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Analysis of Data on Respirable Quartz Dust Samples Collected in Metal and Nonmetal Mines and Mills

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CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

dBa	decibel (A scale)
cm^3	cubic centimeter
h	hour
mg/m^3	milligram per cubic meter
mppcf	million particles per cubic foot
pct	percent
ppm	parts per million
$\mu g/m^3$	microgram per cubic meter
μm	micrometer
WL	working level
yr	year

ANALYSIS OF DATA ON RESPIRABLE QUARTZ DUST SAMPLES COLLECTED IN METAL AND NONMETAL MINES AND MILLS

By W. F. Watts, Jr.,[1] D. R. Parker,[2] R. L. Johnson,[3] and K. L. Jensen[4]

ABSTRACT

This report describes a statistical analysis of 41,502 respirable quartz dust samples collected from 1974 through 1981 in metal and nonmetal mines and mills. The goal of this Bureau of Mines study was to identify commodities and occupations associated with high quartz dust exposure so that future enforcement and research activity can be focused on the high-exposure areas.

For this analysis, the Bureau used its computerized Mine Inspection Data Analysis System (MIDAS), which contains data on nearly 350,000 air samples, including data for 61 contaminants in 45 commodities. The samples analyzed were collected by inspectors of the Mine Safety and Health Administration (MSHA). The data were entered into the MIDAS computer and coded according to commodity, occupation, location, and other categorical information. Occupations and commodities with high quartz dust exposure were identified by grouping the data by code categories.

Workers at sandstone, clay and shale, and miscellaneous nonmetallic mineral mills had the highest quartz dust exposures. Within these mills, occupations with high exposures were baggers, general laborers, and persons involved in crushing, grinding, and sizing operations. Dust concentrations in these mills were not necessarily the highest, but because the dust contained a high percentage of quartz, the health risk from dust exposure was the greatest.

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INTRODUCTION

The 1980 National Academy of Science report on respirable dust in mines (1)[5] concluded that there was a critical need to assess the magnitude of respirable dust exposures in noncoal mines. Exposure to respirable quartz dust (RQ)[6] has been linked to silicosis, a form of pulmonary fibrosis. Pulmonary fibrosis is disabling, progressive, and sometimes fatal. Silicosis tends to occur after years of exposure, but occasionally high exposures of only a year or more lead to acute silicosis (2). To assist researchers and enforcement personnel in their efforts to protect workers from RQ hazards, the Bureau of Mines undertook a statistical analysis designed to identify mine and mill commodities and occupations associated with high quartz dust exposure. The results of this analysis are presented in this report.

The Federal Government agency responsible for establishing and enforcing mine health and safety standards is MSHA. MSHA inspectors determine compliance with metal and nonmetal mine and mill Federal health standards through the collection and analysis of environmental air samples. They collect many types of samples for a variety of contaminants in noncoal mines and mills, and these samples constitute a large body of historical industrial hygiene data. Since 1974 MSHA has collected nearly 350,000 samples in metal and nonmetal mines and mills, and records of these exposures are stored in MIDAS, a computerized information system operated by the Bureau (3). MIDAS is a data base and software system designed to analyze the industrial hygiene data collected by MSHA, and to associate these data with other mine information collected from other sources. MIDAS is accessible from remote terminals around the country via the Bureau's telecommunications network. Certain aspects of the system are discussed in this report, and a description of the software used in MIDAS has been previously reported (4).

MSHA CODING SYSTEM

MSHA uses a coding system to describe the occupational environments where personal samples (obtained from monitors worn by personnel) are collected.

The codes are substituted for a comprehensive written description of the workplace in order to facilitate automated data processing. They provide a description of the industry (commodity produced at the mine site), operation (occupation of the person monitored for sampling), and a location (mine type) for personal sample collected. Personal samples are collected over an entire workshift, and for each sample an individual computer record is maintained. Other valuable information in the computer record includes mine identification number, date, contaminant measured, concentration, threshold limit value (TLV), and social security number of the miner. A typical set of codes might describe a respirable dust sample collected for a load-haul-dump diesel operator in a limestone quarry in Illinois.

The approach used in this analysis was to calculate exposures for different populations of workers. The codes were used individually or in combinations to define population groups. Grouping similar codes together helped compensate for the recurring problem of inadequate sample size. A complete discussion of the groups used in the analysis is included in the "Results" section. Complete lists of the descriptors used for contaminant, commodity, location, and occupation are in appendix tables A-1 through A-5.

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[5] Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

[6] Except for unit of measure abbreviations, all abbreviations are identified the first time they are used and are also listed in appendix C. (Unit of measure abbreviations are listed after the table of contents.)

MINE INSPECTION DATA ANALYSIS SYSTEM (MIDAS)

FILE STRUCTURE

MIDAS includes 5 master files that contain over 400,000 records. The master files are used to create smaller files for analysis. The master files are known as the personal exposure file, the area sample file, the Minerals Availability System (MAS) data base, the 22-mine survey file, and the mines file; and each has a different format. The RQ data are contained in the edited personal exposure file, which is described in the next section.

The mines file is an index of all metal and nonmetal mine properties in the United States. Each property is listed with a unique mine identification number, its location, the property name, company name, approximate number of employees (if any), year-round or other status, and other data. Information from this file is stripped off and added to records of personal and area samples, thus allowing records from similar commodities and mine types to be sorted and grouped together. This sorting and grouping is possible because every record in MIDAS, regardless of its format, has a mine identification number of seven digits. Thus all data are cross-referenced by mine identification numbers.

Worldwide commodity information for about 200,000 mine properties is available in the MAS data base. Data from this file contribute to the ability of MIDAS to group producers of similar commodities together for analysis, particularly when mine properties that produce both primary and secondary products are involved. Often the first clue pointing to a potentially hazardous exposure comes from knowledge of what product or products are mined. The classification system used in the MAS is more extensive than that available in the mines file. Among the sources of data gathered for the MAS are mine operators, government agencies, and published literature.

In 1976-77 MSHA conducted an environmental health survey of 22 underground metal and nonmetal mines with assistance from the National Institute of Occupational Safety and Health (NIOSH) and the Bureau. The results of this survey are in the 22-mine survey file. (The Public Health Service and the Bureau had previously surveyed some of the same mines in the late 1950's.) About 17,000 personal and area samples have been collected at the 22 mines. These samples are the only industrial hygiene data in MIDAS that were not collected during mine inspections.

The area record file contains 136,174 records of area samples. An area sample is a grab sample collected by a sampling device (detector tube, bistable, vacuum bottle, instantaneous monitor, glass impinger, or charcoal tube) located near the worker. The area samples are for toxic and asphyxiant gases, mists and vapors, and radon daughters.

The RQ data are contained in the personal exposure file. This file also contains data on occupational exposures to other airborne contaminants regulated by MSHA. The data were collected by monitoring miners over the course of an entire workshift. The file, as received from MSHA, contained 206,888 records of personal exposure, of which 183,995 (89 pct) passed an editing process. Editing was necessary because of errors in the records. These errors included duplicate entries, decimal place errors, coding errors, erroneous TLV's, and misclassification of samples.

DATA EDITING

MSHA regulates health and safety conditions in mines under the authority of the Federal Mine Safety and Health Act of 1977 (5). The specific regulations are found in the Code of Federal Regulations, Title 30, (6), but for RQ and other airborne contaminants, MSHA adopted the 1973 recommended TLV's of the American Conference of Governmental Industrial

Hygienists (ACGIH) (7). The TLV for RQ is determined by collecting a respirable dust sample, analyzing for quartz content,[7] and calculating the TLV using the formula

$$\frac{10\ \text{mg/m}^3}{\text{percent respirable quartz} + 2}$$

when the quartz content (percent respirable quartz) is $\geq$1 pct. (The resultant TLV is expressed in milligrams per cubic meter.) The TLV for respirable dust containing quartz is therefore inversely proportional to the quartz content of the sample. Thus, for a given exposure level, the magnitude of toxicity is proportional to the quartz content (8).

Respirable dust is capable of deep lung penetration and is generally defined as that fraction of an aerosol which includes particles with an aerodynamic diameter of less than 5 µm. However, the size classifiers used with personal samplers do not have a sharp size cutoff; they reject some dust particles with diameters less than 5 µm and allow small numbers of larger particles to pass (8). The factor 2 in the denominator of the TLV formula ensures that dust exposures will not be excessively high when the quartz content is less than 5 pct and effectively limits the dust concentration to 5 mg/m^3 when no quartz is identified in the sample.

The MIDAS records of RQ exposure were edited using the TLV formula. By substituting 1.0 and 100 for percent respirable quartz in the formula, it was determined that the TLV for RQ-bearing dusts must be between 0.10 and 3.33 mg/m^3. Therefore, when the TLV recorded in a record fell within this range, the record was considered valid; otherwise, the data were recoded based upon alternative rules (3).

Editing the RQ records resulted in retention of 75 pct of the original records, the creation of 11,582 respirable nuisance dust records (21 pct of the original records), the recoding of 937 records (1.7 pct), and the rejection of 1,047 records (1.9 pct). The number of respirable nuisance dust records created during the editing process was large because MSHA inspectors have only one code for respirable dust regardless of quartz content. MIDAS was used to create a code for respirable nuisance dust when the TLV exceeded 3.33 mg/m^3, which indicated the sample contained less than 1.0 pct quartz.

