

TECHNOLOGICAL FEASIBILITY OF CONTROLLING
ASBESTOS AND SILICA AT MINES AND MILLS

FINAL REPORT

VOLUME 1

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ABSTRACT

The objective of this study, conducted under NIOSH Contract No. 210-81-4104, is to determine the technological feasibility of reducing silica and asbestos exposure in the noncoal mining industries. Two permissible exposure limits (PEL's) for silica were considered; these were stated in terms of silica dust concentrations (not respirable dust concentrations) of 0.05 and 0.075 mg/m³. Three PEL's were considered for asbestos fiber exposure, 0.1, 0.5, and 1.0 fibers/cc. The methods and conclusions of this study will provide MSHA with information to be considered in promulgating standards based on these PEL's.

The study was divided into three tasks. First, silica dust and mineral fiber exposure data from samples collected by MSHA inspectors at mines and mills during 1977-1981 were used as the data base from which exposure profiles were developed for each industry and each mining or milling operation. Depending on the commodity, the noncoal mining industries were classified into 15 groups such as copper, gold and silver, molybdenum, limestone, and talc. Based on MSHA job codes, processes commonly used in the mining industry were classified into 14 operation categories such as surface drilling, underground blasting, cutting and boring, and concentrating and finishing. The exposure profiles were used to obtain worse-case estimates of maximum silica and asbestos exposures within each industry and operation category. Extensive literature searches and site visits were then conducted in Task 2 to gather information on existing and developing technology for reducing worker exposure to airborne respirable dust. The effectiveness and applicability of various methods of dust formation control, point source control, ambient source control, and worker isolation control were assessed in relation to each of the 14 operations.

In the third task, the data collected in Tasks 1 and 2 were used to determine the technological feasibility of controlling silica dust and asbestos fiber exposures to the prescribed PEL's. The estimates of worse-case exposure were used as the basis for determining the extent of reduction in dust or fiber exposure that is required to meet the PEL's. Based on information in the literature, an expected dust reduction efficiency was derived for each applicable dust control method. The expected dust reduction efficiency attainable by a control method (or a combination of methods) was then compared to the reduction in exposure necessary to meet the PEL's to determine the feasibility of the PEL's. Results were reported for each industry group and for each operation category in which exposure data were available.

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EXECUTIVE SUMMARY

Under National Institute for Occupational Safety and Health (NIOSH) Contract No. 210-81-4104, JRB Associates has assessed the technological feasibility of controlling asbestos and silica at mines and mills to certain alternative permissible exposure levels (PEL's). This study addresses only the metal and nonmetal mining industries; the coal mining industry is not included in this assessment. The project's results and conclusions are presented in two volumes. Volume 1 contains five chapters discussing the work performed and the results of the study; Volume 2 contains the appendixes, including the exposure profiles and site visit reports.

This project was divided into three tasks: (1) a compilation of silica dust and mineral fiber exposure data from Mine Safety and Health Administration (MSHA) sampling data contained in the Mine Inspection Data Analysis System (MIDAS); (2) an evaluation of dust control technologies and their efficiencies, as reported in the literature and observed during site visits; and (3) an assessment of feasibility. In Volume 1, Chapter 2 summarizes the silica dust and mineral fiber exposure data compiled during Task 1 of the project. In Chapters 3 and 4, which summarize Task 2 of the project, the effectiveness of dust control methods is assessed. Assumptions and procedures used in determining the technological feasibility of achieving the alternative PEL's, and the results of the feasibility assessments, are described in Chapter 5. For this study, JRB evaluated two alternative silica PEL's: 0.05 and 0.075 mg/m³ (absolute silica concentration levels in air). Three alternative asbestos PEL's were considered: 0.1, 0.5, and 1.0 fibers/cc.

In Task 1, silica dust and mineral fiber exposure data from samples collected by MSHA inspectors at mines and mills during 1977-1981 were used as the data base from which exposure profiles (exposure concentrations versus cumulative percent distribution) were developed for each industry and each mining or milling operation. For profiling the exposure data, the metal and nonmetal industries were classified into 15 industry groups: copper; gold and silver; iron; lead and zinc; molybdenum; uranium; other metals; limestone; other stone; clay and shale; asbestos; talc; oil shale; sand and gravel; and other nonmetals. Processes for extraction and beneficiation of ores commonly used in the mining industry were classified into 14 operation categories. These operation categories were surface drilling; underground drilling; blasting; cutting and boring; surface production; surface mobile transport; surface haulageway maintenance; underground production; underground mobile transport; underground haulageway maintenance; crushing, grinding, and sizing; concentrating and finishing; nonspecific surface operations; and nonspecific underground operations.

In Task 2, an extensive literature search of over 700 articles and documents was conducted to gather information on existing and developing control technology for reducing worker exposure to airborne silica dust and mineral

fibers in mines and mills. Site visits to eight mining operations were conducted to observe field applications of control technology and to obtain information on industry experience in using dust controls. Control methods that are currently available and in either widespread or limited use in the mining or milling industry were classified as existing technology. Controls that are still under development but that could reasonably be expected to be available in the future were classified as potential technology.

In Task 3, the technological feasibility of controlling dust and fiber exposures to the alternative PEL's was assessed for each industry group and for each operation where exposure data were available. Each operation category was considered separately (excluding the nonspecific surface and underground operation categories); a total of 180 possible industry-operation combinations (15 groups x 12 operations) were considered in the analysis. For each industry-operation category, the 95 percentile exposure concentration, calculated from the result of least squares regression analyses of the MSHA sampling data, was used as an estimate of a worse-case exposure; this exposure level was used as the starting point for the feasibility analysis. The assessment of feasibility for a PEL was based on the capability of applicable dust control methods to reduce this 95 percentile concentration to the PEL's.

To perform a study such as this under ideal circumstances, recent silica and asbestos samples should be available from all job codes and all mines and mills in all of the industries studied; the information available to conduct this assessment clearly falls far short of this ideal. To overcome data limitations and gaps, several critical assumptions have been made. In addition, several important facts, interpretations, and constraints should be borne in mind:

- (1) Technological feasibility is defined in accordance with its statutory meaning, as interpreted in recent court decisions. This means that the cost of controls, or their effects on productivity, have not been taken into consideration in determining feasibility (short of costs that would destroy the "long-term competitive structure of the industry"). In addition, control technology capable of being used anywhere in the industry is considered in this study as existing technology; the term potential technology is reserved for technology still in the developmental stages.
- (2) The 95 percentile exposure level, based on MSHA samples taken at job codes at various mines and mills, has been selected as the point of reference for the feasibility analysis, although this point is probably higher than typical exposures in any of the industry sectors. Use of the 95 percentile data increases the likelihood that any industry-operation judged feasible in this analysis is feasible in the real world, and means that operations judged marginally feasible may in fact be feasible as well.
- (3) Dust control removal efficiency values reported in the literature are used in this analysis even though some values may not have been proven under field conditions.

- (4) Although work practice controls are critically important in the real world and personal protective equipment may be needed to limit exposure in certain work situations, the dust control efficiencies of work practices and personal protective equipment have not been considered in this analysis.
- (5) Asbestos PEL's were analyzed on the assumption that all of the mineral fibers counted in the MSHA samples were in fact asbestos fibers.
- (6) Dust control technology was assumed to remove respirable silica dust and asbestos fibers with equal efficiency.

Use of these assumptions and techniques, especially Items 2, 4, and 5, would tend to bias the results of this feasibility assessment strongly in the conservative direction, that is, to increase the likelihood that industry-operations judged marginally feasible may actually be in the feasible range. Despite these efforts to ensure that the results of this feasibility assessment are conservative for the industry as a whole, there may be special instances in which feasibility is more difficult to achieve than is indicated here.

Applicable dust control methods for an operation were evaluated for their effectiveness at four lines of control, i.e., at the point of dust formation, at the dust source, at the ambient source, and at the worker's location. Dust control at one line of control might be augmented by a method from successive lines of control. The operation categories were classified according to MSHA job codes; therefore, control methods applicable to an operation are assumed to be effective in reducing dust exposures of workers represented by the job codes included in that operation (see Chapter 2). For the feasibility assessment, each applicable control method was assigned an expected dust reduction efficiency based on information available in the literature.

The expected reduction efficiencies for combinations of dust control methods that could be used in each operation category were then calculated to determine the maximum dust control efficiencies attainable in each operation category. Controls known to be widely used in an industry or operation through literature, site visits, or interviews with MSHA and BOM personnel were considered baseline controls for that industry-operation. Since these baseline controls were assumed to be in place at the time the MSHA sampling data were collected, JRB did not count the dust reduction efficiencies of these controls in the feasibility assessment.

A 5 percent margin of error was used in feasibility assessments because of the uncertainties involved in assigning expected dust reduction efficiencies to the various control methods. Therefore, for a PEL to be considered feasible for a particular industry-operation category, the expected dust reduction efficiency of a control system had to be at least 5 percent higher than the dust reduction efficiency required for that industry-operation category to meet the PEL. If the dust reduction required for a particular industry-operation to meet a PEL was 5 or more percent greater than the

maximum dust reduction efficiency achievable by control methods applicable to that industry-operation, the PEL was judged to be infeasible for that particular industry-operation. For industry-operations in which the expected and required reduction efficiencies were no more than 5 percent apart, the PEL was considered to be marginally feasible. When a PEL was judged to be infeasible or marginally feasible for a particular industry-operation, the specific factors contributing to this judgment, and their relative importance, were described.

Results of the feasibility analysis and the maximum level of silica dust or asbestos fiber exposure that can be reduced to the alternative PEL's are presented in summary tables (Tables 5-22, 5-23, and 5-24). In the tables summarizing the results of the feasibility analysis, combinations of industry-operation cells with limited data were specially designated. Cells were so designated if they contained data from fewer than five samples or if the samples were obtained either from one site or from fewer than 5 percent of the active sites. The results of the feasibility analysis are discussed briefly below.

The $0.05 \text{ mg}/\text{m}^3$ silica PEL was judged to be feasible in a majority of industries for most operations. Silica exposure data were available for the feasibility analysis in 121 of the 180 industry-operation cells. The $0.05 \text{ mg}/\text{m}^3$ PEL was found to be technologically feasible in 73 of these cells, while the $0.075 \text{ mg}/\text{m}^3$ PEL was feasible in an additional 13 cells. Among operation categories, underground production; crushing, grinding, and sizing; and concentrating and finishing operations had the highest number of industry groups in which either one or both PEL's were judged to be technologically infeasible. Both silica PEL's were judged to be feasible in surface drilling; surface haulageway maintenance; and underground haulageway maintenance operations for all industries for which exposure data were available. Among industry groups, the copper, molybdenum, other stone, clay and shale, oil shale, and other nonmetals industries had more operations for which the $0.05 \text{ mg}/\text{m}^3$ PEL was judged infeasible than other industry groups. The $0.05 \text{ mg}/\text{m}^3$ PEL was judged technologically feasible for almost all operations in the iron and talc industries.

Compared with the silica dust exposure data, the amount of data on mineral fiber exposure was limited; only 48 of the possible 180 industry-operation cells had mineral fiber exposure data that could be used for the feasibility analysis. Most of the mineral fiber exposure data were related to crushing, grinding, and sizing; concentrating and finishing; and surface mobile transport operations. There were no fiber data for the blasting; cutting and boring; surface production; surface haulageway maintenance; and underground haulageway maintenance operations. More mineral fiber data were available for the talc industry than for other industries, and no fiber data were available for the oil shale, and lead and zinc industries. The highest asbestos PEL of 1.0 fibers/cc was judged to be feasible for all but two industry-operation cells for which data were available. The second asbestos PEL, 0.5 fibers/cc, was judged to be either feasible or marginally feasible in all but seven industry-operation cells for which data were available. These additional cells were underground operations in the molybdenum, talc, and other nonmetals industries; underground drilling operations in the limestone industry; and

concentrating and finishing operations in the other stone, asbestos, and other nonmetals industries. The lowest PEL, 0.1 fibers/cc, was judged to be either infeasible or only marginally feasible for at least one industry in each operation category for which data were available. Achieving this PEL was considered feasible in 15 of the 48 industry-operation cells analyzed by JRB.

1. INTRODUCTION

1.1 PURPOSE

Silica dusts and asbestos fibers are recognized as potential health hazards to workers in the mining and milling industry. To protect workers from these hazards, the Mine Safety and Health Administration (MSHA) enforces rules limiting worker exposure to certain permissible exposure levels (PEL's). The current MSHA PEL for asbestos is 2 fibers/cc and the current MSHA PEL for silica is based on a formula that calculates permissible respirable dust concentration in accordance with the silica content in the dust. The National Institute for Occupational Safety and Health (NIOSH) is developing criteria on silica and asbestos in the mining industry that will consider the bases for reducing the current PEL's. This project assesses the technological feasibility of achieving lower PEL's; specifically, the project evaluates which of a series of silica dust and asbestos fiber count levels is attainable at various mining and milling processes using existing or developmental methods of dust control. The information gathered and generated during this project and the final evaluation of feasibility will provide MSHA with data to be used in decisionmaking. To achieve these goals, the project has been divided into three tasks.

For Task 1, exposure levels of silica dust and mineral fiber in different industry sectors and in different types of mining and milling processes were profiled. The primary data source for these exposure profiles was dust samples collected by MSHA field inspectors from 1977 to early 1981. For the purpose of quantifying silica and asbestos exposure, the noncoal mining industry was divided into 16 industry groups, according to commodity. The process steps for extraction and beneficiation of ores were classified into 14 operation categories. For each combination of industry group and operation category, available MSHA data were used to plot a cumulative percent distribution profile of silica and asbestos exposure.

The objective of Task 2 was to assess the potential of existing and developmental technology for reducing worker exposure to airborne dusts, and therefore silica dusts and mineral fibers, in the mining industry. For each operation category, control technology was assessed by reviewing the available literature on dust control methods, by analyzing data on the effectiveness of each method, and by evaluating ways and situations in which control methods can be applied. Additionally, several site visits to mines and mills were conducted to observe actual applications of dust control technology and to obtain additional technical information from the industry. Numerous interviews with MSHA inspectors and Bureau of Mines (BOM) personnel were also conducted to help develop information on the current state of dust control in the industry. The persons interviewed included Sheri Hutchason, Gene Audio, Max Slade, Steve Viles, and Marvin Nichols of MSHA and John A. Breslin of BOM.

