show that the quartz percentage for samples collected from the refuse truck driver, bulldozer operator, and highwall drill operator occupations averaged approximately 6, 12, and 15 percent, respectively.

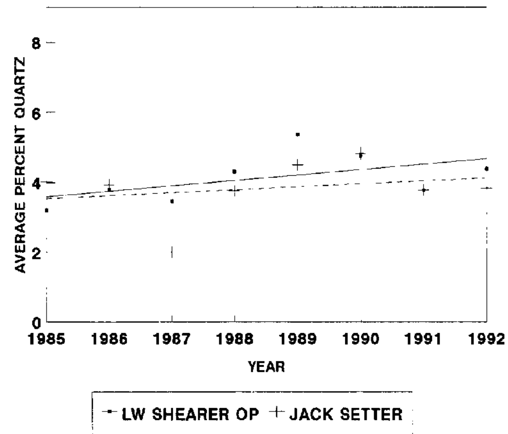


FIGURE 2. Quartz trends for longwall mining operations.

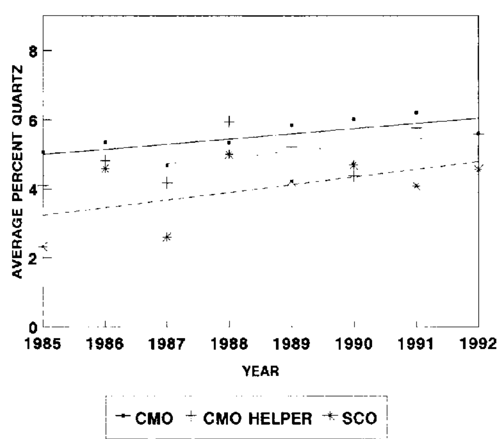


FIGURE 1. Quartz trends for continuous-mining operations.

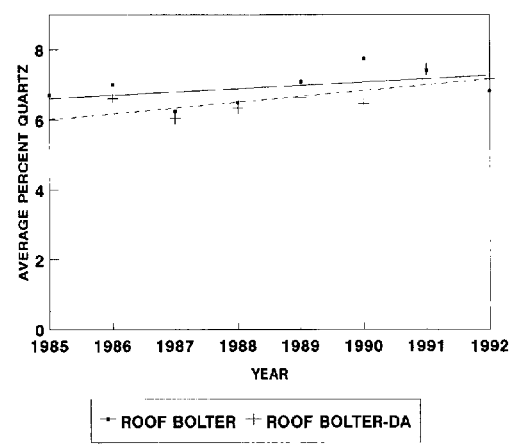


FIGURE 3. Quartz trends for roof bolting operations.

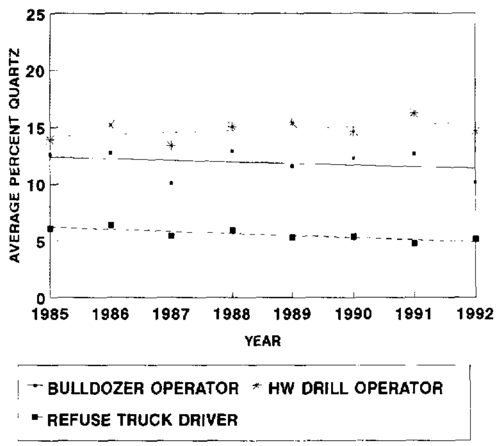


FIGURE 4. Quartz trends for surface operations.

Table 6 shows a summary of the statistics obtained from the regression analysis used to determine the significance of any trends in average annual occupational quartz determination during the period 1985 through 1992. As the data depict, the only underground entities for which established trends were found to have statistical significance are the continuous-miner operator, the cutting machine operator, and the roof bolter (DA). For these entities, the annual average quartz percentage was estimated to increase an amount between 0.12 and 0.19 percent quartz per year. However, the fact that the sign of the slope of the regression line was positive for nine of the ten occupations statistically supports the hypothesis that the average annual quartz percentage for all occupations has increased. This apparent increasing trend was not found for surface occupations. For three of the four occupations studied, the trends were decreasing. Only the trend for the highwall drill operator was increasing. The trends established for the highlift operator and refuse truck driver were found to have statistical significance.

### *Intramine Quartz Variability*

Table 7 shows the results of the analysis of variance of the inter-MMU data. The analysis showed that for both the DO and roof bolter samples, the data provide no evidence of any inter-MMU effect within mines. As would be expected, there is strong evidence of differences between mines; for roof bolters there is weak evidence (confidence level of approximately 85%) of an upward trend in quartz percentage from 1988 through 1992.