Other important features of the editing process were additions made to each record to simplify sorting and analysis. MIDAS calculated the concentration-to-TLV ratio (C/TLV) for every record of personal exposure and added it to each record. The percentage of silica in every dust sample was also calculated and added to the records. The following information from the mines file was added to each record: commodity code, mine type, mine status, size group, and number of employees at the sampled mine. For computing geometric statistics (statistics based on a log transformation), concentrations reported as zero were considered equal to 0.001 mg/m^3.

SAMPLING STRATEGY

MSHA inspectors collect samples to ensure compliance with the 1973 ACGIH TLV's, which have been adopted as standards by MSHA. The samples are not collected as they would be in a scientifically designed survey; rather, sampling is judgmental. This creates a statistical problem: These data may not be representative, so the classical statistical assumptions of randomness, homoscedasticity (homogeneous variance), and normal distribution may not apply. The factors discussed below (in order of relative importance) are believed to influence MSHA's sampling strategy.

[7] Quartz content is determined by X-ray diffraction after the filter has been weighed.

The 1977 Mine Safety and Health Act mandates that each underground mine be inspected four times per year and each surface mine or mill must be inspected two times per year. This requirement reflects the general opinion of Congress and the miners' unions that a Federal presence is important at every mine, and that underground mines are more hazardous than surface mines and mills.

MSHA establishes mine health ranking criteria which are used as sampling guidelines (9). (The criteria are listed in part in appendix B.) In fiscal year 1982, these guidelines included three ranks: A, B, and C. Rank A lists mine categories known to have the greatest health risks. Mines with a history of noncompliance receive more frequent inspections. However, resampling of an area previously out of compliance is not done unless the mine operator has instituted environmental controls or a personal protection program. The mine operator may request additional sampling to demonstrate the effectiveness of the control measures, which may result in a cluster of samples being collected at certain properties. Inspectors are instructed to sample employees having the greatest potential for exposure, and this determination depends upon the judgment of the inspector. In addition, the number of employees at the mine site affects the proportion of employees sampled and to some extent the number of inspectors required per visit. An illustration of the effect commodity and employment have on sample distribution was provided in a previous report (3) where it was shown, for instance, that 0.13 samples were collected per employee from molybdenum properties and 0.41 samples were collected per employee from limestone properties. From the same properties, 7 samples were collected per limestone property in contrast to more than 50 samples per molybdenum property. In this case there were many small limestone mines with few employees, but only a few large molybdenum mines with many employees.

Market forces affect the number of mines of any one type which are in operation, and their production and employment levels. Mines inspected one year may not be inspected the next, because of strikes, mine shutdowns or closures which result from a drop in commodity price or declining ore quality, or other similar circumstances.

MSHA is affected by changes in budget appropriations and administrative policies. These changes affect the number and location of MSHA district offices, the number of inspectors, and the number and types of inspections conducted each year.

Since much of MSHA's sampling strategy is "worst case," it is nonrandom and may be biased. However, the degree and direction of all possible biases are obscure. Several factors suggest that MSHA's data are representative. Companies are not given prior notice of inspections, so operators cannot make special preparations. No operator can deny an MSHA inspector access to its property, thus every mine can be inspected. This differs from a research survey in which mines are asked to participate and know well in advance when samples will be collected. Although inspectors are instructed to select workers with the greatest potential for overexposure, most of the samples reported had low dust concentrations. In attempting to pick out "high-risk" workers, the inspectors cannot know if individual workers will actually encounter high dust exposures. However, the results were typical of environmental sampling. Environmental samples are typically log-normally distributed, meaning that many low concentrations are reported. The authors therefore believe the MSHA data are typical of the results that would be expected from a survey using sampling strategies designed to assure randomness. The results suggest that the MSHA inspectors, using common sense and judgment, collected "representative" samples within each occupation, location, and commodity group. Finally, certain commodities, occupations, and locations are sampled so frequently that MSHA may approach a census of those mining subpopulations.

RESULTS

DATA DISTRIBUTION

The first part of the analysis was aimed at determining (1) the distribution of the number of samples by contaminant, commodity, location, and occupation and (2) the best measures of exposure. Table 1 shows that 12 contaminants accounted for 94 pct of all the samples collected, and that RQ samples accounted for 13 pct, ranking it second to noise (28 pct). However, if the samples for RQ, total nuisance dust,[8] respirable nuisance dust,[9] and total silica dust[10] are combined, they acount for about 25 pct of all the industrial hygiene samples collected. Tables A-1 and A-2 in appendix A list all airborne contaminants for which personal or area samples were collected, and tables A-3 through A-5 show the number of RQ samples distributed by commodity, location, and occupation. It can be seen from these tables that the number of RQ samples collected varied considerably from code to code.

From 1974 through 1981 MSHA collected 41,502 RQ samples at 4,815 mine and mill properties on 32,188 miners. From table 2 it can be calculated that these samples were collected at 30 pct of the properties on 12 pct of the workforce.

[8]Total nuisance dust has a TLV of 10 mg/m^3. This value is used when samples collected for total dust contain less than 1.0 pct quartz. Total dust samples are collected on filters without a cyclone preclassifier to remove nonrespirable particulate.

[9]Respirable nuisance dust has a TLV of 5.0 mg/m^3. This value is used when samples collected for respirable dust contain less than 1.0 pct quartz. Respirable dust samples are collected on filters with a cyclone preseparator ahead of the filter to remove nonrespirable-size particulate.

[10]Total silica dust has a TLV determined by the formula

$$\frac{30\ mg/m^3}{\text{percent quartz} + 3}.$$

This value is used when a dust sample contains 1.0 pct or more quartz.

TABLE 1. - Contaminants most frequently sampled in metal and nonmetal mines

Contaminant	Type of sample	Number of samples	Percentage of total samples
Noise[1]	P	89,830	27.9
RQ	P	41,566	12.9
Methane	A	28,217	8.7
Carbon monoxide	A	28,170	8.7
Radon daughter	A	27,311	8.5
Carbon dioxide	A	24,292	7.5
Oxygen	A	15,663	4.9
Total nuisance dust	P	13,415	4.2
Total silica dust	P	12,515	3.9
Respirable nuisance dust[2]	P	11,582	3.6
Nitrogen dioxide	A	9,261	2.9
Hydrogen sulfide	A	2,450	.8
Subtotal		304,272	94.4
Others		17,897	5.5
Total		322,169	100.0

A Area. P Personal. RQ Respirable quartz dust.
[1]Includes both noise dosimeter and sound level meter measurements.
[2]Category created during editing process.

TABLE 2. - Number of mines and employment by mine type

Mine type	Underground	Surface	Mill	Total
NUMBER OF MINES				
Metal	829	507	585	1,921
Nonmetal	213	1,069	757	2,039
Sand and gravel	0	6,554	0	6,554
Stone	133	3,759	1,863	5,755
Total	1,175	11,889	3,205	16,269
EMPLOYMENT				
Metal	28,547	30,152	37,397	96,096
Nonmetal	9,987	12,184	25,157	46,628
Sand and gravel	0	35,725	0	35,725
Stone	2,081	34,557	43,792	80,430
Total	39,915	112,618	106,346	258,879

NOTE.--Based on final 1981 figures from MSHA, Health and Safety Analysis Center, which show 1,182 uniquely identified mills and 2,023 associated mills.

These are crude estimates because the number of properties and employment fluctuate from year to year, but it is clear that a large percentage of the mines, mills, and workforce was sampled. Overall, the average number of samples per mine sampled was 8.6, and the average number of samples per employee sampled was 1.3.

Table 2 provides information on employment and mine type which is essential for understanding the numerical distribution of the RQ samples. A majority of the mines were either sand and gravel pits or stone quarries with relatively few employees, while the largest segment of the workforce was employed at very large metal mines and mills. The average number of employees at an underground metal mine is 50, whereas the average number of people employed at a sand and gravel pit is 5. Nearly every worker can be sampled at a sand and gravel pit during the course of an inspection; but because of the large number of pits, samples are not collected at every site visit. In contrast, the relatively few large underground metal mines are visited frequently, but only a tiny percentage of the workforce is sampled each time. Thus, the number of RQ samples collected was affected by the number of inspections required by the 1977 Mine Health and Safety Act, the number and types of mines and mine employment, and the degree of hazard perceived by individual inspectors.

In an array of data such as the RQ data, frequency distributions and probability ploys are useful in selecting the appropriate geometric or arithmetic statistics to estimate central tendency and dispersion. A previous report (3) used these techniques to show that the RQ concentrations and C/TLV's reported from 1974 through 1980 approximated a log-normal distribution. This finding suggested that the geometric mean (GM) and geometric standard deviation (GSD) were better indicators of central tendency and dispersion than the corresponding arithmetic values. Figure 1 is a log-normal probability plot of the RQ C/TLV's from 1974 through 1981. The figure suggests that the distribution of C/TLV's approximates a log-normal distribution, although extreme values are present at both tails. (A description of the computer program used to generate this plot can be found in reference 10.)