The objective of Task 3 was to analyze the exposure data from Task 1 in conjunction with the control effectiveness data from Task 2 so that the feasibility of reducing dust levels in the various mining processes could be determined. For this feasibility study, NIOSH has asked JRB to evaluate two PEL's for silica dust (0.05 and 0.075 mg/m³) and three PEL's for asbestos fibers (0.1, 0.5, and 1.0 fibers/cc). The PEL's for silica dust that were selected by NIOSH are absolute silica concentrations in air, in contrast to the MSHA PEL's, which are based on respirable dust concentrations and vary with the percentage of silica in the dust. The feasibility of controlling silica dust and fiber exposures to the prescribed PEL's was determined for each industry group and for each operation category.

1.2 SCOPE

The focus of this project was on the feasibility of controlling silica and asbestos exposures in metal and nonmetal mines and mills; the coal industry was not included in the assessment. Based on the MSHA coding system used to organize exposure data, the metal and nonmetal mining industry were initially grouped into 16 industries for this project. These 16 industry groups are copper, gold and silver, iron, lead and zinc, molybdenum, uranium, other metals, limestone, other stone, clay and shale, asbestos, talc, oil shale, other nonmetals, sand and gravel, and peat. There were no exposure data for the peat industry; the feasibility analyses were therefore performed on the remaining 15 industry groups.

Based on MSHA job code categories, mining and milling processes were classified into 14 operation categories for this project. These operation categories are surface drilling; underground drilling; blasting; cutting and boring; surface production; surface mobile transport; surface haulageway maintenance; underground production; underground mobile transport; underground haulageway maintenance; crushing, grinding, and sizing; concentrating and finishing; nonspecific surface; and nonspecific underground. The technological feasibility of dust control for each of these categories, with the exception of the two nonspecific categories, was assessed in this study for all industry groups for which exposure data were available.

MSHA coal dust data are not coded and stored in the same manner as the data for the metal and nonmetal industries. Although a large amount of coal dust data were available, the lack of comprehensive machine-readable data precluded efficient access to these data for use in this study. Dust control technologies reviewed for this project were therefore not evaluated specifically for application in the coal mining industry. A brief review of current MSHA standards and control practices in the coal mining industry is provided in Section 5.16.

1.3 REPORT ORGANIZATION

This report consists of two volumes. Volume I contains five chapters, which are preceded by an executive summary and followed by a list of references. Volume II contains three appendices; they are the silica dust exposure profiles, the mineral fiber exposure profiles, and eight site visit reports.

Chapter 2 is a summary of the Task 1 report submitted for this project and describes the silica dust and mineral fiber exposure profiles for each combination of industry group and operation category for which MSHA exposure data were available. Bar graphs illustrating the percentages of samples that meets various PEL's are provided; the profiles of cumulative percent probability distribution are included in Appendixes A and B.

Chapters 3 and 4 are summaries from the Task 2 report submitted in the course of this project. Based on literature review, site visits, and personal communications, a compendium of existing and developing dust control technologies applicable to various operations in the mining industry is presented in Chapter 3. It introduces the concept of lines of control for considering combinations of applicable methods. Tables include information on applicable control methods; their reported dust reduction efficiencies; and data on literature sources, costs, and relevant comments on each.

Chapter 4 describes dust control methods applicable in two or more operations and evaluates the information obtained on dust reduction efficiencies to derive an expected dust reduction efficiency for each method. The expected reduction in dust exposure that results from using combinations of these control methods is used in Chapter 5 to assess the technological feasibility of achieving alternative silica and asbestos PEL's in each mining operation category.

Chapter 5 assesses the feasibility of reducing silica dust and asbestos fiber exposures from an estimated maximum exposure to the prescribed PEL's in the various operations and industry groups. Summary tables showing the results of these feasibility assessments for all industry-operation matrices are presented at the end of Chapter 5. The expected dust reduction efficiencies of various combinations of controls applicable to each operation category, and the maximum exposure levels that can be reduced to a PEL using these methods, are also tabulated. Unless otherwise noted, all tables and figures used in this report were developed by JRB Associates.

2. SILICA DUST AND MINERAL FIBER EXPOSURE

This chapter summarizes JRB's Task 1 Report, which develops and describes a profile of worker exposure to airborne silica dusts and mineral fibers in the mining and milling industry. Section 2.1 discusses the methodology used to develop the profiles; Section 2.2 describes workplace exposure to silica; and Section 2.3 discusses exposure to mineral fibers.

2.1 METHODOLOGY

2.1.1 Data Sources

The exposure profiles and analyses in this report are based on data supplied to NIOSH by the Mine Safety and Health Administration (MSHA) and the Bureau of Mines (BOM). The dust concentration data consist of records of airborne dust samples collected by MSHA inspectors. JRB has abridged, reformatted, and synthesized these records and other MSHA data, which were supplied either as automated data files or hard-copy reports, into a single automated data base referred to here as the exposure data base.

MSHA Inspection Sampling Data Files--

The MSHA and the BOM jointly developed the Mine Inspection Data Analysis System (MIDAS). MIDAS contains edited records of the industrial hygiene samples collected by MSHA inspectors during routine inspections and special surveys of establishments in the metal/nonmetal mining industry (Watts et al. 1981). The sampling methods and analytical procedures used by the inspectors conform to MSHA regulations as specified in Title 30 of the Code of Federal Regulations and MSHA field manuals for inspectors.

Personal samples representing a time-weighted average of a full work shift were taken for silica exposure. The MIDAS sampling data for silica were assayed by determining the mass percent of silica by x-ray diffraction analysis of the dust. These samples were collected by the mass method, in which a membrane filter is used to collect a dust sample. The mass of the dust is determined by weighing the filter before and after the sampling period. The volume of air that is filtered to collect the sample is calculated by multiplying the calibrated air pumping rate of the sampling device by the duration of the sampling period.

The MIDAS files obtained for this project include the following contaminant categories and numbers of samples collected from 1974 to 1981.

<u>Airborne contaminant</u>	<u>Number of samples</u>
Respirable quartz dust (quartz content greater than or equal to 1 percent)	38,683
Respirable dust (silica content less than 1 percent)	9,750
Respirable cristobalite dust (cristobalite content greater than or equal to 1 percent)	172
Respirable tridymite (tridymite content greater than or equal to 1 percent)	3
Total dust containing silica (silica content greater than or equal to 1 percent)	11,820
Asbestos (fibers greater than 5 micrometers)	1,170

The MIDAS files also contain results for samples collected with midget impingers. However, without a conversion factor for each dust source, these results cannot be compared with the results for respirable dust samples collected by the mass method and therefore have not been considered in constructing the exposure profiles. Similarly, the sampling data on total silica dust have been omitted from the exposure profiles because of the lack of a uniform relationship between total dust and respirable dust. The cristobalite samples were collected from 19 establishments; the tridymite samples from only two. Because of this limited coverage, the sampling data for these forms of silica have not been included in the exposure profiles used in this report.

The MIDAS sampling data for asbestos (the sixth contaminant noted above) represent personal short-term exposure samples reported as fiber counts based on use of the optical microscope counting method (Leidel et al. 1979). In the terminology adopted for this report, these samples have been described as mineral fiber samples because the MIDAS records do not indicate the mineral identity of the fibers.

MSHA Address and Employment Files--

The Address and Employment files contain information on mining industry establishments, including the mine ID, location, commodity produced, operating status, types of major operating subunits, and the average number of employees working at each major subunit. Separate annual MSHA files are maintained for the coal and the metal/nonmetal industries.

MSHA Reports of Silica in Coal Dust Samples--

MSHA regulations require that coal miners not be exposed to more than 2 mg/m³ of respirable coal dust in air over an 8-hour shift if the silica content of the dust is less than 5 percent. Mines with airborne respirable dust containing 5 percent silica or more must operate under a reduced respirable coal dust standard. The allowable level of respirable coal dust is calculated by dividing the percent silica content into the number 10. For enforcement purposes, the MSHA Division of Coal Mine Health maintains records of those coal mining establishments that were inspected and found to have respirable dust samples containing more than 5 percent silica. MSHA supplied copies of these monitoring reports to NIOSH for this project. JRB abstracted and entered the data in the automated file to expedite analysis of the establishments and operations that appeared in the reports between July 1974 and March 1981. The sampling results included the percent silica in the dust but not the dust concentration in air. Therefore, the airborne silica dust concentration could not be calculated for use in the exposure profiles for the coal industry. Instead, the profiles show the silica percentage in the coal dust. This information can be used to determine the dust levels that must be attained to meet the alternate PEL's for those coal mining establishments represented in the data base.

MSHA Fiber Survey--

Between 1973 and 1976, environmental investigations and dust surveys showed that mineral fibers (sometimes identified as asbestos minerals) were associated with many types of metamorphic rock formations. In 1977, MSHA began a screening survey to determine which mining establishments and mineral deposits might have an asbestos hazard. MSHA produced a listing of 6,210 establishments with mining operations in metamorphic rock formations. MSHA field inspectors have been collecting short-term samples for the screening survey at many of these establishments. If samples showed a fiber count above the MSHA PEL (currently 2 fibers/cc, but 5 fibers/cc until January 1978), the samples were sent for electron microscopy analysis to identify the mineral composition of the fibers. The results of 57 analyses of mineral composition were available at the time of this report; these are presented in Section 2.3 but are not included in the data base.

With the cooperation of MSHA, JRB project staff reviewed and abstracted data from fiber count samples. These were personal and area samples, and many were collected over a period of less than 10 minutes. In many cases, the fiber count and the sampling time were both so low that the samples were of questionable value. Thus, JRB included only those sampling data where the fiber count was greater than or equal to 1 fiber/cc or the sampling time was 30 minutes or more.

Other Surveys and Studies--

The literature search performed during the project covered other sources including published and open file reports of dust surveys conducted by BOM, NIOSH, MSHA, and private organizations. Information from these sources is reviewed in Sections 2.2 and 2.3, but data from them have not been included in the exposure data base because the sampling data reported in the literature were believed not to be comparable to the MIDAS data.

2.1.2 Data Processing

JRB made several important changes in the format of the MSHA files to make them easier to use in the exposure data base. These changes included omitting unnecessary data elements and adding or revising data to reflect JRB's system of codes for industry groups and operation categories. This coding system includes 17 industry groups and 14 operation categories. The 17 industry groups are copper, gold and silver, iron, lead and zinc, molybdenum, uranium, other metals, limestone, other stone, clay and shale, asbestos, talc, oil shale, sand and gravel, other nonmetals, peat, and coal. There are no data for the peat and coal industries in the MIDAS files, and therefore exposures in these two industries are not discussed. The 14 operation categories are surface drilling; underground drilling; blasting; cutting and boring; surface production; surface mobile transport; surface haulageway maintenance; underground production; underground haulageway maintenance; underground mobile transport; crushing, grinding, and sizing; concentrating and finishing; surface nonspecific; and underground nonspecific. A cross-reference of MIDAS data source codes and JRB industry groups is shown in Table 2-1. A cross-reference of MIDAS operation codes with JRB operation categories is shown in Table 2-2.

JRB's system of classification was specifically designed for use in profiling exposure or describing control technology, while the MSHA files were designed to permit many other uses. For example, many of the MIDAS samples were coded for operations in which a single worker was typically involved in work processes falling in several of the specific JRB operation categories. Since the level of such a worker's primary exposure at a single process could not be determined, these samples were classified in the nonspecific operations category. This addition allowed all of the MIDAS sampling data to be cross-referenced with a JRB operation category. The exposure levels for the nonspecific operations in each industry group therefore represent the general exposure of employees who are involved in several operations at one establishment.

The MIDAS sampling records include a location code that was used to classify samples from the other operation categories as surface or underground. The exposure data base was made to indicate whether the data were collected from an underground or a surface location. This variable is at least as important as the differences among operation categories or industry groups for most operations in the extraction phase of the mining cycle. For the two categories of milling operations (the crushing, grinding, and sizing operations and concentrating and finishing operations), the distinction

Table 2-1. Cross-reference of data source codes and mining industry groups (numerical order by MIDAS industry code).

MIDAS industry		MSHA SIC		JRB
Code	Name	Code	Name	Industry group
0	Closed site		Closed site	Closed site
1	Cement	32410	Cement	Limestone and related
2	Granite	14111	Granite (dim)	Other stone
2	Granite	14230	Granite (c&b)	Other stone
3	Limestone	14112	Limestone (dim)	Limestone and related
3	Limestone	14220	Limestone (c&b)	Limestone and related
4	Lime	32740	Lime	Limestone and related
5	Marble	14113	Marble (dim)	Other stone
5	Marble	14291	Marble (c&b)	Other stone
6	Sandstone	14114	Sandstone (dim)	Other stone
6	Sandstone	14292	Sandstone (c&b)	Other stone
7	Slate	14115	Slate (dim)	Other stone
7	Slate	14293	Slate (c&b)	Other stone
8	Traprock	14116	Traprock (dim)	Other stone
8	Traprock	14294	Traprock (c&b)	Other stone
9	Misc. stone	14110	Stone (dim), nec	Other stone
9	Misc. stone	14290	Stone (c&b), nec	Other stone
10	Antimony	10991	Antimony	Other metals
11	Bauxite	10510	Aluminum ore	Other metals
11	Bauxite	28191	Alumina (mill)	Other metals
12	Beryl	10992	Beryl	Other metals
13	Chromite	10611	Chromite	Other metals
14	Copper	10210	Copper ore	Copper
15	Gold and silver	10410	Gold	Gold and silver
15	Gold and silver	10440	Silver ores	Gold and silver
16	Iron	10110	Iron ore	Iron
17	Lead and zinc	10310	Lead and zinc ores	Lead and zinc
18	Manganese	10614	Manganese	Other metals
19	Molybdenum	10615	Molybdenum	Molybdenum
20	Titanium	10996	Titanium	Other metals
21	Tungsten	10617	Tungsten	Other metals
22	Uranium	10940	Uranium and vanadium	Uranium

(continued)

Table 2-1. Cross-reference of data source codes and mining industry groups (numerical order by MTDAS industry code).