Figure 5 shows a plot of the DO data that were used in performing the informal analysis. The figure also shows a comparison of the standard deviations characterizing the inter-MMU variability for the respective mines and the average of the standard deviations of the respective MMUs within the mine. These data show that for 73 percent of the mines the inter-MMU variability, as characterized by the standard deviation, is less than 1.5 percent quartz; and for 41 percent of these mines the standard deviation was less than 1 percent. The data also show that, on average, the variability associated with measurements obtained on the same MMU is approximately twice (1.9) the variability associated with inter-MMU quartz determinations.

Figure 6 similarly shows a graphical plot of the roof bolter data. The comparisons in this figure show that the standard deviation of the MMU roof bolter means was less than 1.5 percent quartz for 70 percent of the mines and less than 1 percent in 45 percent of the mines. The variability associated with measurements obtained on the same MMU was approximately 2.6 times the variability associated with inter-MMU quartz determinations.

In general, both the rigorous statistical and informal analyses of quartz data from multisection mines indicate that the percentage of quartz in respirable dust samples collected on different MMUs in a multisection mine would be expected to be similar (within ±1.5%).

### *Data Bias*

The quartz data that were used to perform the preceding analyses are not representative of all the samples collected. To maintain the precision of a quartz determination to that specified by NIOSH for an analytical method,[15] samples that have a net weight gain of less than 0.45 mg are not analyzed for quartz content. As a result of the minimum weight limit imposed on samples to be analyzed, approximately 40 percent of samples collected for underground occupations and 70 percent of samples collected for surface occupations are not analyzed. In utilizing the results of these analyses, it is important to recognize that if the distribution of quartz determinations for the unanalyzed samples is different than for the analyzed samples, the results of these analyses would be biased. The magnitude and direction of the bias (underestimation or overestimation of the average quartz percentages presented) would be dependent on the number of samples used and not used in estimating the averages.

Although a rigorous analysis of the data was not performed, it is the opinion of the authors that, for the underground mine data, the distribution of quartz percentages of the unanalyzed samples would be similar to that of the analyzed samples and would therefore have little effect on the estimated averages. This opinion is based on the fact that the number of DO and roof bolter samples, which are characteristic of the aerosol in the environment of the MMU, is large and representative of a high percentage of the underground mines. Also, an examination of sample weight versus average sample quartz percentage data compiled for the shuttle car operator and jacksetter occupations showed that the average quartz percentage was independent of sample weight.

For the surface mine data there is more potential for bias. This is because a high percentage (70%) of surface samples have net weight gains less than 0.45 mg/m$^3$, and the number of samples representative of the different occupations is limited. Also, the number of mines for which representative occupational samples are collected is limited. However, a sample weight versus average quartz percentage analysis of the highlift operator occupation data also showed no dependence of the quartz percentage on sample weight.

Clearly, the fraction of samples showing a concentration in excess of 100 $\mu$g/m$^3$ would be lower if the unanalyzed samples

TABLE 6. Summary of Regression Analysis Statistics

| Occupation | Number of Samples | Average Quartz (%) | Standard Deviation of Annual Average | Estimated Rate of Change (% Qtz/Year) | Standard Error | Statistical Significance[A] (%) | Sign of Regression[B] Line |
|---|---|---|---|---|---|---|---|
| Underground | | | | | | | |
| Coal drill operator | 395 | 3.29 | 0.51 | — | — | 54.0 | + |
| Continuous-miner helper | 1386 | 5.48 | 0.50 | — | — | 42.0 | + |
| Continuous-miner operator | 10,793 | 5.54 | 0.50 | 0.15 | 0.060 | 5.0 | + |
| Cutting machine operator | 1067 | 2.47 | 0.40 | 0.12 | 0.046 | 4.0 | + |
| Jacksetter | 815 | 3.98 | 0.44 | — | — | 84.0 | − |
| Longwall shearer operator | 762 | 4.02 | 0.63 | — | — | 11.0 | + |
| Roof bolter | 6061 | 6.97 | 0.43 | — | — | 22.0 | + |
| Shuttle car operator | 1883 | 4.33 | 0.45 | — | — | 51.0 | + |
| Scoop car operator | 721 | 4.27 | 0.45 | — | — | 81.0 | + |
| Roof bolter (DA)[C] | 3508 | 6.77 | 0.50 | 0.19 | 0.072 | 4.9 | + |
| Surface | | | | | | | |
| Bulldozer operator | 1980 | 11.92 | 1.04 | — | — | 34.0 | − |
| Highlift operator | 1116 | 4.20 | 0.84 | 0.31 | 0.10 | 1.8 | − |
| Highwall drill operator | 1687 | 14.91 | 0.75 | — | — | 37.0 | + |
| Refuse truck driver | 1064 | 5.51 | 0.49 | 0.18 | 0.049 | 1.0 | − |

[A]Low percentages indicate statistically significant results.
[B]Positive value indicates increasing trend; negative value indicates decreasing trend.
[C]Data available only since 1986.

could be included. However, the majority of underweight samples are collected at surface operations, which also include those occupations with the highest quartz content in the dust to which they are exposed. Even though the dust levels are low, there may be overexposure to quartz. For example, of the samples collected from the highwall drill operator which weighed less than 0.5 mg but were analyzed for quartz content, approximately 20 percent showed over 100 $\mu g/m^3$ of quartz.