A straight-line normal probability plot indicates that a population is normally distributed. The abscissa of a point is an observed value, and the ordinate is its expected standard normal value, which is computed by ordering the observed values, assigning a cumulative probability

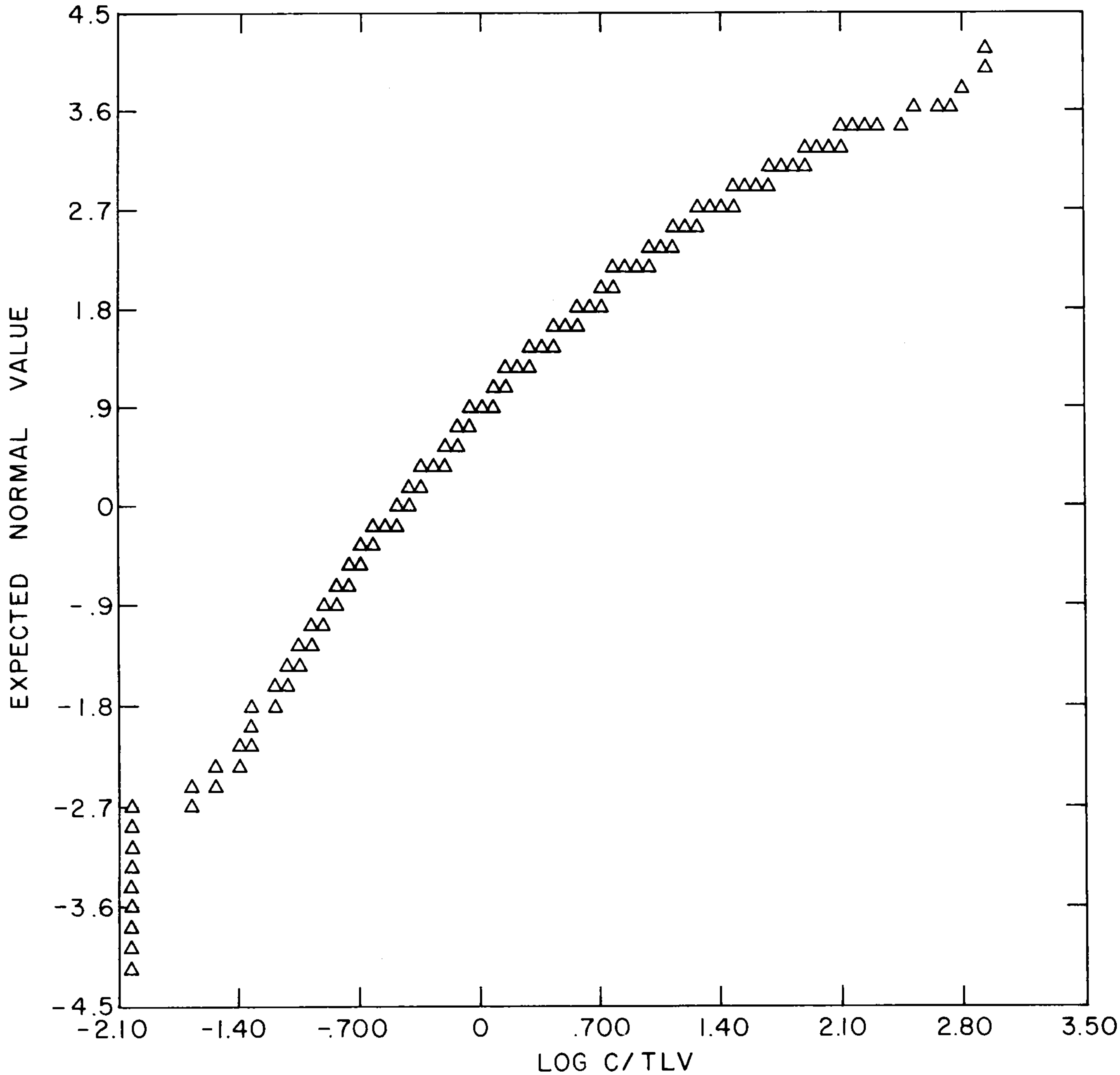

FIGURE 1. - Log-normal probability plot of C/TLV's for RQ.

value to each based upon its rank order within the sample, and then determining the standard normal value corresponding to that cumulative probability value. A standard normal value is a value on the normal distribution (or log-normal distribution in this case) with a mean equal to zero and a standard deviation equal to one. The absolute value of the expected standard normal value of a particular observed value can be understood as the number of standard deviations away from the mean that an observed value of that rank would be expected to lie. Thus, an observed value is related to a cumulative probability value, which is then related to an expected standard normal value. If the plot representing these relationships is close to a straight line, the population may be normally distributed (11).

For log-normally distributed data, the GM C/TLV is an excellent index of exposure because it relates the concentration to the TLV, which is determined by the quartz content of the sample. This allows an immediate assessment of exposure. A C/TLV greater than 1 indicates that an overexposure has occurred. Other measures of exposure are the geometric mean concentration (GM CONC), the median concentration, and the percentage of samples greater than the TLV. The concentration of quartz dust can also be calculated (percent quartz × concentration) and compared to the NIOSH recommended permissible exposure limit (PEL) of 50 μg/m^3 crystalline silica (13) or the maximum allowable level of 100 μg/m^3 under the current TLV (12). The GM C/TLV, the percentage of samples greater than the TLV, and quartz concentration are used in the next section to assess exposure.

VARIABLES ANALYSIS

Year and Mine Type

The second part of the RQ analysis was based on partitioning of the RQ data by year, commodity, occupation, location, and combinations of variables. Such an analysis was possible because each record of exposure includes supplementary coded information. However, as shown in the previous section, the frequency with which each code was used varied considerably, and this was the limiting factor in grouping the data.

Table 3 shows the yearly statistics for RQ; and for comparison, similar statistics are given for respirable nuisance, total nuisance, and total silica dust. It appears that the RQ dust levels were on a downward trend until 1980 and 1981, when slight increases occurred; but in those same years there was a sharp decrease in the number of samples collected, which suggests a shift in dust sampling strategy. Each year, 15 to 20 pct of the RQ dust samples equaled or exceeded the TLV, which demonstrates the continuing problem mines and mills have with RQ.

The average TLV and the average quartz content can be calculated from the GM RQ CONC and the GM C/TLV shown in table 3. These two averages provide a crude estimate of the permissible level of dust in metal and nonmetal mine environments under existing standards. For all years the average TLV was 1.16 mg/m^3 and the average quartz content was 6.6 pct. In comparison, the GM TLV for total silica dust was 3.91 mg/m^3 and the average quartz content was 4.7 pct.

Table 4 shows RQ exposure by mine type. The data were grouped according to the codes shown in tables A-4 and A-5. Table 4 also shows a third variable, time; the RQ data for all years (1974-81) are shown on the left side of the table, and data for only the last 4 yr (1978-81) are shown on the right. Most of the samples were collected in surface stone mines, mills, and quarries, which would be expected given the large number of these facilities. The highest concentrations of dust were found in samples from underground stone mines, but the highest GM C/TLV's were found in samples from nonmetal mills.

Commodity and Occupation

Many of the samples were collected at clay and shale, barite, and miscellaneous nonmetal mills, and a high proportion of the samples from these mills exceeded the TLV (table 5). In this analysis, the category "miscellaneous nonmetals" was used to clarify MSHA's commodity code number 59, which is termed "other nonmetal." This commodity group includes three or four producers of tripoli. Tripoli is typically ground to a fine particle size and contains a high percentage of quartz; as a result, the TLV is low. Samples collected at these two mills severly skew the data for the entire commodity group. Higher concentrations of dust are tolerable at most other facilities because the dust contains a lower percentage of quartz, which increases the TLV.

TABLE 3. - Yearly statistics for RQ, respirable and total nuisance dust, and total silica dust

Year	Total samples	≥ TLV, pct	Concentration, mg/m^3 GM	Median	GSD	GM C/TLV
		RQ				
1974	284	46.13	0.58	0.54	2.62	0.86
1975	2,652	28.39	.49	.47	2.95	.53
1976	6,232	25.69	.51	.48	3.12	.45
1977	7,579	19.44	.44	.43	3.02	.37
1978	7,854	16.16	.40	.38	3.04	.34
1979	7,806	14.16	.38	.35	3.07	.32
1980	4,750	15.24	.40	.37	2.71	.33
1981	4,345	17.35	.43	.40	2.61	.36
Total or average	41,502	18.82	.43	.40	2.98	.37
		RESPIRABLE NUISANCE DUST				
1974	8	0	0.18	0.12	2.87	0.04
1975	479	8.35	.52	.56	5.70	.10
1976	1,309	3.82	.36	.39	5.65	.07
1977	1,840	2.77	.29	.45	8.12	.06
1978	2,312	3.16	.23	.36	9.76	.05
1979	1,803	2.50	.23	.27	7.43	.05
1980	1,624	.99	.14	.13	6.49	.03
1981	2,149	1.26	.11	.12	8.06	.02
Total or average	11,524	2.62	.21	.27	7.99	.04
		TOTAL NUISANCE DUST				
1974	67	25.37	3.95	4.19	3.72	0.04
1975	436	40.37	6.14	7.47	6.36	.61
1976	1,194	34.17	4.59	5.10	5.97	.46
1977	1,600	34.00	4.65	5.62	6.08	.46
1978	2,061	25.52	3.09	4.17	7.40	.31
1979	3,213	20.67	2.22	3.00	7.69	.22
1980	3,035	14.53	1.59	2.16	7.19	.16
1981	1,761	16.47	1.86	2.70	8.24	.19
Total or average	13,367	22.94	2.55	3.43	7.49	.26
		TOTAL SILICA DUST				
1974	34	41.18	1.92	1.65	4.29	0.69
1975	196	66.84	6.50	8.28	4.20	1.59
1976	781	42.25	3.29	3.13	3.68	.76
1977	1,622	39.27	2.78	2.71	4.80	.69
1978	1,693	22.15	1.43	1.46	4.90	.35
1979	3,823	19.88	1.41	1.30	3.69	.37
1980	3,291	21.67	1.66	1.50	3.35	.43
1981	1,071	23.06	1.62	1.51	4.29	.42
Total or average	12,511	25.63	1.76	1.61	4.10	.45

GM Geometric mean.
GM C/TLV Geometric mean concentration-to-TLV ratio.
GSD Geometric standard deviation.
RQ Respirable quartz dust.
TLV Threshold limit value.