MIDAS industry		MSHA SIC		JRB
Code	Name	Code	Name	Industry group
22	Uranium	10941	Uranium	Uranium
23	Mercury	10920	Mercury	Other metals
29	Metals, nec	10610	Ferroalloy ores	Other metals
29	Metals, nec	10612	Cobalt	Other metals
29	Metals, nec	10613	Columbium and tantalum	Other metals
29	Metals, nec	10616	Nickel	Other metals
29	Metals, nec	10942	Vanadium	Other metals
29	Metals, nec	10990	Metal ores, nec	Other metals
29	Metals, nec	10993	Platinum group	Other metals
29	Metals, nec	10994	Rare earths	Other metals
29	Metals, nec	10995	Tin ore	Other metals
29	Metals, nec	14997	Zircon	Other metals
40	Asbestos	14991	Asbestos	Asbestos
41	Barite	14720	Barite	Other nonmetals
42	Boron minerals	14741	Boron minerals	Other nonmetals
43	Clay and shale	14530	Clay (fire)	Clay and shale
43	Clay and shale	14550	Clay (common)	Clay and shale
43	Clay and shale	14590	Clay (cer&ref), nec	Clay and shale
43	Clay and shale	14596	Shale (common)	Clay and shale
44	Feldspar	14593	Feldspar	Other nonmetals
45	Fluorspar	14730	Fluorspar	Other nonmetals
46	Gypsum	14920	Gypsum	Other nonmetals
47	Magnesite	14595	Magnesite	Other nonmetals
48	Mica, vermiculite	14994	Mica	Other nonmetals
48	Mica, vermiculite	14998	Vermiculite	Other nonmetals
49	Phosphate rock	14750	Phosphate rock	Other nonmetals
50	Potash	14742	Potash	Other nonmetals
51	Pumice, perlite	14996	Perlite	Other nonmetals
51	Pumice, perlite	14997	Pumice	Other nonmetals
52	Salt	14760	Salt, rock	Other nonmetals
52	Salt	28991	Salt, evaporated	Other nonmetals
52	Salt	28992	Salt, brine	Other nonmetals

(continued)

Table 2-1. Cross-reference of data source codes and mining industry groups (numerical order by MIDAS industry code).

MIDAS industry		MSHA SIC		JRB
Code	Name	Code	Name	Industry group
53	Sodium compounds	14743	Trona	Other nonmetals
53	Sodium compounds	14744	Sodium compounds	Other nonmetals
54	Sulfur	14770	Sulfur	Other nonmetals
55	Talc, etc.	14960	Talc, etc.	Talc, etc.
58	Oil shale	13111	Oil shale	Oil shale
59	Nonmetals, nec	14591	Aplite	Other nonmetals
59	Nonmetals, nec	14592	Brucite	Other nonmetals
59	Nonmetals, nec	14594	Kyanite	Other nonmetals
59	Nonmetals, nec	14740	Potash, etc., nec	Other nonmetals
59	Nonmetals, nec	14790	Chemical and fertilizer	Other nonmetals
			Minerals, nec	
59	Nonmetals, nec	14791	Lithium	Other nonmetals
59	Nonmetals, nec	14792	Pigment material	Other nonmetals
59	Nonmetals, nec	14793	Pyrites	Other nonmetals
59	Nonmetals, nec	14794	Strontium	Other nonmetals
59	Nonmetals, nec	14990	Nonmetal minerals, nec	Other nonmetals
59	Nonmetals, nec	14992	Gemstones	Other nonmetals
59	Nonmetals, nec	14993	Gilsonite	Other nonmetals
59	Nonmetals, nec	28190	Industrial chemicals, nec	Other nonmetals
59	Nonmetals, nec	28193	Bromine	Other nonmetals
59	Nonmetals, nec	29900	Leonardite	Other nonmetals
60	Sand and gravel	14410	Sand and gravel	Sand and gravel
76	Peat	14995	Peat	Peat
80	Coal	11110	Coal, anthracite	Coal
80	Coal	12110	Coal, bituminous	Coal

"
(dim) = diminished
(c&b) = crushed and broken
(cer&ref) = ceramics and refractory
nec = not elsewhere classified

Table 2-2. Cross-reference of operation categories
with MIDAS operation codes.

JRB operation category	MIDAS operation	
	Code	Name
Blasting	7	Blasting
Cutting and boring	8	Rock sawing
Drilling (surface, underground)	5	Rock bolting
	9	Drilling, percussive
	10	Drilling, rotary
	11	Drilling, diamond
	40	Jet piercing
Haulageway maintenance (surface, underground)	4	Timbering
	19	Concrete operations
Production (surface, underground)	1	Slushing
	2	Machine mucking
	3	Hand mucking
	16	Mining machine operation
	22	Slurrying
Mobile transport (surface, underground)	39	Dredging
	6	Back filling
	12	LHD, electric
	13	LHD, diesel
	14	LHD, gasoline
	15	LHD, compressed air
	17	Track crew
Crushing, grinding, and sizing	21	Bulldozing
	20	Hoisting
	27	Crushing
	28	Grinding
	31	Sizing
	90	Storing
	91	Transfer
	92	Conveying
Concentrating and finishing	29	Roasting, retorting
	30	Drying, filtering, etc.
	32	Concentrating
	33	Chemical operations
	37	Bagger
	38	Pelletizing
Nonspecific (surface, underground)	18	Complete cycle
	23	General labor, etc.
	24	General shop work
	25	Welding
	26	Mechanic
	34	Supply handling
	35	Technical services
	36	Administration

between surface and underground locations is not important for assessing control technology, since the process steps are similar. In addition, the cutting and boring operation category and the blasting operation category contained only a small number of samples. Therefore, the two types of milling operations, cutting and boring and blasting, have not been categorized as to surface or underground location.

It was also necessary to convert the MSHA exposure data into the terms of the PEL's being evaluated. MSHA uses the TLV formula for quartz silica as its dust standard; this formula is stated in terms of a quantity of dust in a unit volume of air. The alternative PEL's, on the other hand, are defined as a quantity of respirable silica in a unit volume of air. To make the conversion, JRB multiplied the dust concentration in the air by the percentage of silica in the dust.

JRB also conducted an analysis to determine whether the data in the MIDAS files, which were collected beginning in 1974, showed a trend that would bias the estimates of current dust levels. Based on this analysis, JRB decided to exclude both silica concentration samples and mineral fiber data collected prior to 1977 from the MIDAS exposure data for use in this report.

2.2 SILICA DUST EXPOSURE

This section presents exposure levels of respirable silica in 15 mining industry groups. In Section 2.2.1, information from the exposure data base is provided for each industry. Information collected during JRB's literature review is summarized in Section 2.2.2. The findings were evaluated in relation to the two alternate PEL's (0.05 and 0.075 mg/m³ of silica). The PEL's are expressed as absolute silica concentrations in air that do not vary with the percentage of silica in the dust. All of the current and alternate PEL's are time-weighted averages for an 8-hour workday.

2.2.1 Exposure Data Base and Literature Review

Figures 2-1 through 2-14 present information for each industry group and operation category on the sample size and the percentage of the samples that meet each of the two alternate PEL's.

The main features of the available MSHA data for each industry, as shown in the figures, and the available information on silica exposure found in the literature review are discussed below.

Copper (Figure 2-1)--

Data were available for all applicable operation categories in the copper industry. These data indicated that 75 percent or more of the samples were already below the low PEL.

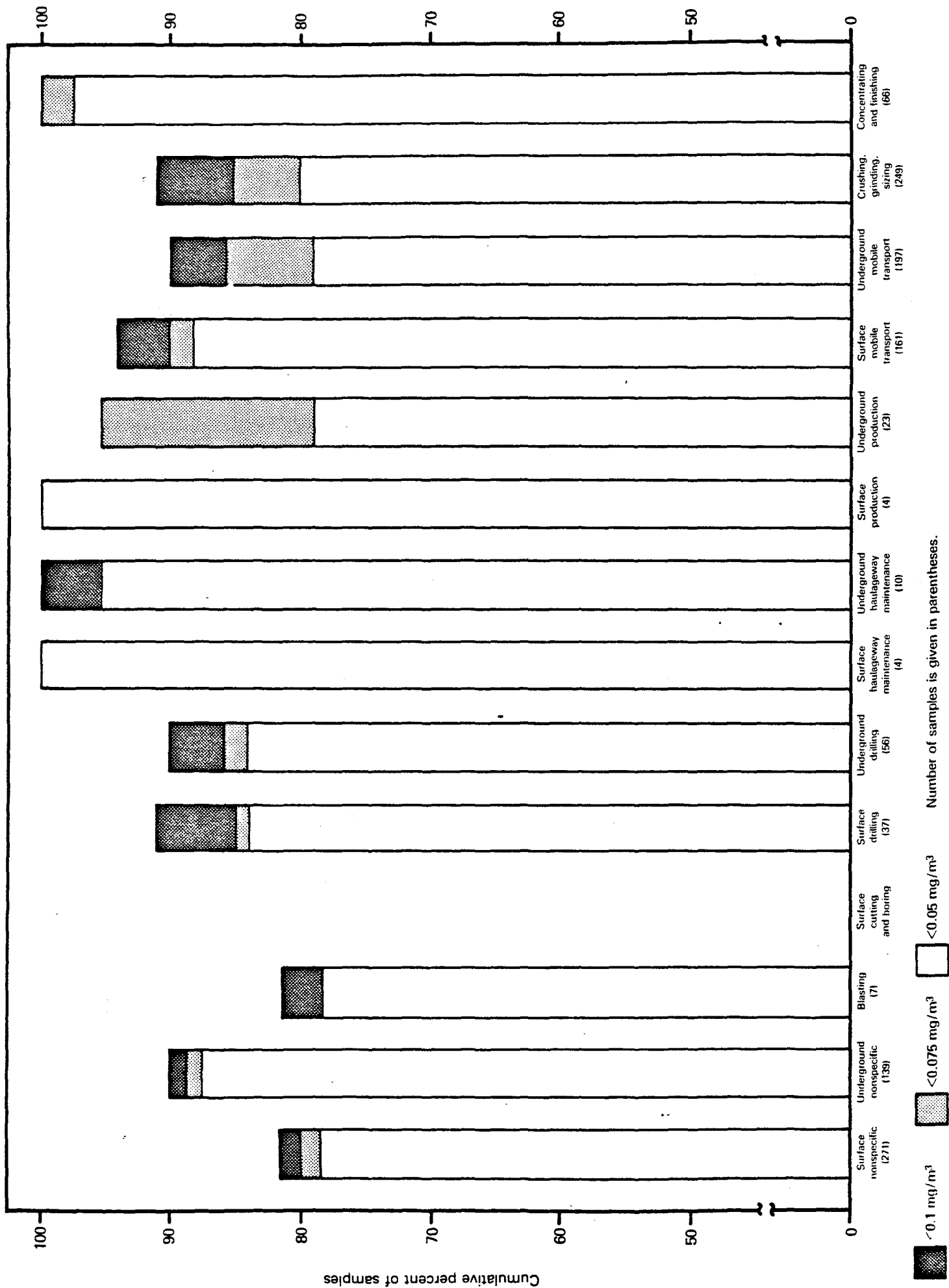


Figure 2-1. Copper industry respirable silica concentrations.