## Summary

Occupational quartz exposure data gathered by the MSHA during the period 1985 through 1992 were compiled and analyzed to characterize current occupational exposures to quartz; to determine if the quartz percentages of samples collected for different occupations have changed during the period 1985 through 1992; and to study the variability associated with quartz sample percentages of DOs and the roof bolter occupation working on different MMUs within the same mine.

The analysis showed that:

TABLE 7. Analysis of Variance

| Null Hypothesis $H_o$ | Continuous Miners | Roof Bolters |
|---|---|---|
| $\alpha_i = 0$ for all mines | 0.00[A] | 0.00[A] |
| $\beta = 0$ | 0.91 | 0.14[B] |
| Var $[\delta_{ij}] = 0$ | 1.00[C] | 1.00[C] |

[A]Less than 0.001.
[B]$\beta$ = coefficient of time effect = 0.21 ± 0.15.
[C]More than 0.999.
$\alpha_i$ = fixed mine effect.
$\delta_{ij}$ = random MMU effect for jth MMU in ith mine.
Tabled values are 1 − confidence level for rejecting $H_o$.

1. Regardless of the type of coal extraction process used, there are a substantial number of occupational samples that contain greater than 5 percent quartz and indicate overexposure to quartz. Underground, more than 30 percent of the samples collected at the continuous-miner operator and continuous-miner operator helper occupations on continuous-mining operations, and at the roof bolting occupation on both conventional and continuous-mining operations, had quartz exposures that exceeded 100 $\mu g/m^3$. Approximately 60 percent of the samples collected at the roof bolting occupation and 40 percent of the samples collected at the continuous-miner operator and continuous-miner

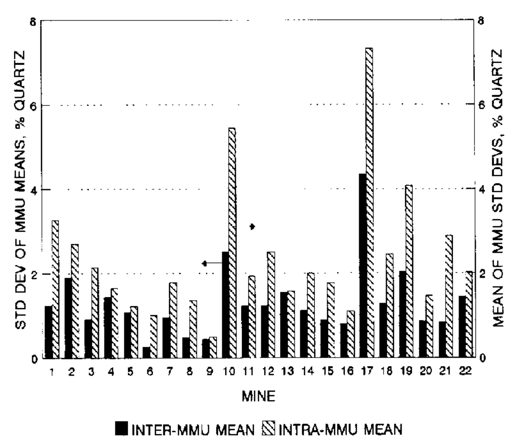


FIGURE 5. Standard deviations of MMU means: DO data.

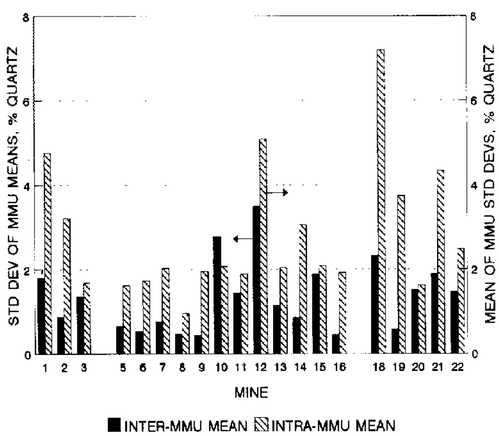


FIGURE 6. Standard deviations of MMU means: roof bolter data.

operator helper occupations had greater than 5 percent quartz. At surface operations, several occupations, including highwall drill operators, highwall drill helpers, bulldozer operators, and road scraper operators, had an even larger proportion of samples indicating excessive exposure (approximately 60% of the samples) and high quartz fraction (approximately 70% of the samples).

2. For underground mines, the quartz exposures of the continuous-miner operator and cutting-machine operator occupations and roof bolter (DA) have increased by 0.12 to 0.19 percent quartz per year. While not statistically significant, the trend of the annual average quartz percentage for all underground occupations except the jacksetter on longwall mining operations was to increase. For surface mines, the average quartz percentage of three of four occupations studied decreased. Only the average quartz percentage of the highwall drill operator showed an increase.
3. Occupational quartz determinations on different MMUs in multisection mines were found to be statistically and empirically similar.

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