TABLE 4. - RQ exposures by mine type for 1974-1981 and 1978-1981[1]

Industry group	1974-81 UG mine	1974-81 Surface mine	1974-81 Mill	1974-81 Total	1978-81 UG mine	1978-81 Surface mine	1978-81 Mill	1978-81 Total
Stone:								
N..................	797	12,745	7,071	20,613	602	8,505	3,525	12,612
GM CONC......mg/m^3..	0.79	0.36	0.55	0.43	0.73	0.36	0.51	0.41
GM C/TLV............	0.40	0.28	0.45	0.34	0.36	0.27	0.45	0.31
Metal:								
N..................	3,301	1,474	2,942	7,717	1,516	1,007	1,611	4,134
GM CONC......mg/m^3..	0.56	0.27	0.43	0.44	0.51	0.26	0.39	0.39
GM C/TLV............	0.45	0.26	0.40	0.39	0.40	0.24	0.35	0.34
Nonmetal:								
N..................	631	1,471	3,314	5,416	299	729	1,718	2,746
GM CONC......mg/m^3..	0.76	0.39	0.77	0.64	0.67	0.34	0.72	0.56
GM C/TLV............	0.57	0.34	0.70	0.56	0.47	0.28	0.64	0.50
Sand and gravel:								
N..................	0	5,180	1,545	6,725	0	3,701	942	4,643
GM CONC......mg/m^3..	NAp	0.27	0.37	0.29	NAp	0.27	0.39	0.29
GM C/TLV............	NAp	0.29	0.59	0.35	NAp	0.29	0.59	0.34
Total:								
N..................	4,730	20,869	14,872	40,471	2,418	13,941	7,796	24,155
GM CONC......mg/m^3..	0.62	0.33	0.54	0.43	0.58	0.32	0.50	0.40
GM C/TLV............	0.45	0.29	0.50	0.37	0.40	0.28	0.46	0.34

GM CONC Geometric mean concentration.
GM C/TLV Geometric mean concentration-to-TLV ratio.
N Sample size (number of samples).
NAp Not applicable.
UG Underground.

[1]Excluded are 1,031 samples which could not be classified by industry group because the mines from which they were taken are permanently closed and were therefore deleted from the master mine file.

The 24 commodities listed in table 5 account for 97 pct of all the samples. The commodities are ordered according to their 1978-81 GM C/TLV's, and the percentage of samples that exceeded the TLV is shown. (Miscellaneous nonmetals encompasses nonmetals not elsewhere classified, such as aplite, vermiculite, kyanite, and tripoli; and miscellaneous stone includes a variety of products such as basalt, diabase, gabbro, and others.) Each mine was assigned a commodity code, but some mines produce more than one product, so the classification system was not perfect. The periods 1974-77 and 1978-81 were chosen because the 1977 Mine Health and Safety Act resulted in changes in the MSHA inspection program, which in turn affected the sampling strategy.

With the exception of traprock, each GM C/TLV was lower in 1978-81 than it was in the preceding 4 yr, which suggests there was improvement in environmental conditions. The GM C/TLV ranking of the first seven commodities in table 5 listed would be the same for 1974-77 as for 1978-81, except that feldspar would be rated second rather than twentieth.

TABLE 5. - Ranking of 24 commodities[1] by 1978-81 RQ GM C/TLV

(In order of decreasing GM C/TLV for 1978-81)

Commodity	1974-77			1978-81		
	N	> TLV, pct	GM C/TLV	N	> TLV, pct	GM C/TLV
Barite	84	61.9	1.44	56	26.8	0.76
Misc. nonmetals	242	43.4	.83	499	40.9	.68
Molybdenum	348	34.2	.71	178	30.9	.65
Clay and shale	1,723	34.9	.65	1,490	28.3	.58
Sandstone	1,363	37.4	.67	1,767	29.9	.55
Misc. stone	161	38.5	.63	307	25.7	.53
Gold and silver	259	28.2	.60	615	16.1	.43
Granite	1,236	22.9	.47	2,273	19.2	.42
Copper	1,214	21.7	.44	785	18.2	.41
Talc	54	29.6	.52	88	13.6	.40
Lead and zinc	566	18.2	.42	339	11.8	.40
Slate	137	18.2	.51	129	7.0	.40
Traprock	307	11.1	.28	404	17.3	.38
Fluorspar	56	30.4	.59	66	12.1	.37
Sand and gravel	2,082	21.8	.35	4,643	15.1	.34
Lime	193	20.2	.31	200	14.5	.30
Cement	1,264	18.3	.36	1,083	10.8	.30
Phosphate	341	19.3	.46	121	9.1	.30
Uranium	487	18.5	.41	610	6.2	.28
Feldspar	65	40.0	.88	128	12.5	.27
Mica	18	16.7	.56	116	6.0	.27
Iron	650	20.6	.39	1,527	10.6	.26
Limestone	3,308	14.4	.29	6,444	6.6	.23
Gypsum	34	11.1	.28	134	2.2	.20
Total	16,212	ND	ND	24,002	ND	ND
Total metal and nonmetal.	16,747	23.2	.43	24,755	15.1	.34

GM C/TLV Geometric mean concentration-to-TLV ratio.
N Sample size (number of samples).
ND Not determined.
TLV Threshold limit value.

[1]Not included are marble, antimony, bauxite, beryl, chromite, manganese, titanium, tungsten, mercury, other metals, asbestos, boron, magnesite, potash, pumice, salt, sodium compounds, sulfur, gilsonite, and oil shale.

Table 5 also shows the sample size (N) for each commodity group. For limestone the total N (1974-81) was large, 8,752 samples; but for fluorspar total N was only 122 samples. The uneven distribution of samples became a problem when further subgrouping by occupation, location, and time was attempted, because N sometimes became too small--or it became zero. This was especially true of the minor commodities. The problem was reduced somewhat by grouping similar commodities together when there was an insufficient number of samples. (This is discussed in more detail later.)

Table 6 lists 28 occupations which account for 97 percent of all the RQ samples. The occupations are ranked according to their 1978-81 GM C/TLV's; and the sample size is included; and the percentage of samples that exceeded the TLV is shown. The 1978-81 GM C/TLV for baggers, the first-ranked occupation, was 35 pct higher than that of the second-ranked occupation, slushing; and nearly 40 pct of the bagger samples exceeded the TLV. A closer examination of the data for baggers showed that the product most often bagged is some type of industrial sand such as glass sand, frac sand, or silica

TABLE 6. - Ranking of 28 occupations[1] by 1978-81 RQ GM C/TLV

(In order of decreasing GM C/TLV for 1978-81)

Occupation	1974-77			1978-81		
	N	> TLV, pct	GM C/TLV	N	> TLV, pct	GM C/TLV
Bagger	786	46.2	0.90	1,232	39.8	0.83
Slushing	103	55.3	1.09	111	27.0	.54
Supply	152	25.7	.47	198	27.3	.49
Blasting	57	24.6	.46	56	17.9	.48
Grinding	762	37.0	.71	622	22.7	.47
Welding	89	27.0	.51	61	18.0	.47
Percussive drilling	808	25.9	.48	1,047	22.2	.46
General labor	2,101	31.3	.58	2,450	21.9	.44
Drying, filtering, and thickening	561	30.5	.54	753	21.0	.44
Crushing	2,215	30.1	.57	4,402	18.5	.40
Rotary drilling	374	28.6	.51	552	19.4	.39
Administration	232	18.5	.32	133	15.8	.39
Sizing	640	29.1	.48	936	18.1	.37
General shop	148	16.9	.35	196	16.8	.37
Complete cycle	613	14.7	.38	479	11.5	.37
Roasting and retoring	136	22.8	.45	173	13.9	.36
Concentrating	189	23.8	.45	268	15.7	.31
Concrete operations	150	27.3	.56	67	11.9	.31
Mechanic	651	15.0	.34	559	10.7	.30
Load, haul, dump electric	400	15.2	.34	574	10.6	.30
Rock sawing	142	15.5	.43	117	6.8	.29
Bulldozing	442	16.5	.35	519	10.2	.28
Pelletizing	98	15.3	.32	204	13.7	.26
Hoisting	43	7.0	.21	89	10.1	.26
Mining machine	22	18.2	.46	39	5.1	.25
Load, haul, dump gas	194	20.1	.35	306	7.5	.24
Technical services	134	14.9	.29	112	5.4	.24
Load, haul, dump diesel	4,116	9.9	.25	7,999	6.2	.23
Total	16,358	ND	ND	24,254	ND	ND
Total metal and nonmetal	16,747	23.2	.43	24,755	15.1	.34

GM C/TLV Geometric mean concentration-to-TLV ratio.
N Sample size (number of samples).
ND Not determined.
TLV Threshold limit value.

[1]Not included are machine mucking, hand mucking, timbering, rock bolting, backfilling, diamond drilling, load, haul, dump compressed air, track crew, slurry, chemical operations, dredging, and jet piercing.

flour, which all have high quartz contents. The high quartz content results in a low TLV, meaning that dust controls must be very effective in order for the baggers to avoid overexposure.