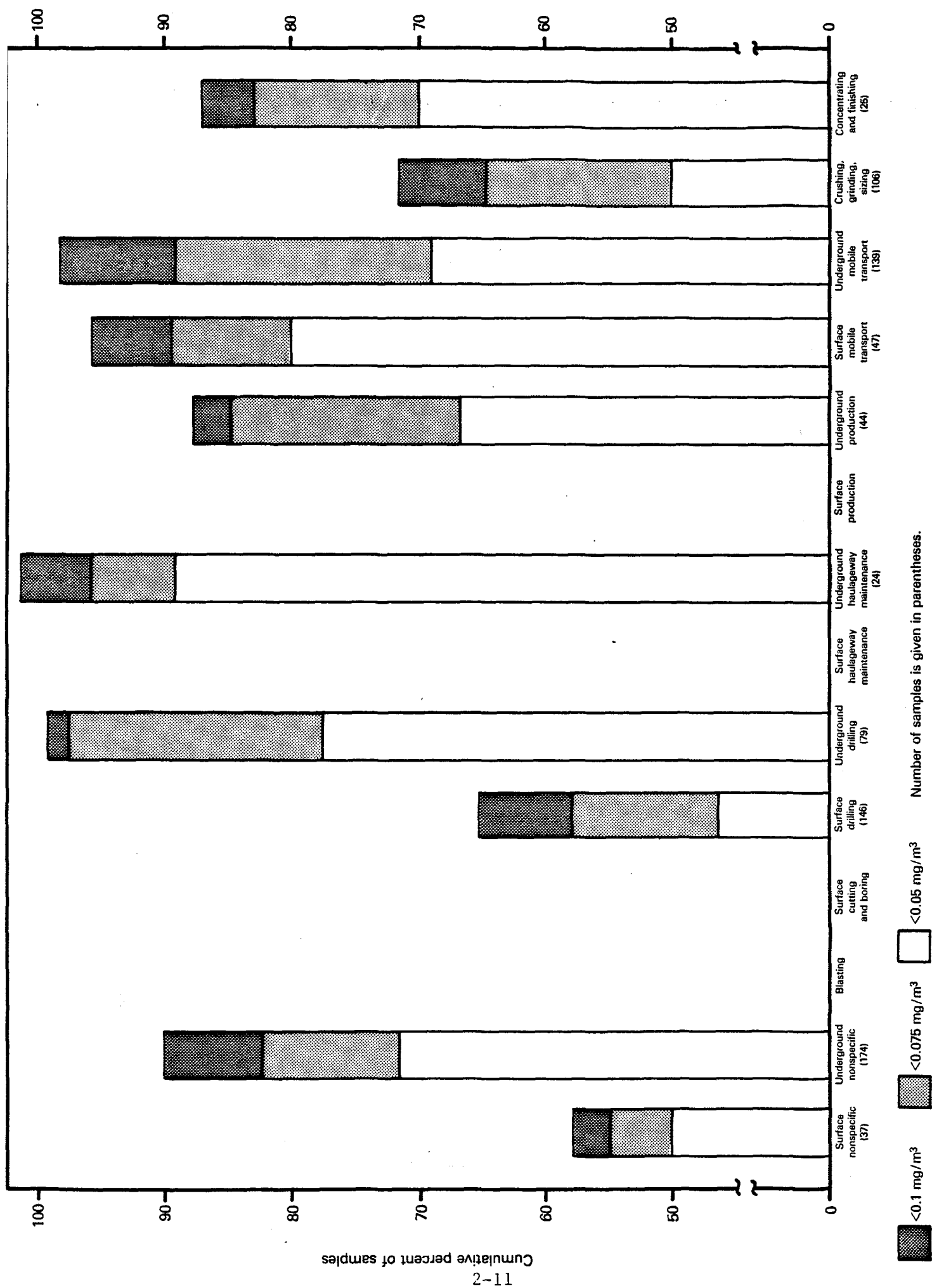
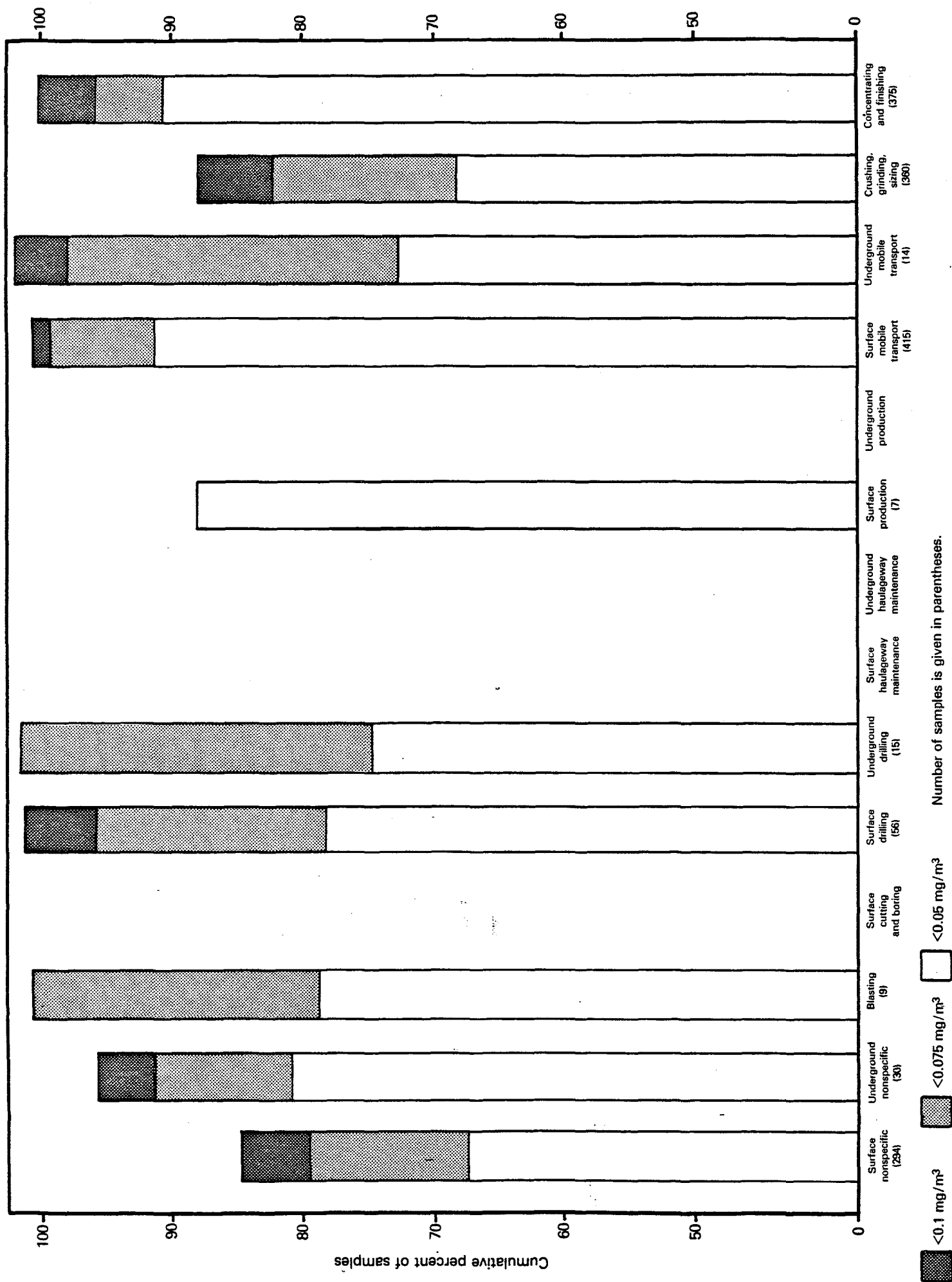


Figure 2-2. Gold and silver industry respirable silica concentrations.



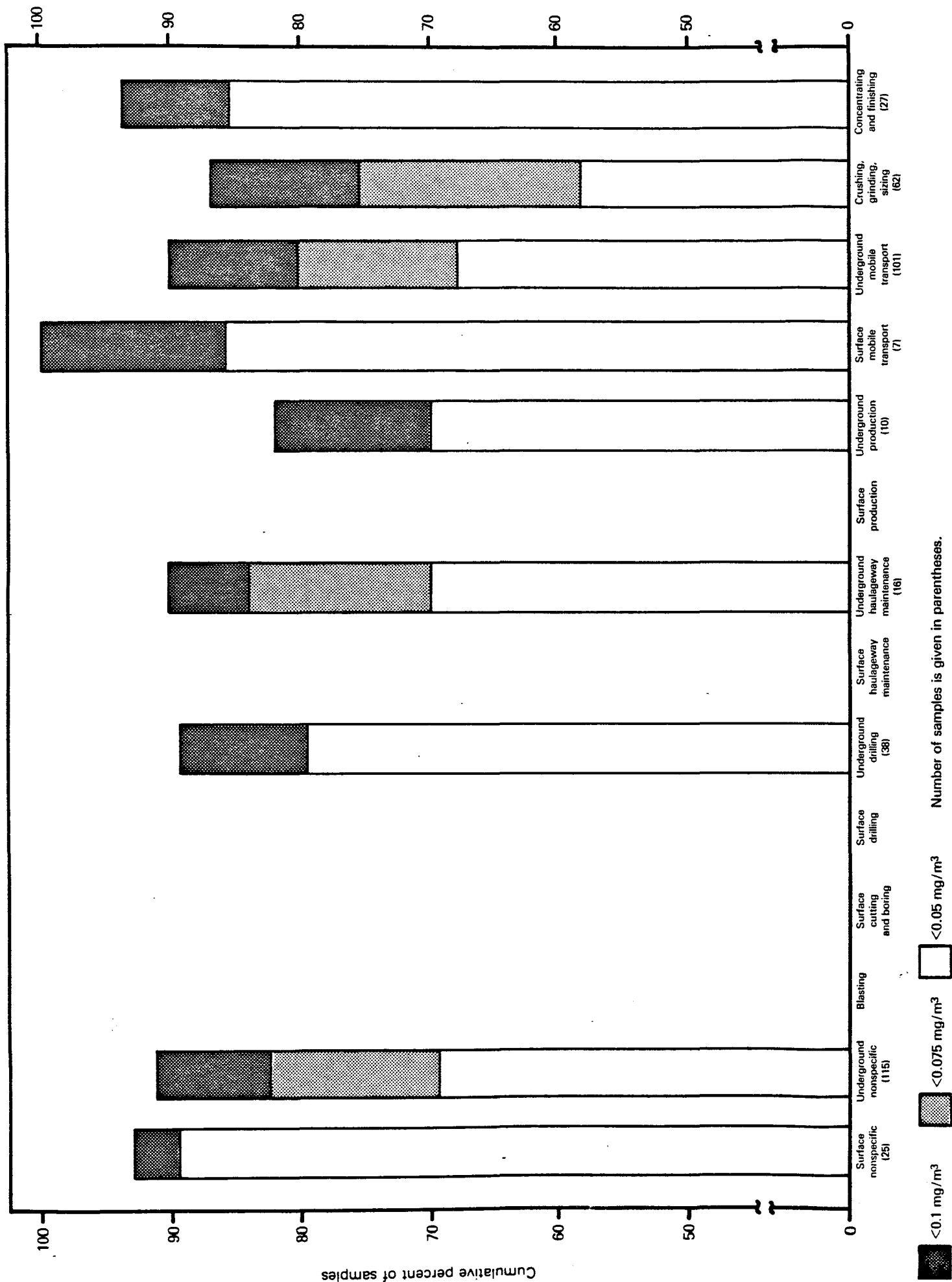


Figure 2-4. Lead and zinc industry respirable silica concentrations.

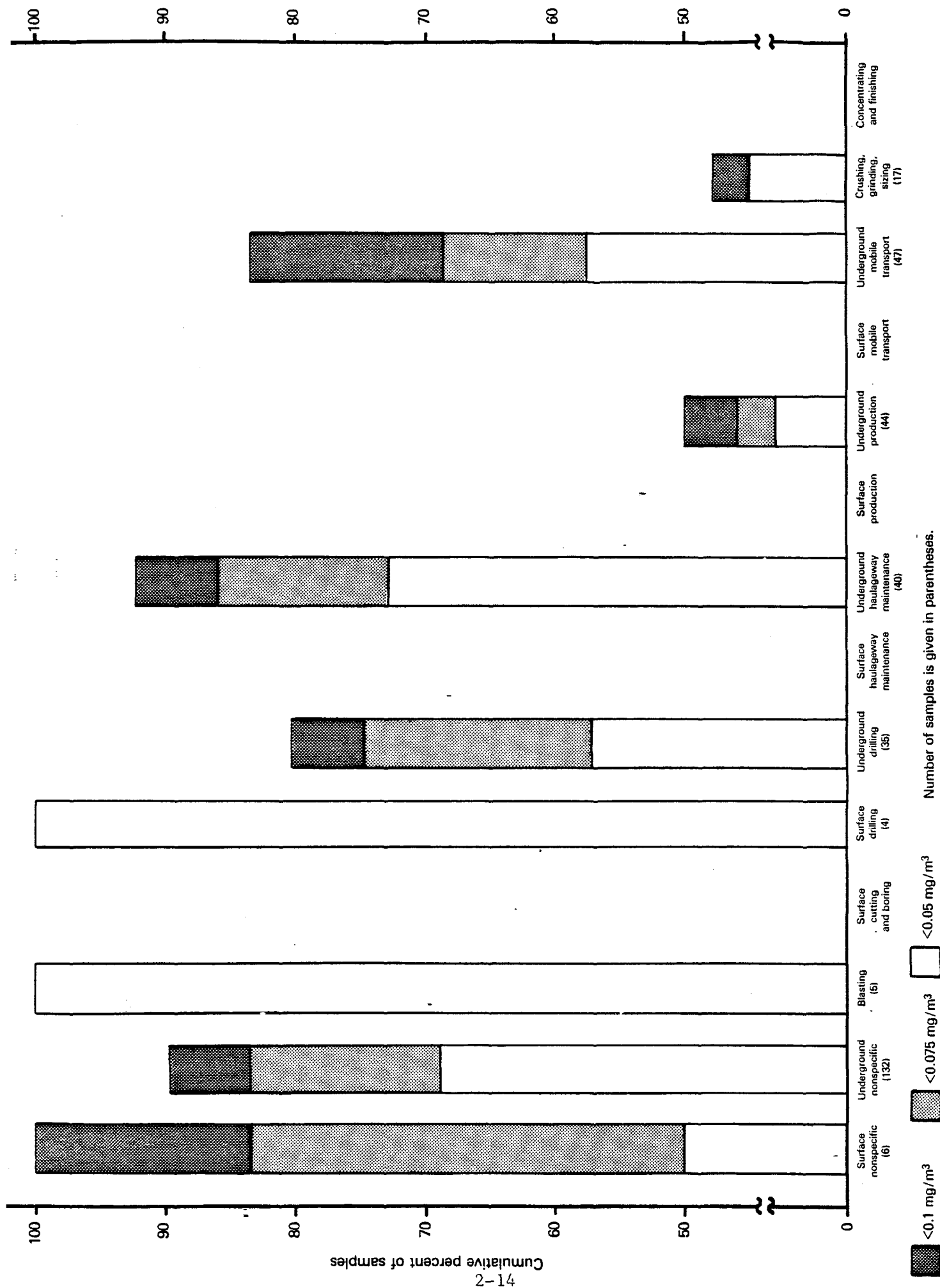


Figure 2-5. Molybdenum industry respirable silica concentrations.