Of the 28 occupations listed in table 6, 23 showed a reduction in the GM C/TLV from the first to the second time period, although 5 showed slight GM C/TLV increases (supply, blasting, administration, general shop, and hoisting). Blasting and administration showed decreases in the percentage of samples exceeding the TLV, and the other three either showed slight increases or remained the same.

There were extreme differences in N among the occupational categories. The load, haul, dump diesel operator code was used 12,115 times, but the code for mining machine was used only 61 times. The explanation for the extreme difference is that most metal and nonmetal mines use diesel equipment, but relatively few use continuous miners. The principal method of rock breaking in underground noncoal mines is drilling and blasting, except for a few industrial minerals such as trona, potash, and gypsum, for which mining methods used in coal mines can be adapted (1).

Commodity, Location, and Time

It was possible to further subdivide the RQ data using location (i.e., underground mines, surface mines, or mills) as a variable, but in doing this the problem of inadequate sample size became very evident in specific subsets. However, despite this limitation, problem areas can be identified with such an analysis. Table 7 utilizes the GM C/TLV to show a commodity, location, and time analysis for the same commodity groups as are listed in table 5. Each of the mining locations includes commodities that pose potential problems. Underground molybdenum and clay and shale mines have GM C/TLV's that were considerably higher than the mean for all underground locations. The same was true for surface

TABLE 7. - RQ GM C/TLV by commodity, location, and time period

Commodity[1]	Underground		Surface		Mill	
	1974-77	1978-81	1974-77	1978-81	1974-77	1978-81
Barite	1.74 +	ND	ND	ND	1.32 +	0.90 +
Misc. nonmetals	0.51 +	0.51 ++	0.55 +	0.24 *	0.96 *	1.09 *
Molybdenum	.68 *	.63 *	ND	ND	1.27 +	.94 +
Clay and shale	.83 *	.64 *	.35 *	.36 *	.78 **	.68 **
Slate	ND	ND	.35 +	.37 ++	.64 ++	.45 +
Misc. stone	ND	ND	.27 ++	.49 *	1.07 ++	.62 *
Gold and silver	.55 *	.40 *	.58 +	.30 +	.99 +	.61 *
Granite	ND	ND	.45 *	.41 **	.53 *	.50 *
Copper	.45 *	.41 *	.31 *	.36 *	.54 *	.45 *
Lime	ND	ND	.22 ++	.22 ++	.38 *	.37 *
Talc	.07 +	ND	.42 +	.37 +	1.29 +	.41 ++
Lead and zinc	.46 *	.42 *	ND	ND	.31 *	.37 ++
Traprock	ND	ND	.24 *	.32 *	.35 *	.53 *
Fluorspar	.78 +	.38 +	ND	ND	.21 +	.34 +
Sand and gravel	ND	ND	.30 **	.30 **	.59 *	.59 *
Sandstone	.67 +	.38 ++	.44 *	.44 *	.83 *	.80 *
Cement	ND	ND	.33 *	.23 *	.38 *	.35 *
Phosphate	.30 +	.31 +	.51 *	.28 +	.40 ++	.31 +
Uranium	.47 *	.32 *	.30 +	.19 ++	.26 ++	.26 *
Feldsapr	ND	ND	.71 +	.18 +	1.00 +	.33 ++
Mica	ND	ND	ND	.22 ++	.56 +	.32 ++
Iron	ND	.58 +	.20 *	.22 *	.45 *	.30 *
Limestone	.50 *	.36 *	.24 **	.21 **	.39 **	.28 **
Gypsum	.27 +	.19 +	.39 +	.20 ++	.18 +	.23 +
Mean	.52	.40	.31	.28	.55	.46

ND Not determined because there were less than 10 samples.
+ 10-49 samples.
++ 50-99 samples.
* 100-999 samples.
** More than 999 samples.
[1]Listed in same order as in table 5 to allow comparison.

miscellaneous stone, sandstone, and granite mines, although the magnitude of the GM C/TLV's was lower. Of the three location categories, mills had the highest GM C/TLV's. Within the mill category, miscellaneous nonmetal mills had the highest GM C/TLV's, and barite, molybdenum, and sandstone mills followed close behind. One problem with this analysis is that samples taken at some mills were grouped together with the surface and reported with surface mine location codes. Samples collected indicated that exposures in mills were generally higher than those in surface mines. Therefore, the effect of grouping some mill samples with the surface mine samples would be to raise the surface mine exposures and decrease the difference between mill and surface mine exposures. Unfortunately, there was no way to separate these data.

The data shown in table 7 are useful for identifying locations with higher RQ exposures. Listed below are the eight locations with the highest GM C/TLV's for 1978-1981. At least 50 RQ samples were collected at each of these locations during this time period. The first value listed for each location is the GM C/TLV, and the percentage of samples greater than or equal to the TLV is shown in parentheses.

Misc. nonmetal milling.......	1.09 (56.0)
Sandstone milling............	.80 (41.7)
Clay and shale milling.......	.68 (33.7)
Clay and shale underground mining......................	.64 (27.3)
Molybdenum underground mining	.63 (31.5)
Misc. stone milling..........	.62 (29.1)
Gold and silver milling......	.61 (30.0)
Sand and gravel milling......	.59 (30.1)

The bulk of the samples collected from miscellaneous nonmetal mills came from two tripoli mills with histories of dust problems. These and similar mills have received special attention from MSHA and NIOSH because they produce a finely ground product with a high quartz content, and because acute cases of silicosis in young workers have been identified at these mills (14). An occupational breakdown of data collected from these mills showed that general laborers, baggers, and workers involved with crushing and other mill activities encountered exposures for which the GM C/TLV exceeded 1.00. The GM RQ CONC for these facilities was 0.65 mg/m^3, and the average quartz content of each sample was 60 pct, resulting in an average TLV of 0.17 mg/m^3. Dust control at these plants would have to be excellent in order for them to meet the RQ TLV.

Workers in metal and nonmetal mills are generally exposed to more quartz dust than their counterparts in mining activities. This is illustrated in figure 2,

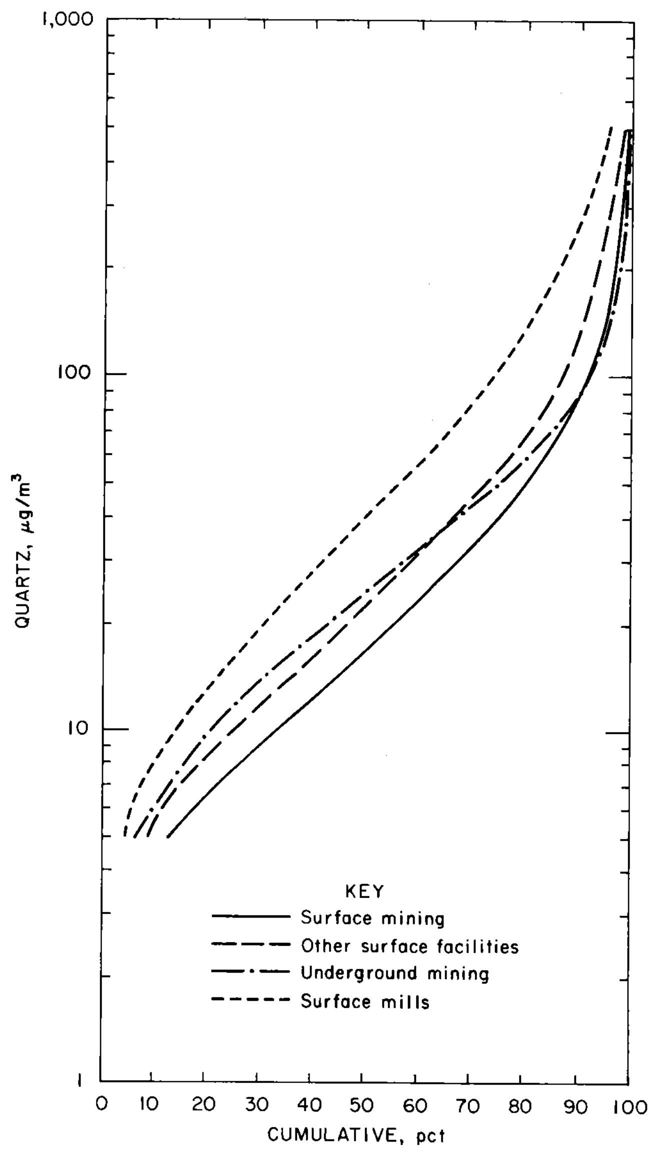

FIGURE 2. - Cumulative frequency plot of quartz concentrations grouped by location.

a cumulative frequency plot of quartz concentrations grouped by location for 1978-81. Quartz concentrations are derived by multiplying the quartz content by concentration. Samples from mills contained more quartz than samples from other locations. A sample containing 100 μg/m^3 or more of quartz always exceeds the RQ TLV when the respirable dust concentration is less than 10 mg/m^3, and 26 pct (838) of the samples from mills exceeded this level. This compares to 8 pct of the underground and surface mines samples and 14 pct of the other surface facilities samples.

Commodity and Occupation Group

As previously mentioned, the sample size N becomes smaller every time the RQ data are partitioned into smaller subgroups. One way to deal with this problem is to group similar codes together, thus making fewer subgroups. An example of this has already been shown in table 4, in which all the commodities were grouped into four categories and all the location codes were grouped into three categories. However, table 4 does not show occupation, which is also a variable of interest. In order to group the codes in a meaningful manner, several parameters must be considered. These include N for each code, the similarity of codes, and the distributions of dust concentration and C/TLV. For some commodity and occupation codes, N is very large; for example, limestone and load, haul, dump diesel can stand alone as individual groups.

Using the parameters listed above, the codes for location, commodity, and occupation were grouped for further analysis. The location codes were logically grouped by similar mine activities defined as (1) underground or surface mining and (2) surface mineral processing including milling. Since 24 commodities and 28 occupations accounted for 97 pct of the 1974-81 data, only these commodities and occupations were included in the consolidated commodity and occupation groups. This eliminated data from 20 commodities and 12 occupations, which are listed below tables 5 and 6. The remaining codes were grouped into 8 commodity groups and 9 occupation groups. Both sets of groups are listed below. The commodity groups included--

1. Limestone.

2. Sandstone.

3. Stone; cement, granite, lime, slate, traprock, and miscellaneous stone.

4. Metal; copper, gold and silver, iron, lead and zinc, molybdenum, and uranium.

5. Clay and shale.

6. Miscellaneous nonmetals.

7. Nonmetals; barite, feldspar, fluorspar, gypsum, mica, phosphate rock, and talc.

8. Sand and gravel.

The occupation groups included--

1. Bagger.

2. Crushing.

3. Load, haul, dump; electric, diesel, gasoline, and bulldozer.

4. Drilling; rotary and percussive.

5. Grinding and sizing.

6. Finishing; roasting and retorting; drying, filtering, and thickening; concentrating; and pelletizing.

7. General labor; including complete cycle and general shop work.

8. Welder and mechanic.

9. Other; slushing, blasting, rock sawing, mining machine operator, concrete operations, hoisting, supply handling, technical services, and administration.

The GM C/TLV's and percentages of samples greater than the TLV for these commodity and occupation groups are shown in tables A-6 and A-7.

The data were further broken down into the two time periods used in the previous analyses, the periods before and after passage of the Mine Health and Safety Act of 1977 (1974-77 and 1978-81). Combining the 8 commodity groups, 9 occupation groups, 3 location groups, and 2 time periods creates a 8 × 9 × 3 × 2 matrix with 432 cells for which the GM C/TLV, GM CONC, GSD, and other statistics can be calculated by a computer program in MIDAS. The table produced by this program is too extensive to be reproduced in this report, but the highlights are shown in table 8. The computer program that calculated the figures in table 8 is also capable of calculating the same values for different commodity, occupation, location, and time groups (and in fact this was done before the final grouping was adopted). There are 28 occupation, commodity, and location combinations listed in table 8. For each, N was at

TABLE 8. - Occupation groups with highest RQ exposures[1]

(In order of decreasing GM C/TLV for 1978-81)

Occupation group	Commodity group	Location group	N	> TLV, pct	GM CONC, mg/m^3	GM C/TLV
General labor......	Misc. nonmetal...	M	64	75.0	0.69	1.89
Bagger.............	Sandstone........	S	60	73.3	.40	1.58
Do...............	Misc. nonmetal...	M	100	62.0	.82	1.54
Do...............	Sandstone........	M	191	52.9	.44	1.25
General labor......	...do............	M	88	53.4	.52	1.05
Crushing...........	...do............	M	135	40.7	.42	.90
Grinding, sizing...	...do............	M	85	45.9	.37	.90
Bagger.............	Clay and shale...	M	300	41.7	1.16	.85
Grinding, sizing...	Sand and gravel..	M	98	42.9	.48	.84
Bagger.............	...do............	M	196	38.3	.45	.84
Other..............	Clay and shale...	M	81	39.5	.91	.77
Crushing...........	...do............	M	62	37.1	.72	.75
Do...............	Metal............	UG	53	34.0	.69	.73
Drilling...........	Sandstone........	S	57	36.8	.44	.73
Grinding, sizing...	Clay and shale...	M	143	32.9	.83	.72
Finishing..........	Sand and gravel..	M	183	32.8	.43	.66
General labor......	Clay and shale...	M	114	29.8	.75	.64
Finishing..........	...do............	M	150	29.3	.71	.62
Grinding, sizing...	Sandstone........	S	93	35.5	.26	.62
Drilling...........	Limestone........	UG	112	26.8	1.43	.60
Bagger.............	Stone............	M	93	23.7	.68	.58
Load, haul, dump...	Clay and shale...	UG	54	16.7	.79	.56
Drilling...........	Stone............	S	620	29.8	.56	.56
Crushing...........	Metal............	M	409	25.4	.45	.56
Finishing..........	Sandstone........	M	137	24.8	.45	.53
Grinding, sizing...	Stone............	M	134	21.6	.66	.52
Crushing...........	...do............	M	350	21.4	.60	.52
Finishing..........	Sand and gravel..	S	100	17.0	.32	.52

GM CONC Geometric mean concentration.
GM C/TLV Geometric mean concentration-to-TLV ratio.
M Mill.
N Sample size (number of samples).
S Surface.
TLV Threshold limit value.
UG Underground.

[1]Based on the 1978-81 data with a minimum N of 50 and a minimum GM C/TLV of 0.50.

least 50 and the GM C/TLV was at least 0.50; in all but two groups, more than 20 pct of the samples exceeded the TLV.

Occupations in sandstone, clay and shale, and miscellaneous nonmetal mines and mills account for 17 of the occupation, commodity, and location groups listed in table 8. Eight of the ten highest ranked groups fell into one of these categories. The four sand and gravel combinations in table 8 (grinding, sizing--mill, bagger--mill, finishing--mill, and finishing--surface) primarily represent data from industrial sand processing plants. A mine-by-mine investigation of the ten highest ranked groups revealed that the results for these occupational groups were greatly influenced by samples collected at industrial sand facilities. The industrial sand producers, including the producers of silica flour, are classified by MSHA in the sandstone, sand and gravel, and miscellaneous nonmetal categories. The extremely high quartz content, small particle size, and abrasive nature of sand make sand dust difficult to control and result in high GM C/TLV's at these establishments. An anomaly in the table is that certain finishing occupations occur twice, once with a mill location and once with a surface mining location. One reason for this is that some mines do not have a separate identifiable mill, and thus it was necessary to use the surface mine location code; however, in some cases this anomaly resulted from failure to use the correct code.

The occupational groups most frequently listed in table 8 are bagger, crushing, grinding, and sizing. They account for 16 of the 28 high exposure groups. The data shown in table 8 indicate that workers in these areas are frequently exposed to levels exceeding the TLV. The occupation bagger occurs 6 times in table 8, accounting for 940 out of a total of 1,232 (or 76 pct of the total) samples, for the period 1978-81. Baggers had the highest risk of overexposure of any occupation; 40 pct of all bagger samples exceeded the TLV.

Three underground mine groups appear in table 8: Drilling--limestone, load-haul-dump--clay and shale, and crushing--metal. Drilling at surface sandstone and other stone quarries also had an above-average risk of excessive exposure.

Another way of estimating the risk from exposure is to calculate the quartz content in each sample and plot the frequency distributions, as was done in figure 2 for location groups. Figure 3 shows the 1978-81 frequency distributions for seven of the eight commodity groups shown in table 8. The other group, stone, is not included because the plotted line for stone closely resembles the line for sand and gravel. Quartz

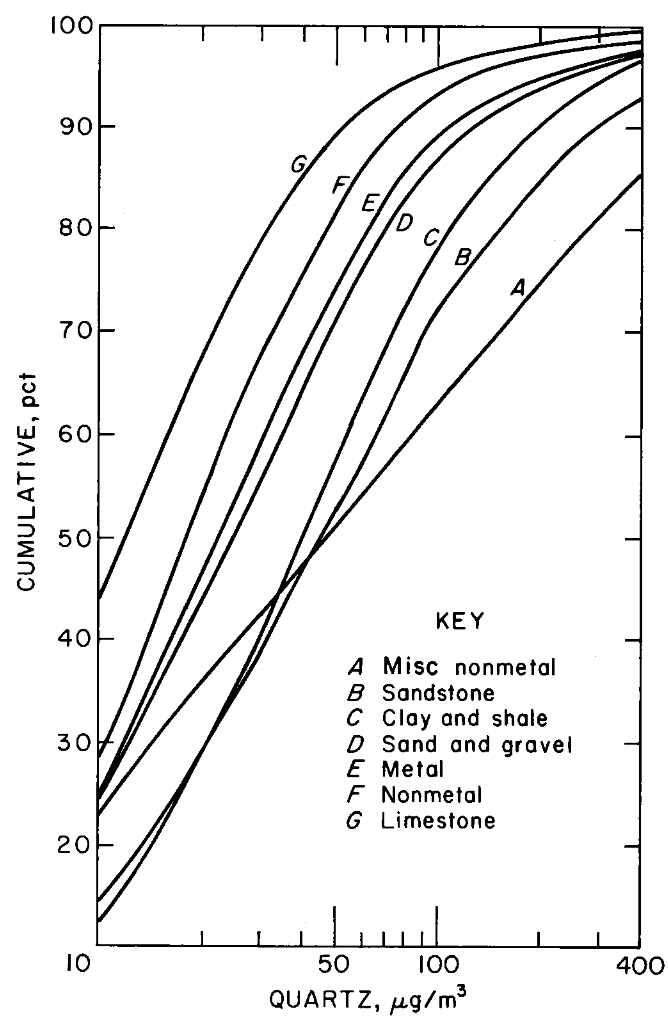

FIGURE 3. - Cumulative frequency plot of quartz concentrations grouped by commodity.

content is important in determining TLV's and in assessing the impact of changes in regulations. NIOSH has proposed an occupational standard of 50 µg/m^3 of crystalline silica as a time-weighted average to protect workers for up to a 10-h work day and 40-h work week over a working lifetime (13). This contrasts with the 100-µg/m^3 standard which is used by the Occupational Safety and Health Administration (OSHA) and is now being proposed by MSHA. Figure 3 clearly shows the effect these two levels would have had on the rate of past overexposure. If the NIOSH proposed standard had been in effect, many more samples would have been considered to represent overexposures. Miscellaneous nonmetals, sandstone, and clay and shale are commodities with high quartz contents, and therefore they would have had a greater percentage of samples exceeding a lower standard than would limestone producers.