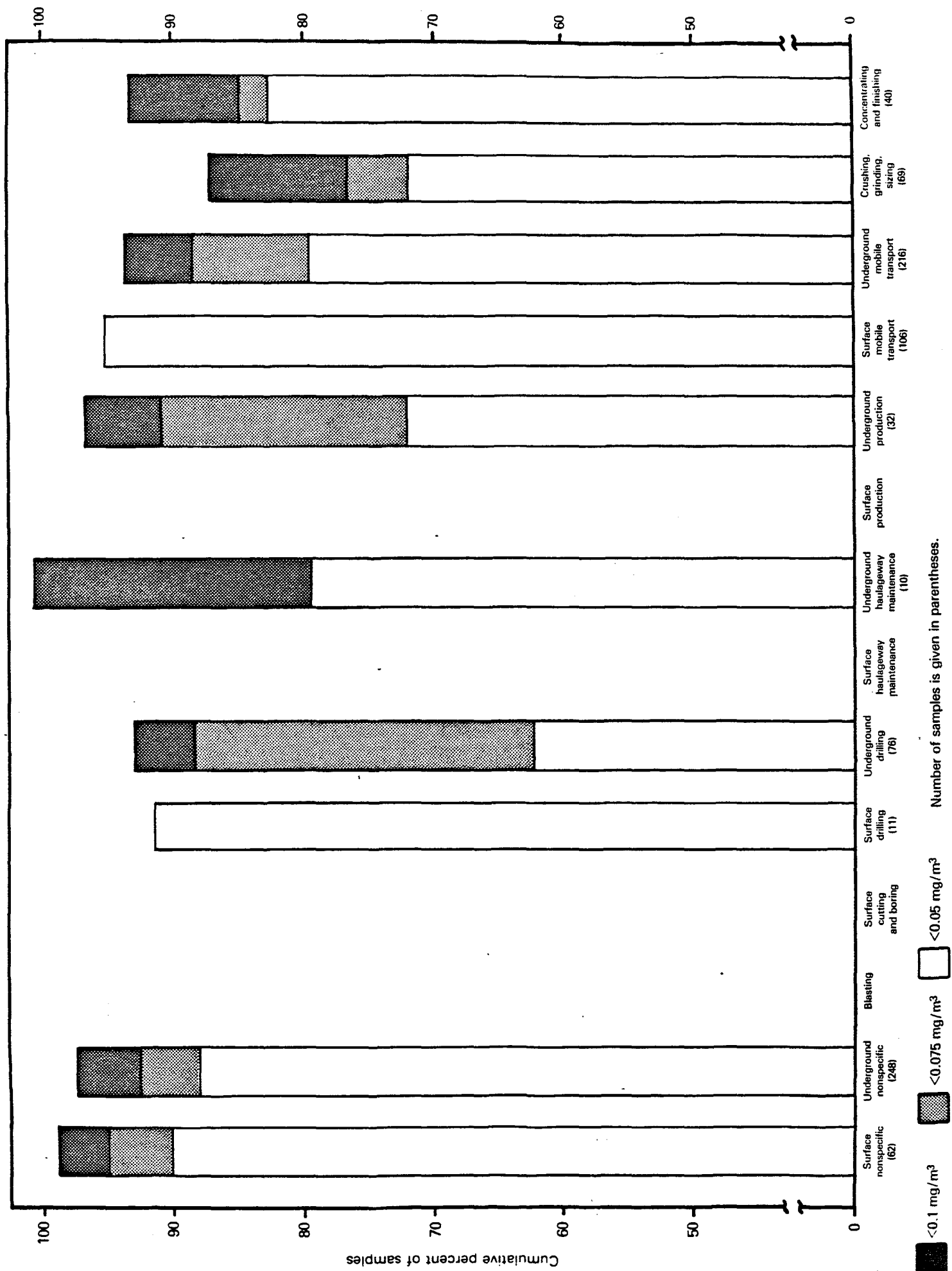


Figure 2-6. Uranium industry respirable silica concentrations.

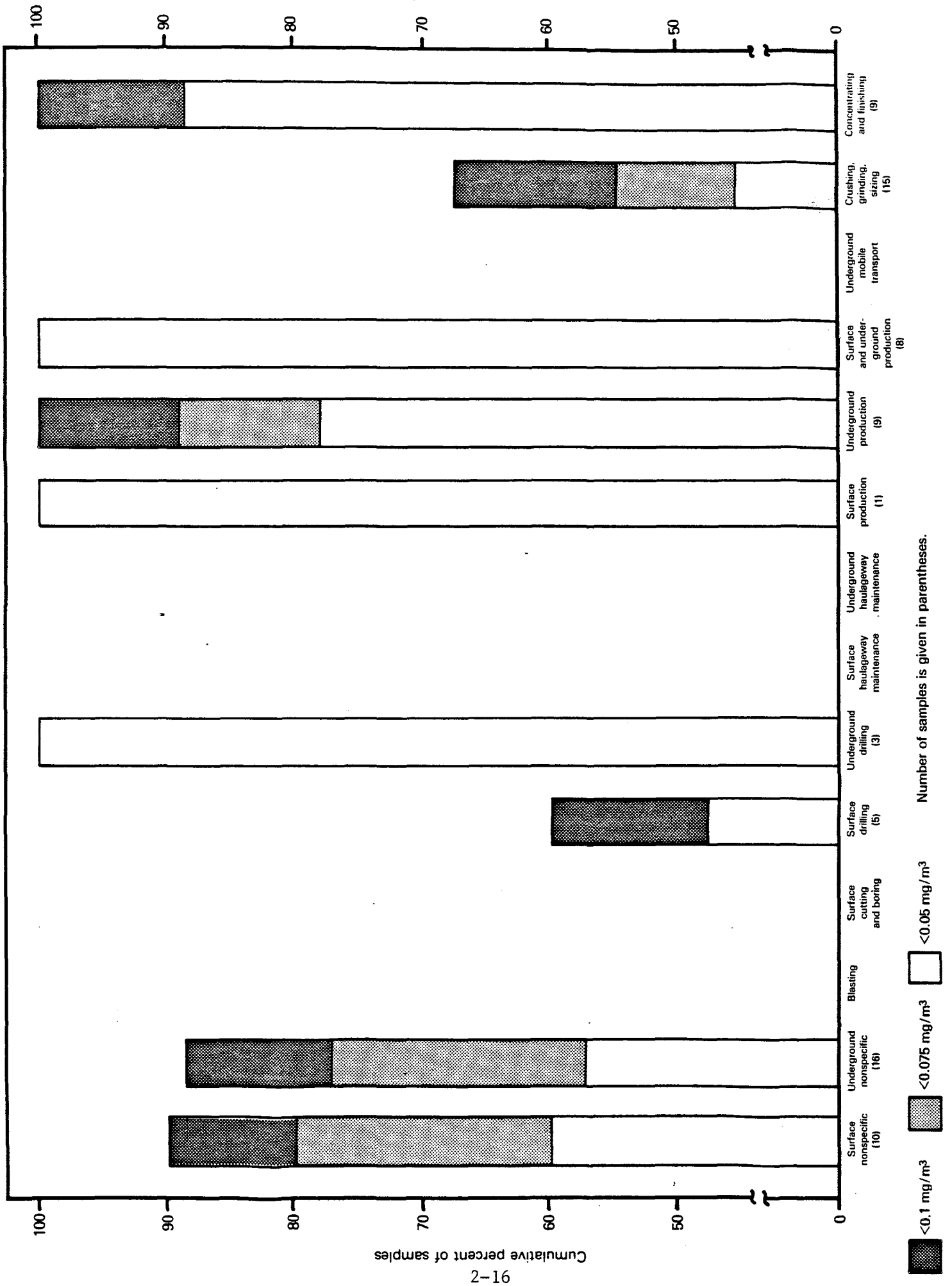


Figure 2-7. Other metals industry respirable silica concentrations.

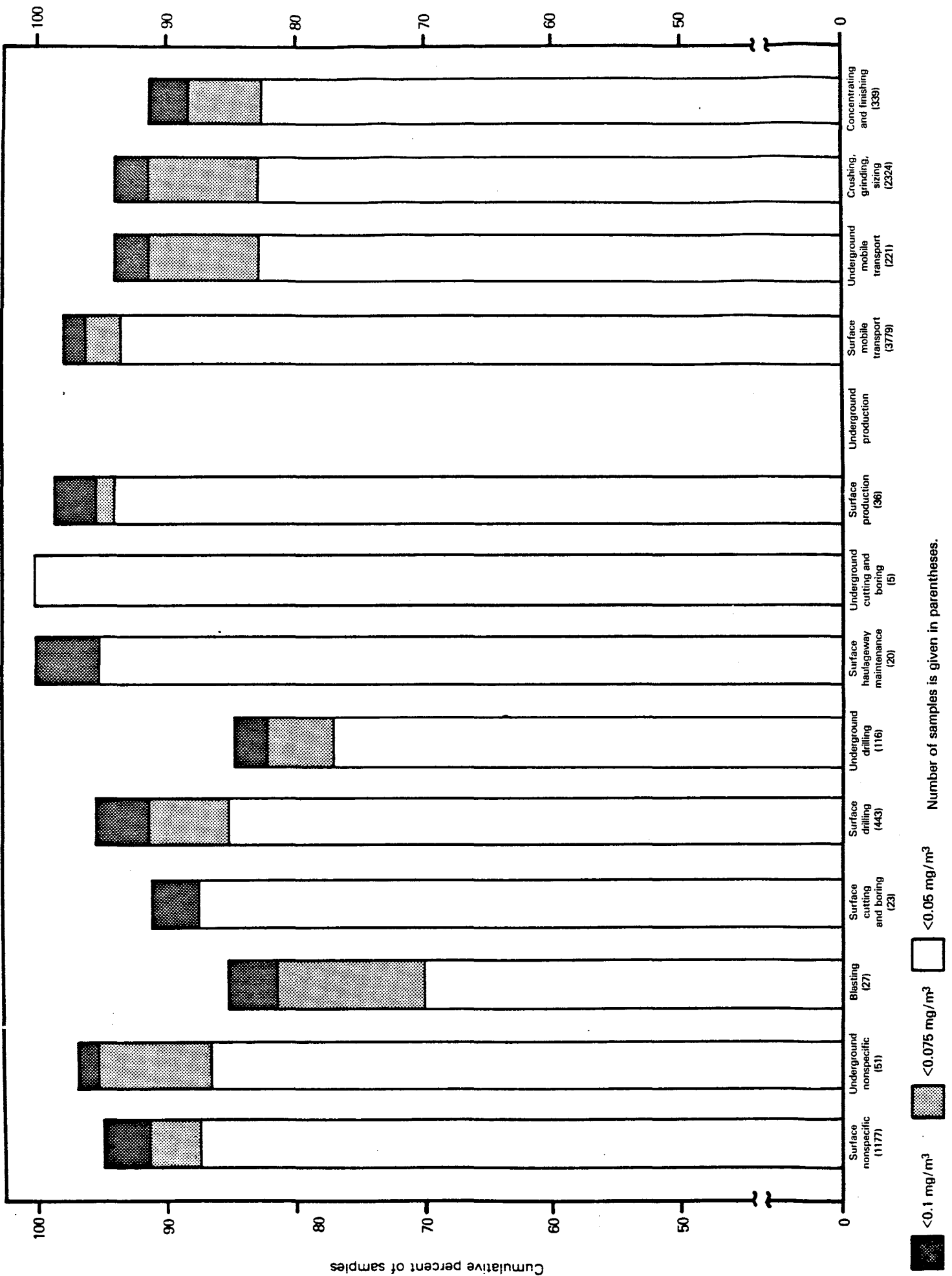


Figure 2-8. Limestone industry respirable silica concentrations.