High concentrations of respirable dust with less than 1 pct quartz content could constitute overexposures if the standard were changed to 100 µg/m^3 of quartz. Table 9 lists 15 occupation groups that are not listed in table 8 but have GM dust concentrations greater than 0.50 mg/m^3. Again, mill locations predominate, but table 9 also includes four underground occupational groups for metal and limestone mines. Other commodities with high dust levels were identified from total nuisance dust data not shown; they include underground salt, trona, and potash mines where quartz is not a constituent of the host rock.

Many of the workers sampled by MSHA inspectors were wearing respirators at the time the sample was collected, so the actual exposure of the individual was somewhat lower than the reported exposure. In 1981, 4,345 RQ samples were

TABLE 9. - Other occupation groups with high RQ exposures[1]

(In order of decreasing GM CONC)

Occupation group	Commodity group	Location group	N	> TLV, pct	GM C/TLV	GM CONC, mg/m^3
Bagger	Nonmetal	M	98	15.3	0.43	0.77
General labor	Stone	M	342	21.9	.43	.68
Grinding, sizing	Limestone	M	182	11.5	.32	.68
Finishing	Stone	M	120	20.0	.41	.67
Load, haul, dump	Limestone	UG	231	8.2	.31	.67
Welder, mechanic	Stone	M	70	7.1	.35	.58
Crushing	Limestone	M	532	10.3	.30	.58
Drilling	Metal	UG	173	9.2	.37	.56
General labor	Limestone	M	162	11.1	.32	.56
Other	Metal	UG	204	18.6	.46	.55
Load, haul, dump	...do	UG	466	11.4	.40	.54
Finishing	Nonmetal	M	50	14.0	.33	.50
Load, haul, dump	Clay and shale	M	122	22.1	.45	.52
Crushing	Stone	S	510	22.6	.47	.50
Do	Limestone	S	920	9.0	.26	.50

GM CONC Geometric mean concentration.
GM C/TLV Geometric mean concentration-to-TLV ratio.
M Mill.
N Sample size (number of samples).
S Surface.
TLV Threshold limit value.
UG Underground.

[1]Based on the 1978-81 data with a minimum N of 50 and a minimum GM CONC of 0.50 mg/m^3.

collected, and 17.35 pct of these samples equaled or exceeded the TLV (table 3). In instances where the C/TLV was 1.0 or more, 68 pct of the workers were wearing respirators. The percentage wearing respirators decreased as exposure declined below the TLV, but 52 pct of the 261 workers exposed where C/TLV ranged between 0.80 and 0.99 were wearing respirators. Data from table 8 showed that general laborers and baggers employed in sandstone and miscellaneous nonmetal mills had the greatest risk of RQ overexposure. MSHA records show that of the 89 samples collected on baggers at these properties in 1981, 64 pct had C/TLV ratios of 1.0 or greater, and of these, 52 workers (91 pct) wore respirators. Of general laborers with similar exposures, 82 pct wore respirators. MSHA regulations require the use of respiratory protection on an interim basis in situations where overexposures occur and the implementation of engineering controls to permanently protect workers.

SUMMARY AND CONCLUSIONS

The objective of this report was to statistically analyze records of RQ exposures collected by MSHA from 1974 through 1981 to identify commodities and occupations associated with high quartz dust exposure. The analysis was conducted using the Mine Inspection Data Analysis System (MIDAS), a computerized system designed by the Bureau with the collaboration of MSHA.

Editing the RQ data left 41,502 records for analysis, and these were unequally distributed among the occupation, commodity, and location codes used by MSHA. The primary reason for the unequal distribution is that MSHA is mandated by law to inspect all properties within its jurisdiction, and this type of sampling strategy would tend to assess dust levels in all types of mines rather than in high-risk areas only.

The C/TLV was shown to approximate a log-normal distribution, and the GM of this distribution was shown to be a good index of exposure because it relates dust concentration to the TLV, which is determined by a formula dependent upon the percentage of quartz found in the sample. The greater the quartz content the lower the TLV. Use of the C/TLV as an index of exposure places an equal weight upon both the quartz content and the dust concentration of the sample; hence the ranking of high-risk subpopulations reflects both. Only samples that contained more than 1.0 pct quartz were considered in this analysis; samples with less than 1.0 pct quartz were reclassified as respirable nuisance dust.

The GM CONC for all samples was calculated to be 0.43 mg/m^3 with a GSD of 2.98. The median concentration was 0.40 mg/m^3, and 18.37 pct of all samples (7,623 samples) exceeded the TLV. The GM C/TLV was 0.37 with a GSD of 3.40. The TLV calculated from these data was 1.16 mg/m^3 with an average quartz content of 6.6 pct. The range of quartz content was between 1.0 and 98.0 pct.

The highest GM C/TLV's and the highest percentage of overexposure were in mills, for workers involved in bagging, crushing, grinding, sizing, and general labor activities. Exposures were highest in industrial sand processing plants. The respirable dust concentrations measured at these plants were not the highest, but the allowable level of exposure was the lowest because the samples contained high percentages of quartz. These mills are located at mines classified as sandstone, sand and gravel, miscellaneous nonmetal, and miscellaneous stone producers. Other mills with high exposures were molybdenum, clay and shale, barite, and gold and silver producers. Crushing, grinding, sizing, and general labor activities at limestone mills were also dusty activities, but the quartz content of the rock was low, making these exposures less serious. More than 100,000 workers were employed in noncoal mills in 1981, which was more than 40 pct of the entire metal and nonmetal mine workforce, so the problem was significant in terms of the number of potentially exposed workers.

Fewer samples were collected in underground mines, and exposures were generally lower than in mills; but several commodities mined underground had relatively high levels of exposure. Underground molybdenum, clay and shale, iron, and miscellaneous nonmetal mines stood out as having higher GM C/TLV's and a greater percentage of overexposures. Underground mine activities with higher than average exposures were crushing, drilling, and diesel vehicle haulage. Slushing was also a dusty underground mine occupation, but very few samples were collected.

Surface mines had the lowest overall exposures, and in these mines drillers in stone quarries had the highest exposures. Crushing at limestone mines was also a dusty occupation, but their relativly low quartz contents resulted in higher allowable dust levels.

The analysis showed that quartz concentrations varied when data were grouped by location and commodity. About 3,200 more samples would have exceeded the exposure limit had the NIOSH recommended PEL of 50 $\mu g/m^3$ been in effect. Quartz content was highest in samples from mills producing products such as industrial sand and tripoli, and in underground mines producing molybdenum and clay and shale. Specific dust control research projects should focus on these high-risk areas with the intention of developing controls that can be transferred to other segments of the industry with minimum modification.

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APPENDIX A.--MSHA SAMPLING CODES AND DESCRIPTORS AND SELECTED GM C/TLV DATA

TABLE A-1. - MSHA contaminant codes for personal samples and number of edited records for each contaminant

Code	Type of measurement	Unit of measure used	Number of records
1	RQ	mg/m^3	41,566
2	Respirable nuisance dust	mg/m^3	11,582
3	Talc, nonasbestiform	mppcf	283
4	Nuisance dust[1]	mg/m^3	13,415
11	Cristobalite, respirable	mg/m^3	168
12	Tridymite, respirable	mg/m^3	3
13	Mercury vapor	mg/m^3	70
14	Lead[1]	mg/m^3	1,357
15	Cadmium[1]	mg/m^3	379
16	Arsenic and compounds[1]	$\mu g/m^3$	457
17	Manganese[1]	$\mu g/m^3$	806
18	Beryllium[1]	$\mu g/m^3$	332
19	Iron oxide[1]	mg/m^3	1,430
20	Asbestos, fibers >5µm	$fibers/cm^3$	1,365
21	Cobalt[1]	mg/m^3	527
22	Copper fume[1]	mg/m^3	714
23	Molybdenum[1]	mg/m^3	490
24	Nickel[1]	mg/m^3	609
27	Vanadium fume[1]	$\mu g/m^3$	508
28	Zinc oxide fume[1]	mg/m^3	860
29	Chromium[1]	mg/m^3	830
31	Oil mist[1]	mg/m^3	56
34	Airborne silica dust, total	mg/m^3	12,515
35	Welding fume[1]	mg/m^3	1,030
40	Noise, dosimeter measurement	pct	86,229
41	Sound level meter measurement	dBA	3,601
81	Magnesium oxides[1]	mg/m^3	898
82	Aluminum oxides[1]	mg/m^3	945
83	Titanium oxides[1]	mg/m^3	717

RQ Respirable quartz dust.
[1]Total particulate.