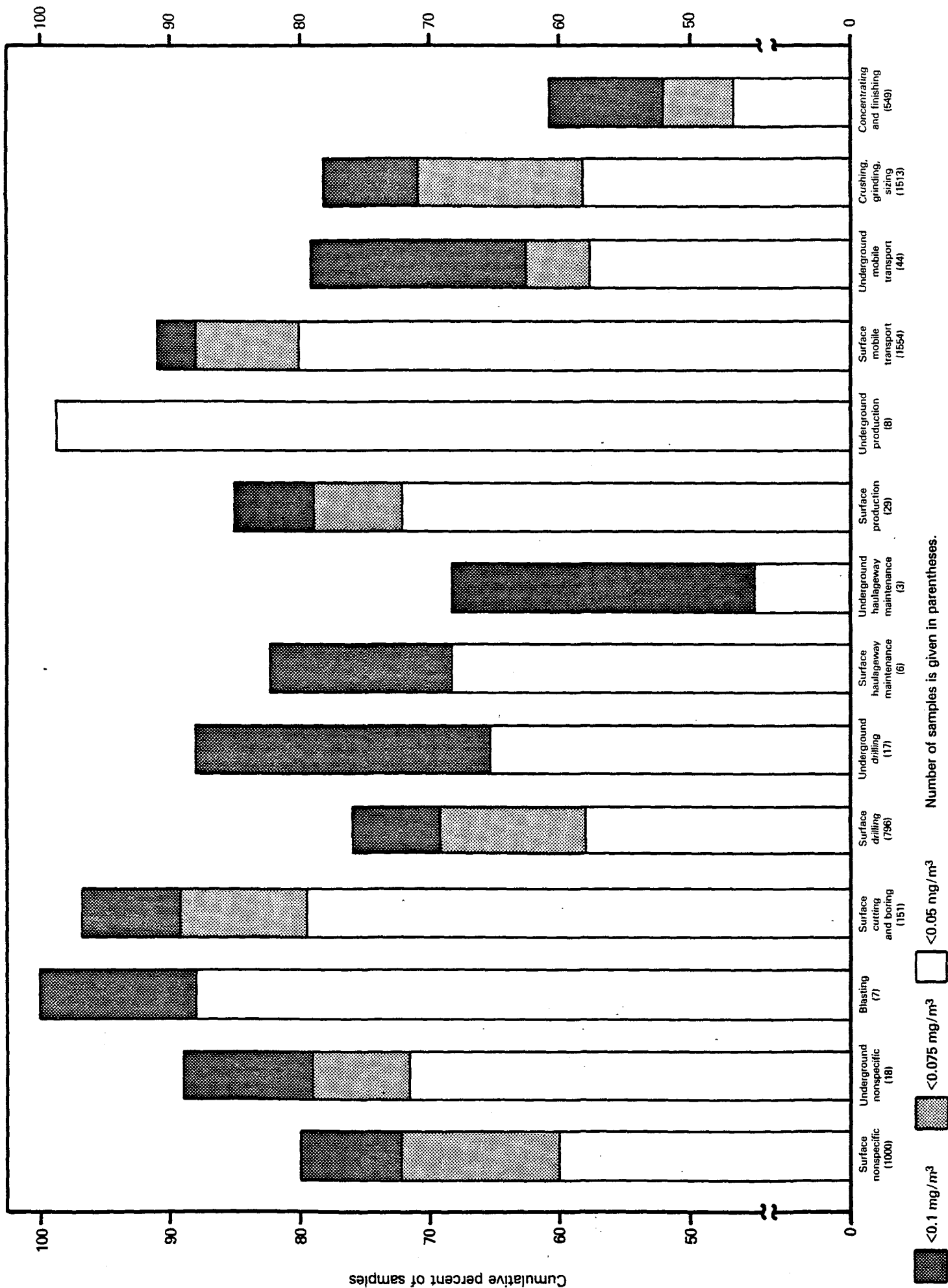
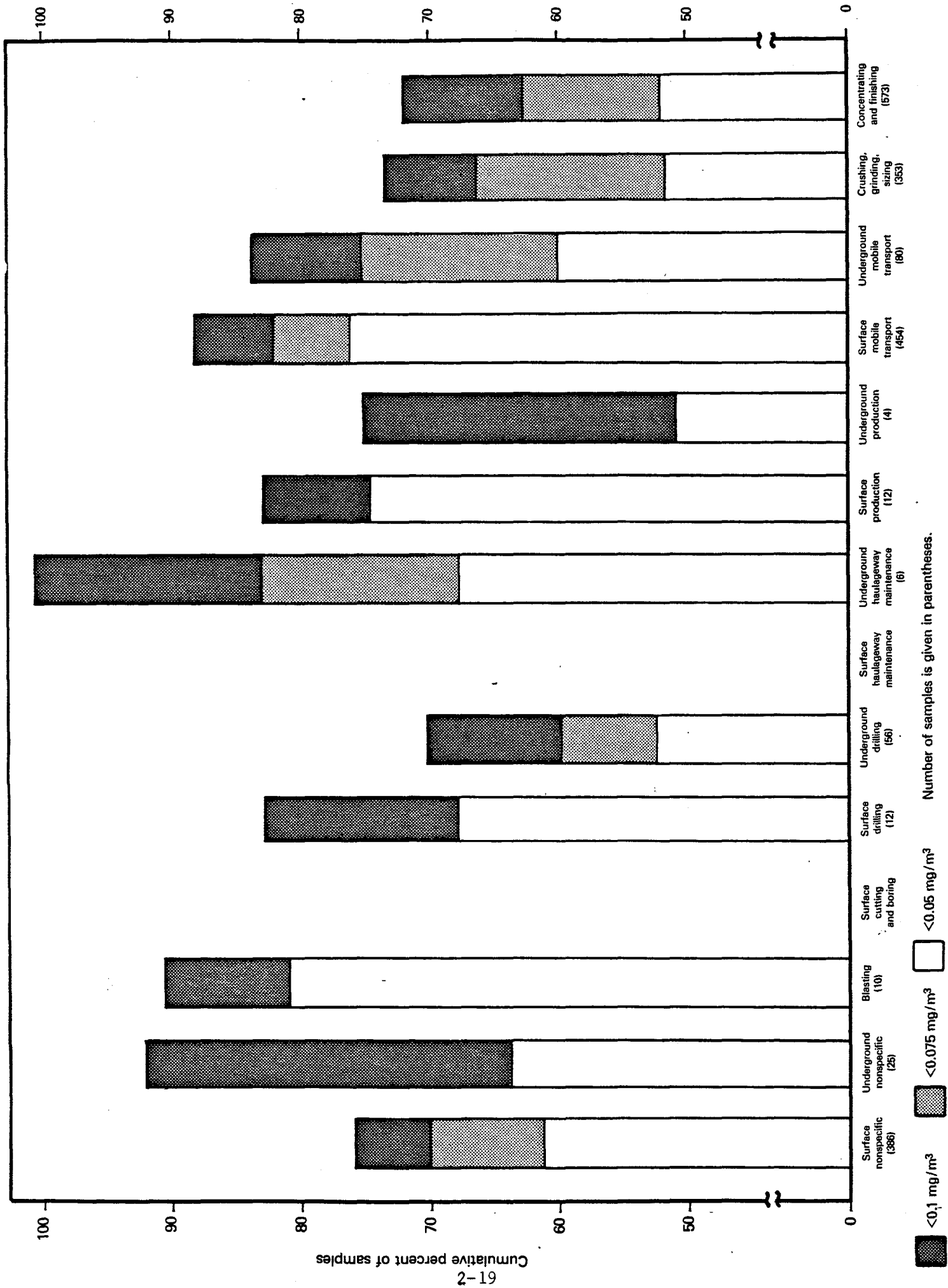


Figure 2-9. Other stone industry respirable silica concentrations.



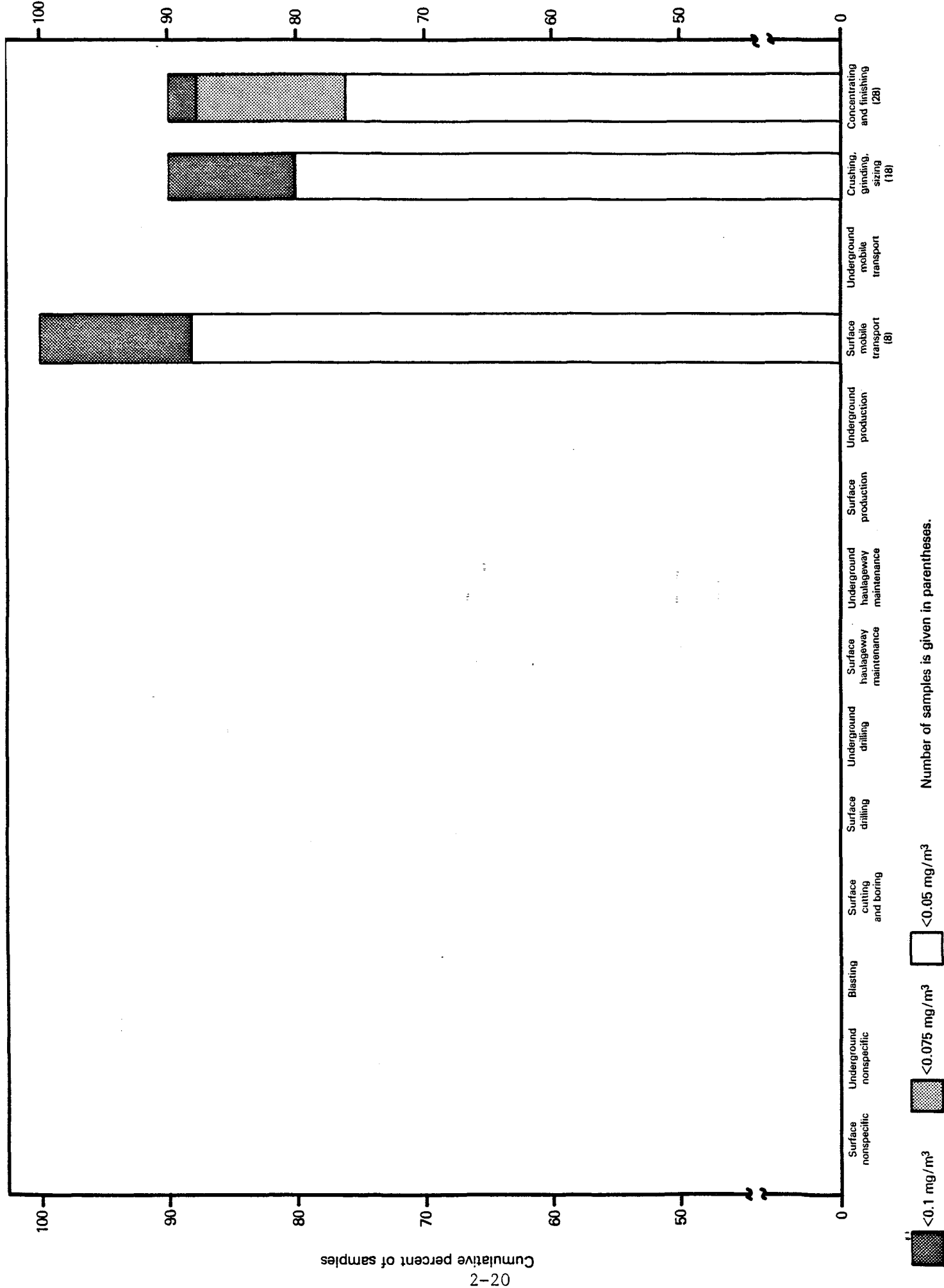


Figure 2-11. Talc industry respirable silica concentrations.

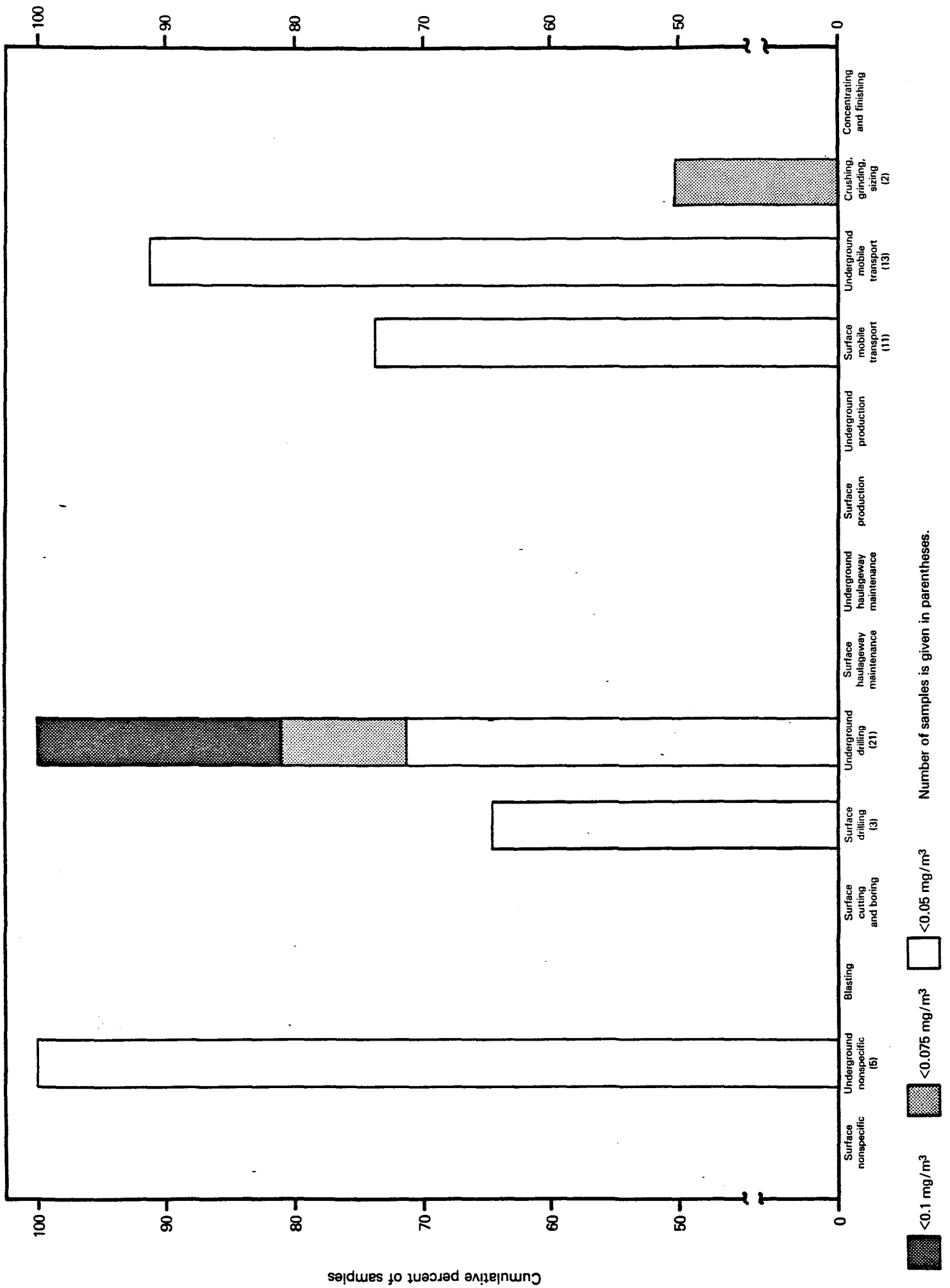


Figure 2-12. Oil shale industry respirable silica concentrations.

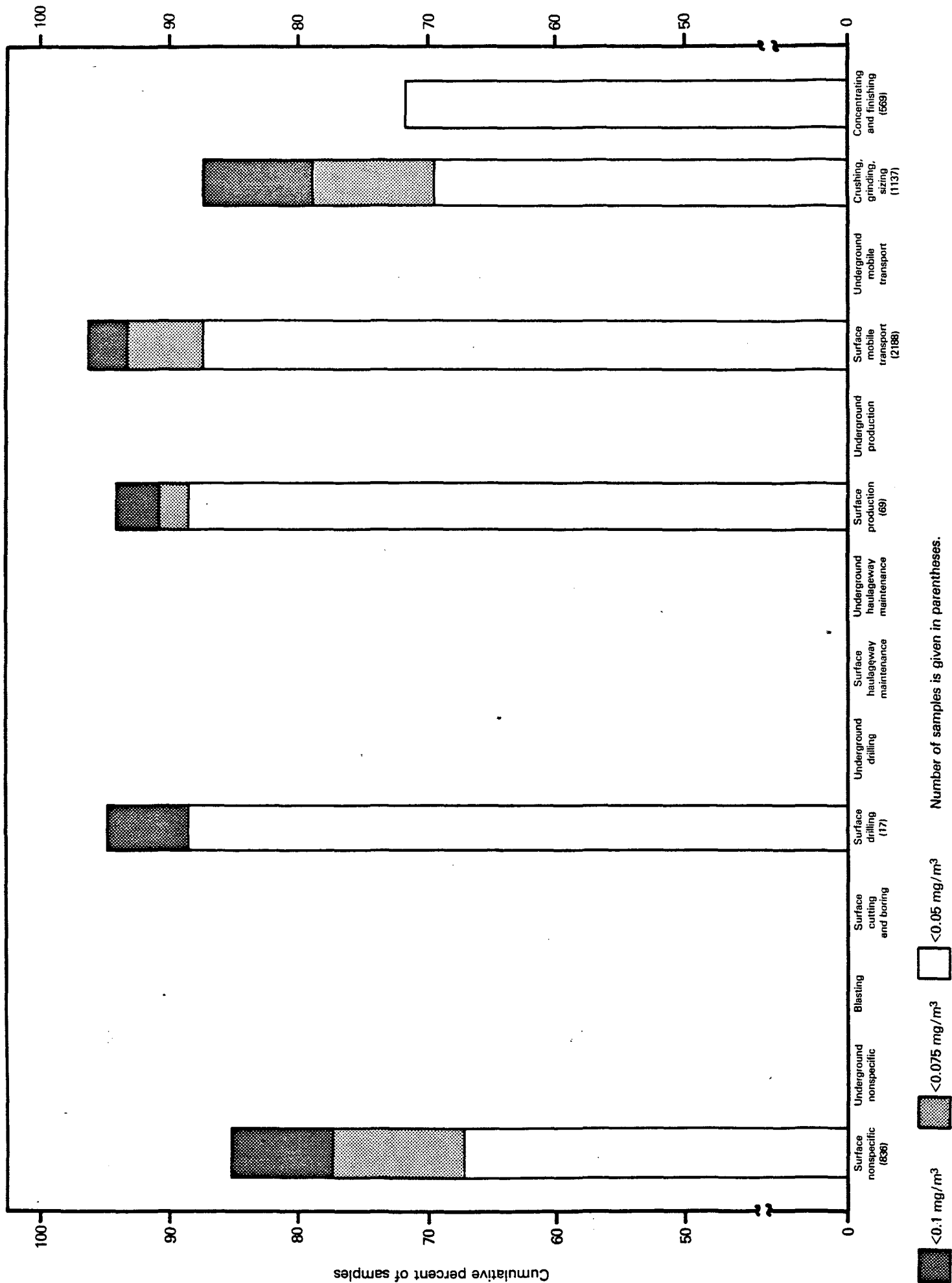


Figure 2-13. Sand and gravel industry respirable silica concentrations.

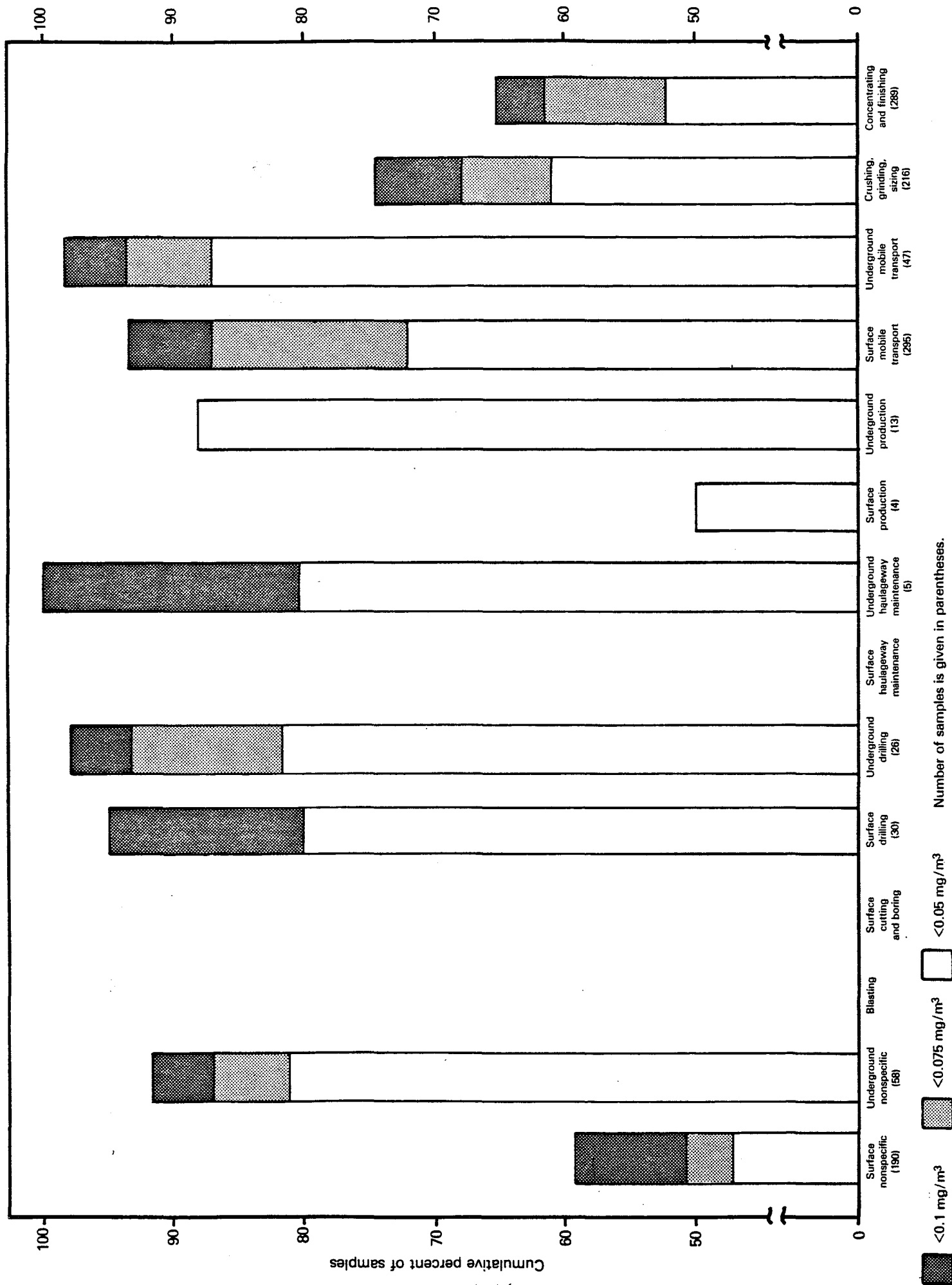


Figure 2-14. Other nonmetals industry respirable silica concentrations.

Gold and Silver (Figure 2-2)--

It is obvious from Figure 2-2 that silica dust exposure in surface drilling and crushing, grinding, and sizing operations in the gold and silver industry group is higher than in other operations. In 1976, the BOM conducted a respirable dust survey at an underground gold mine to determine airborne dust concentrations for different occupations and locations in the mine (Larson and Zeller 1976). Table 2-3 is a summary of dust concentration ranges and concentrations of respirable silica (quartz) found during this survey, which are comparable to the MIDAS data. For all occupations and locations, the highest silica concentration exceeded the low PEL for silica. The highest silica concentrations for five of the nine sampled occupations and locations exceeded the high PEL. Table 2-3 also shows that the silica concentration in samples taken during a short period for the same occupation or location may vary from below the low PEL to above the high PEL.

Iron (Figure 2-3)--

Except for the crushing, grinding, and sizing operation, more than 90 percent of silica dust samples collected in other specific operations in the iron industry were below the PEL of 0.075 mg/m^3 . Large numbers of samples were available for the crushing, grinding, and sizing operation and these showed that 16 percent were higher than 0.1 mg/m^3 .

Two published reports contain silica data for iron mines. In 1976, the BOM conducted a respirable dust survey at an unidentified underground iron mine (Larson and Zeller 1976). Full-shift (8-hour) respirable dust samples were collected for eight different occupations (personal samples) and operations (area samples). The analyses showed that the highest silica concentration was 0.04 mg/m^3 .

The second report, published in 1980, described a mortality study of employees at a taconite mining and processing facility in the Mesabi Range of northeastern Minnesota (Clark et al. 1980). Dust sampling data on which the study was based were taken from industrial hygiene surveys that had been conducted twice yearly at the mine from 1955 to 1975, using the midget impinger sampling method. One group of employees, who were regularly exposed to dust containing 50 percent silica during crushing and grinding operations, had total dust exposures ranging from 0.25 to 6.09 million particles per cubic foot (mppcf). The second group of employees worked with the iron-rich slurry formed after siliceous tailings were removed. The silica content of the dust was 10 percent, and the exposures ranged from 0.21 to 7.74 mppcf. Because of the age of the data and the use of midget impingers for sampling, the results of this study are not comparable to recent MSHA sampling data.

Lead and Zinc (Figure 2-4)--

In 1976, the BOM conducted a respirable dust survey at an underground lead and zinc mine (Larson and Zeller 1976). Both personal and area samples were taken, but no free silica was detected. This is in contrast to the MIDAS data, in which silica dust concentrations were higher than 0.05 mg/m^3 in 30 percent of the samples.

Table 2-3. Respirable dust concentration ranges and respirable silica concentrations in an underground gold mine.

Occupation or location	Sample type	Respirable dust ranges (mg/m ³)	Calculated concentration of respirable silica (mg/m ³)*
Motorman	Personal	0.34-1.05	0.05-0.14
Slushing and scraping	Personal	0.21-0.67	0.03-0.09
Contract miner	Personal	0.16-0.08	0.02-0.10
Local intake	Area	0.18-0.47	0.02-0.06
Local exhaust	Area	0.34-0.55	0.04-0.07
Shift boss	Personal	0.17-0.47	0.02-0.06
Chute puller	Personal	0.37-1.16	0.05-0.15
Square-set miner	Personal	0.19-0.86	0.02-0.11
Ore bypass	Area	2.57-3.46	0.33-0.45

*These values were calculated by JRB Associates from the dust concentration ranges based on the 13 percent respirable silica figure reported in the study.

Source: Larson and Zeller 1976.

Molybdenum (Figure 2-5)--

More data were available from samples collected in underground molybdenum operations than in surface locations. Among the operation categories, the underground production and the crushing, grinding, and sizing operations had the highest concentrations; more than half of the samples in these two categories were higher than 0.1 mg/m^3 .

Uranium (Figure 2-6)--

Most surface operations in the uranium industry, including drilling and mobile transport, had the highest percentage of samples with very low silica dust concentrations. Crushing, grinding, and sizing operations in this industry need more dust controls; only 74 percent of the samples from these operations were below 0.05 mg/m^3 .

Other Metals (Figure 2-7)--

The other metals industry group is composed of industries of many different minerals that use many mining methods, and dust exposure conditions vary a great deal among various commodities. Available data were also limited to only a few minerals.

In 1979, MSHA conducted a dust control evaluation study at a manganese processing plant (Schutz and Weems 1979). Four area samples for total dust were taken in the manganese dioxide building, and two samples were taken in the calcining building at the site. Airborne silica concentrations ranged from 0.30 to 0.34 mg/m^3 in the manganese dioxide building and were about 0.04 mg/m^3 in the calcining building. These results are based on total dust samples and are therefore not directly comparable to the MIDAS data.

Limestone (Figure 2-8)--

With the exception of blasting and underground drilling operations, more than 80 percent of the silica dust exposure data in the limestone industry group were below 0.05 mg/m^3 . Because of the large number of establishments in this industry group, there were many samples.

In August 1979, MSHA conducted a dust control evaluation study at a limestone plant (Hudson and Ulrich 1979). Sixteen area samples for total dust were collected alongside the conveyor, on and around the bagging platform, and at the hydrate operator stations. In October 1979, MSHA conducted a dust control reevaluation study at a cement plant (Weems and Krohlow 1979). Again, area samples for total dust were collected from the problem areas at the grinding/finishing mill building and the silo tunnel. In both of these investigations, silica content in all of the samples was less than 1 percent. Since only total samples were collected, they were not comparable to MIDAS data.

In March 1980, MSHA conducted a dust control evaluation study at another cement plant (Trabant and Spear 1980). Five area samples for respirable dust were collected in the clay-drying area and around the conveyors in the material transfer area. The percentage of silica in the sampled dust ranged from 2.85 to 8.77 percent, with the highest silica concentration at 0.175 mg/m³.

These results indicate that some cement plants may have very low silica dust levels, while other establishments may have significant silica dust control problems because of the difference in silica content of the dust.

Other Stone (Figure 2-9)--

In this industry group, several operation categories had a relatively high percentage of samples higher than the 0.1 mg/m³ level. These operations included surface drilling; underground haulageway maintenance; crushing, grinding, and sizing; and concentrating and finishing.

Asbestos--

The MIDAS files contained no respirable quartz samples from establishments in the asbestos industry.

Clay and Shale (Figure 2-10)--

Underground drilling; crushing, grinding, and sizing; and concentrating and finishing operations in the clay and shale industry group have the highest silica dust concentrations, with more than 30 percent of the samples containing concentrations higher than 0.1 mg/m³.

MSHA conducted a dust control evaluation study at a bentonite mill in May 1974 (Schutz and Spear 1979). Area samples for respirable and total dust were taken at six problem areas in the mill building. The samples were analyzed for free silica and cristobalite. Respirable silica concentrations ranged from 0.046 to 0.146 mg/m³; two samples exceeded the low PEL. Total silica dust concentrations ranged from 0.21 to 1.00 mg/m³. The cristobalite₃ concentrations in the respirable dust samples ranged from 0.04 to 0.08 mg/m³.

Talc (Figure 2-11)--

The talc industry group is small, and dust samples were available for only three operation categories. More than 75 percent of the samples had silica dust concentrations of less than 0.05 mg/m³.

As part of an ongoing survey of worker exposure to various health hazards in the talc mining and milling industry, NIOSH conducted a study at a talc mine and mill site in New York State (Lemen and Dement 1979). The highest silica concentration in the personal breathing zone samples collected during the study was 0.02 mg/m³, which is below the low alternate PEL.

Oil Shale--

The oil shale industry group has only a small number of establishments; there were only 55 samples for the whole group in the MIDAS file.