TABLE A-2. - MSHA contaminant codes for area samples and number of records for each contaminant

Code	Type of measurement	Unit of measure used	Number of records
13....	Mercury vapor..................	mg/m^3..................	810
50....	Radon daughter measurement......	WL......................	27,311
70....	Nitrogen oxide.................	ppm.....................	180
71....	Nitrogen dioxide...............	ppm.....................	9,261
72....	Nitrogen oxides................	ppm.....................	431
73....	Carbon monoxide................	ppm.....................	28,170
74....	Carbon dioxide.................	ppm.....................	24,292
75....	Aldehydes......................	ppm.....................	132
76....	Ammonia........................	ppm.....................	259
77....	Hydrogen sulfide...............	ppm.....................	2,450
78....	Sulfur dioxide.................	ppm.....................	577
79....	Chlorine.......................	ppm.....................	22
80....	Sulfuric acid mist.............	mg/m^3..................	1
87....	Hydrogen cyanide...............	ppm.....................	248
88....	Carbon disulfide...............	ppm.....................	4
89....	Perchlorethylene...............	ppm.....................	17
90....	Phosgene.......................	ppm.....................	20
91....	Oxygen.........................	pct.....................	15,663
92....	Hydrocarbons, total............	ppm.....................	109
93....	Methane........................	pct.....................	28,217

TABLE A-3. - RQ samples collected 1974-81 for each MSHA occupation code

Code	Occupation	Number of personal samples	Code	Occupation	Number of personal samples
1....	Slushing...............	214	20...	Hoisting...............	132
2....	Machine mucking........	79	21...	Bulldozing.............	967
3....	Hand mucking...........	58	22...	Slurry.................	79
4....	Timbering..............	83	23...	General labor and cleanup.	4,551
5....	Rock bolting...........	78			
6....	Backfilling............	4	24...	General shopwork.......	344
7....	Blasting...............	113	25...	Welding................	150
8....	Rock sawing............	259	26...	Mechanic...............	1,210
9....	Drilling, percussive...	1,855	27...	Crushing...............	6,617
10...	Drilling, rotary.......	926	28...	Grinding...............	1,384
11...	Drilling, diamond......	66	29...	Roasting, retorting....	309
12...	Loading, hauling, dumping electric.	974	30...	Drying, filtering, and thickening.	1,314
13...	Loading, hauling, dumping diesel.	12,115	31...	Sizing.................	1,576
			32...	Concentrating..........	457
14...	Loading, hauling, dumping gasoline.	500	33...	Chemical operations....	92
			34...	Supply handling........	350
15...	Loading, hauling, dumping compressed air.	158	35...	Technical services.....	246
			36...	Administration.........	365
16...	Mining machine operator	61	37...	Bagger.................	2,018
17...	Track crew.............	36	38...	Pelletizing............	302
18...	Complete mining cycle..	1,092	39...	Dredging...............	58
19...	Concrete operations....	217	40...	Jet piercing...........	99

TABLE A-4. - RQ samples collected 1974-81 for each commodity

Commodity	N	Commodity	N
STONE			
Cement	2,347	Sandstone	3,130
Granite	3,509	Slate	266
Lime	393	Traprock	711
Limestone	9,752	Misc	468
Marble	37		
METAL MINES AND MILLS			
Antimony	33	Lead and zinc	905
Bauxite (including alumina mills)	12	Manganese	13
Beryl	2	Molybdenum	526
Chromite	0	Titanium	20
Copper	1,999	Tungsten	38
Gold and silver, lode and placer	874	Uranium	1,097
Iron	2,177	Mercury	6
		Other metals	15
NONMETAL MINES AND MILLS			
Asbestos	3	Potash	4
Barite	140	Pumice	31
Boron minerals	7	Salt	7
Clay and shale	3,213	Sodium compounds	11
Feldspar	193	Sulfur	0
Fluorspar	122	Talc, soapstone, and pyrophyllite	142
Gypsum	180	Gilsonite	2
Magnesite	12	Oil and/or shale	4
Mica	134	Misc. nonmetals[1]	741
Phosphate rock	462		
MISC. NONFUEL MINES AND MILLS			
Sand and gravel	6,725	Unspecified	1,031

N Sample size (number of samples).

[1]Other metals and miscellaneous nonmetals are defined in the Standard Industrial Classification (SIC) codes published in 1979 by the National Bureau of Standards.

TABLE A-5. - RQ samples from metal and nonmetal mines, by location

Category	N	Category	N
Underground mine locations:		Surface mill locations:	
Mill	77	Mill (bagging, screening, etc.)	5,575
Shop	22	Crushing	4,210
Metal mine	3,245	Grinding	1,553
Nonmetal mine	1,134	Flotation and reagents	516
Stone mine	455	Shop	313
		Misc	3,068
Open pit mine locations:			
Crushed stone mine	11,339		
Sand and gravel quarry	5,492		
Nonmetal mine	3,050		
Metal mine	1,445		

N Sample size (number of samples).

TABLE A-6. - GM C/TLV's for 9 occupation groups used in table 8

(In order of decreasing GM C/TLV for 1978-81)

Occupation group	1974-77			1978-81		
	N	> TLV, pct	GM C/TLV	N	> TLV, pct	GM C/TLV
Bagger....................	786	46.2	0.91	1,232	39.7	0.83
Drilling..................	1,182	26.7	.49	1,559	21.3	.44
General labor.............	2,862	27.0	.52	3,125	20.0	.43
Crushing..................	2,215	30.1	.57	4,402	18.5	.41
Grinding, sizing..........	1,402	33.4	.60	1,558	19.8	.41
Finishing.................	984	26.6	.48	1,398	17.9	.37
Other.....................	1,035	23.5	.43	922	16.0	.37
Welder, mechanic..........	740	16.5	.36	620	11.4	.32
Load, haul, dump..........	5,152	11.3	.27	9,398	6.7	.23

GM C/TLV Geometric mean concentration-to-TLV ratio.
N Sample size (number of samples).
TLV Threshold limit value.

TABLE A-7. - GM C/TLV's for 8 commodity groups used in table 8

(In order of decreasing GM C/TLV for 1978-81)

Commodity group	1974-77			1978-81		
	N	> TLV, pct	GM C/TLV	N	> TLV, pct	GM C/TLV
Misc. nonmetal............	242	43.4	0.83	499	40.9	0.69
Clay and shale............	1,723	34.9	.65	1,490	28.3	.58
Sandstone.................	1,363	37.4	.67	1,767	29.9	.56
Stone.....................	3,298	20.5	.40	4,396	16.8	.39
Sand and gravel...........	2,082	21.8	.37	4,643	15.1	.34
Metal.....................	3,524	22.2	.46	4,054	13.2	.34
Nonmetal..................	672	27.7	.56	709	10.2	.31
Limestone.................	3,308	14.4	.29	6,444	6.6	.23

GM C/TLV Geometric mean concentration-to-TLV ratio.
N Sample size (number of samples).
TLV Threshold limit value.

APPENDIX B.--MSHA MINE HEALTH RANKING CRITERIA

Rank A

a. All underground uranium mines.

b. All nonuranium underground mines where employees are exposed to radon daughters in excess of 0.10 WL.

c. All mines and mills where employees are exposed to mineral fibers classified as asbestos or talc.

d. All mines and mills where employees are overexposed to toxic or asphyxiant gases.

e. All mines and mills where employees are overexposed to contaminants which have ceiling values recommended by the ACGIH.

f. All mines and mills where employees are overexposed to particulates (except silica) and whose TLV's are less than 10 mg/m^3 or 30 mppcf.

g. All producers of silica sand, glass sand, industrial sand, and silica flour; and all mines and mills where cristobalite or tridymite occur.

h. All mines and mills where employees are repeatedly overexposed to dust containing 1 pct or more of free silica.

i. All mines and mills where employees are exposed to dust containing the following substances at or above one-half their TLV: antimony, arsenic, beryllium, cadmium, chromium, cobalt, manganese, mercury, nickel, lead, uranium, and vanadium.

j. Any other mine or mill where the inspector and supervisor believe that a serious health hazard exists.

Rank B

a. All mines and mills where employees are overexposed to particulates whose TLV's are 10 mg/m^3 or 30 mppcf.

b. All mines and mills where employees are occasionally overexposed to dust containing 1 pct or more free silica.

c. All mines and mills where employees are overexposed to fumes containing the following substances at or above half their TLV: antimony, arsenic, beryllium, cadmium, chromium, cobalt, manganese, mercury, nickel, lead, or vanadium.

d. All mines and mills where employees are overexposed to noise.

e. Any other mine or mill where the inspector and supervisor believe that a health hazard exists.

Rank C

a. All mines and mills where no discernible health hazard exists.

APPENDIX C.--ABBREVIATIONS USED IN THIS REPORT

NOTE.--This listing does not include unit of measure abbreviations, which are listed after the table of contents, or abbreviations that are used only in the tables and identified below the tables.

ACGIH	American Conference of Governmental Industrial Hygienists
C/TLV	concentration-to-threshold limit value ratio
GM	geometric mean
GM CONC	geometric mean concentration
GSD	geometric standard deviation
MAS	Minerals Availability System
MIDAS	Mine Inspection Data Analysis System
MSHA	Mine Safety and Health Administration
N	sample size
NIOSH	National Institute for Occupational Safety and Health
PEL	permissable exposure limit
RQ	respirable quartz dust
TLV	threshold limit value

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