In March 1975, the BOM performed a field survey at the Paraho oil shale mine and mill to determine dust generation sources and respirable dust exposures (Volkwein and Flink 1977). A second survey was performed at Paraho in late 1977 by the Los Alamos Scientific Laboratory under the sponsorship of the American Petroleum Institute and the Department of Energy (Rudnick et al. 1980). Results of the two surveys are presented in Tables 2-4 and 2-5. Both surveys showed a wide variation in silica concentration levels among samples taken at the same mine or mill operation, as was seen in the MIDAS data. Results from both studies also agreed that the mill crushing operation had the highest respirable dust concentrations and the highest silica concentrations.

Sand and Gravel (Figure 2-13)--

The MSHA Technology Support Center in Denver, Colorado, supplied a list of 28 establishments that were producing silica as of October 1981 (personal communication, Glen W. Sutton, MSHA, October 1981). A review of the commodity codes for silica flour establishments in the MSHA Address and Employment File revealed that they are most often categorized as sand and gravel operations, so the reports on exposure conditions in silica flour plants are included in this group. Although data were available in a few operation categories, there were many samples in each of these categories. Dust exposures in crushing, grinding, and sizing operations and in concentrating and finishing operations were higher than in other operations, especially in silica flour plants.

Volkwein (ACGIH 1978) reported the results of a dust survey of silica sand processing mills. Early results revealed that bagging and handling dried silica sand and flour products created the most severe dust problems. The report included no sampling data.

In 1979, NIOSH conducted hazard evaluation surveys at two silica mining and processing operations (Morrison and Banks 1979a and 1979b). In both facilities, the respirable dust was approximately 100 percent silica. Of the 34 area and personal samples taken at one facility, 6 showed silica concentration levels equal to or below 0.05 mg/m³; 23 had levels above 0.1 mg/m³. At the other facility, 8 of 57 samples showed silica concentrations below 0.05 mg/m³; 46 samples were above 0.1 mg/m³.

MSHA conducted a dust control reevaluation study at a silica flour mill in 1979 (Weems and Schutz 1979). Six personal respirable dust samples were collected for workers performing various jobs, including palletizing, bagging, crushing, cleaning, and equipment checking. Airborne silica dust concentrations ranged from 0.39 mg/m³ (palletizer) to 0.91 mg/m³ (bagger operator).

Table 2-4. Respirable dust concentration, percent quartz, and silica concentration in area samples by operation, Paraho Oil Shale Mine and Mill, March 1975.

Area samples	Respirable dust concentration (mg/m ³)	Alpha quartz* (%)	Silica concentration (mg/m ³)
Drilling	2.052	3.5	0.072
Mine scaling	0.654	1.9	0.012
	0.941	0.9	0.008
	2.679	6.7	0.179
	2.508	0.1	0.002
Mine mucking and loading	0.368	8.1	0.029
	0.566	0.7	0.003
	0.440	1.6	0.007
	0.585	1.7	0.009
	0.754	6.6	0.049
	0.771	1.8	0.014
	0.858	4.5	0.039
	0.515	7.8	0.040
	1.575	14.4	0.227
	0.254	6.1	0.015
	0.603	0.1	0.001
Roof bolting	0.772	1.5	0.012
	0.431	1.5	0.006
	0.685	2.3	0.016
Mill crushing and screening	3.659	14.7	0.538
	8.484	15.2	1.289
	0.599	19.2	0.115
	0.932	16.5	0.154
	5.805	13.0	0.755
	1.466	16.2	0.237
	3.901	13.8	0.538
	2.077	17.7	0.368
	0.244	22.4	0.546
	1.986	19.4	0.385
	5.859	13.4	0.785

*The alpha, or low temperature, form of crystalline quartz.

Source: Volkwein and Flink 1977.

Table 2-5. Respirable dust and silica concentration levels by operation, Paraho Oil Shale Mine and Mill, 1977.

Operation	No. of samples	Maximum sampled concentration of respirable dust (mg/m ³)	Silica concentration at 10% quartz (mg/m ³)
Mine area:			
Drilling (area sampler)	7	14.6*	1.46*
Drilling (personal sampler)	2	3.2	0.32
General	2	0.3	0.03
Mine entrance (before blast)	1	3.1	0.31
Mine entrance (after blast)	1	3.4	0.34
Crushing area:			
Primary crusher	2	6.5	0.65
Secondary crusher	1	20.0	2.00
Tertiary crusher	2	11.0	1.10
Crusher conveyor	1	5.2	0.52
Retort area:			
Top seal	7	15.6	1.56
Bottom seal	6	4.5	0.45
Ground level	2	4.4	0.44
Middle distributor	4	4.2	0.42
Outside landings	4	1.8	0.18
Thermal oxidizer	1	0.9	0.09
Retort operator (personal sampler)	1	0.4	0.04
Pilot plant, 1st level	1	1.2	0.12
Pilot plant, 2nd level	1	1.1	0.11
Miscellaneous:			
Retort shale pile	6	7.2	0.72
Retorted shale conveyor	3	16.7	1.67

*Average concentration of respirable dust was 9.8 mg/m³ with a silica concentration of 0.98 mg/m³ at 10 percent quartz.

Source: Rudnick et al. 1980.

In 1980, MSHA conducted a dust control reevaluation study at another silica flour mill (Weems et al. 1980). Eight area samples for respirable dust were taken in the mill building. Except for one sample with no detectable silica, silica dust concentrations ranged from 0.05 to 0.15 mg/m³.

In July 1981, MSHA conducted a dust control evaluation study at a sand pit in Colorado (Weems and Spear 1981). Three personal samples for respirable dust were collected for the screen operator and two operators of front-end loaders. The silica dust concentration in all three samples was below 0.01 mg/m³.

Other Nonmetals (Figure 2-14)--

The other nonmetals industry group is composed of a diverse group of industries. However, the available data indicate that dust exposures in the crushing, grinding, and sizing operation and in the concentrating and finishing operation are higher than in other operations.

In 1972, MSHA conducted a dust control evaluation survey at an establishment that mined brucite (magnesium hydroxides) and magnesite (magnesium carbonate) from pits and processed the ores for use in refractories (Schutz et al. 1972). A total of 101 area and personal samples for total dust were collected by the midget impinger method. None of the samples had a free silica content of 1 percent or greater (Schutz et al. 1973). However, because of differences in sampling methods, these data are not comparable with the MIDAS data.

2.3 MINERAL FIBER EXPOSURE

Asbestos fibers that are small enough to be respirable are an acknowledged health hazard, but not all respirable mineral fibers are asbestos fibers. The analysis of airborne dust for asbestos fibers requires two steps. First, the number of fibers in a sample is determined by a counting procedure with an optical microscope using phase contrast illumination. Second, asbestos fibers are positively identified through microanalysis, which determines the mineral composition of the fibers. When such microanalyses for mineral identification were performed by MSHA, the specific mineral content is mentioned in the discussion that follows.

2.3.1 Limitations in Data

Most of the data available from MSHA consisted of fiber counts taken from samples that had not been further analyzed for mineral identification. To avoid confusion, the term "mineral fiber" is used throughout JRB's report to refer to fibers identified only by the optical microscope counting procedure. Where the mineral composition of the fibers was determined by microanalysis to be asbestos, the term "asbestos" or "asbestos fiber" is used.

Estimating the mineral fiber exposure levels in the mining industry presents a set of problems different from those related to silica. The differences arise in part from the way in which mineral fibers occur and in part from the available sampling data.

Airborne mineral fibers come from minerals that may be minor constituents in rock formations that consist predominantly of other, nonfibrous minerals. The metamorphic conditions necessary for the formation of asbestiform minerals may have occurred irregularly in a deposit, so that the fiber-producing minerals are not uniformly present even in a single formation. By contrast, silica is typically a major and constant constituent of the host rock (as in hardrock metal ore deposits) or of the mineral commodity itself (as in granite, traprock, or sandstone formations).

The MIDAS silica files contain records of more than 29,000 samples, collected between 1977 and 1981, for respirable dust with more than 1 percent quartz. For the same collection period, MIDAS contains only 801 personal samples for mineral fibers. The area and personal samples that were selected from the MSHA fiber survey added only 1,273 more samples (see Section 2.1.1). The lack of representative mineral fiber sampling data across the mining industry is even more apparent when the number of sampled establishments is considered. For example, in the limestone industry group, 24 establishments were sources of personal samples in the MIDAS files and 69 were sources of area samples in the MSHA fiber survey. In 1980, there were 2,094 active establishments in this industry group.

The MSHA fiber survey selected establishments located in areas that had undergone the geologic changes required to create asbestiform minerals. Thus, the samples were collected from establishments that had a higher probability of mineral fiber occurrence. The criteria used by JRB to select valid sampling data further biased the data set toward higher fiber counts. This bias may affect the use of the data for evaluating technological feasibility, i.e., it errs on the conservative side.

Review of the MIDAS data showed that inspectors had collected samples from the same establishment at different times and in different years. This repeated sampling suggests that the inspections were focusing on establishments that were known or suspected to have mineral fiber contamination. Furthermore, the sample collections for mineral fiber counting were generally of short duration and were often at locations considered to be the most dusty operations (personal communication, MSHA inspectors 1983). Therefore, an employee's TWA exposure is likely to be less than the level indicated by the data.

The presentation of the exposure data in the next section is geared to the three alternate asbestos PEL's being evaluated in this project. These are 0.1, 0.5, and 1.0 fibers/cc. The current MSHA standard is 2.0 fibers/cc for asbestos.

2.3.2 Exposure Data Base and Literature Review

Information on exposure samples from both MIDAS records and the MSHA fiber survey is presented by industry group in Tables 2-6 through 2-19. These samples were collected from 1977 to 1981.

The following sections discuss the data, present electron microscopy data if available, and review the findings of other mineral fiber exposure studies.

Copper (Table 2-6)--

The limited fiber count data for the copper industry came from two copper mines, one in New Mexico and one in Michigan. No electron microscopy results were available.

Gold and Silver (Table 2-7)--

The 11 personal samples collected from two underground mines, one in New Mexico and one in South Dakota, indicate that mineral fibers were present at two geographically distant sites.

The South Dakota mine has been studied in a series of BOM-MSHA-NIOSH dust survey projects. Beginning in 1974, the Mine Enforcement and Safety Administration (MESA), in cooperation with NIOSH, conducted a series of four industrial hygiene surveys at the Homestake mine (ACGIH 1978; Pryor 1978). In the first survey (1974), MESA collected 200 personal airborne samples to determine mineral fiber concentrations. Optical microscopy analyses of the samples indicated an average mineral fiber concentration of 0.25 fibers/cc (with fibers longer than 5 micrometers). The highest single concentration was 2.8 fibers/cc. Further analysis of the 25 samples with the highest mineral fiber concentrations showed that 80 to 90 percent of the fibers were amphiboles; 60 to 70 percent of the amphiboles were identified as fibrous cummingtonite-grunerite (amosite). Total fiber concentrations (including fibers shorter than 5 micrometers) in the 25 highest samples averaged 4.82 fibers/cc; concentrations of mineral fibers averaged 0.36 fibers/cc. Approximately 94 percent of the airborne fibers were shorter than 5 micrometers.

In 1976, MESA conducted the second survey. The 19 airborne samples showed mineral fiber concentrations ranging from 0.1 to 0.9 fibers/cc.

NIOSH conducted the third survey in 1977. About 150 workers were sampled, and 455 personal airborne samples were collected. Phase contrast microscopy analyses showed that none of the fiber TWA concentrations exceeded the MSHA standard of 2 fibers/cc. However, all of the fiber concentrations exceeded the first alternate PEL of 0.1 fibers/cc. These results are comparable to those obtained by MESA in the 1976 survey as well as to the data presented in Table 2-7. In addition, further characterization of fibers in the samples showed that, as seen in the 1974 survey, 80 to 90 percent of the fibers were amphiboles. Approximately 70 percent of these were identified as cummingtonite-grunerite.

Table 2-6. Copper industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Comments
					<0.1	0.10-0.49	0.50-0.99	1.0-1.99	>2.0	
Production	82	MI	1	1A						
Mobile transport (underground)	19	NM	1	8P	1	7				The highest mineral count was 0.02 fibers/cc
Crushing, grinding, and sizing	82	MI	1	1A						

A - area sample.
P - personal sample.

Table 2-7. Gold/silver industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	>2.0	
Nonspecific - underground	113	SD	1	1P				1			
		NM	1	2P	1		1				
Drilling - underground	113	SD	1	1P			1				
Production - underground	113	SD	1	3P			1	2			
Crushing, grinding, and sizing	269	SD	4	4P			3	1			

A - area sample.
P - personal sample.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	
Nonspecific - surface	58	MN WI	4 1	27P 1P		5	19	2	1	
Production	58	MI MN	1 2	1A 16A					1	The highest fiber count was 2.06 fibers/cc
Mobile transport - surface	31	MN WI	6 1	44P 37A 2P 10A	3 6 1 1	19 4 2 9	19 13 2 9	2 7	1 7	
Drilling		MN	1	1P 1A		1 1				
Crushing, grinding, and sizing	58	MI MN MO WI	3 10 2	50A 61P 122A 7A 1P 5A	4 11 1	1 12 20 3 1 5	21 40 74 3	15 9 13 2	9 4 1	
Concentrating and finishing	58	MN WI	1 1	2P 1P	1	1				

A - area sample.
P - personal sample.

Table 2-9. Lead and zinc industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-	0.50-	1.0-	>2.0	
							0.49	0.99	1.99		
Production	70	NY	1	2A	1					1	
Crushing, grinding, and sizing	70	MO	2	4A	2				1		1
		NJ	1	2A	1					1	

A - area sample.
P - personal sample.

Table 2-10. Molybdenum industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Comments
					0	<0.1	0.10-	0.50-	1.0- >2.0	
Production - underground	13	1	CO	2P			0.49	0.99	1.99	The highest fiber count was 2.96 fibers/cc

A - area sample.
P - personal sample.

Table 2-11. Uranium industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-	0.50-	1.0-	>2.0	
Concentrating/ finishing - surface	233	CO	1	9P	2	3	4				

A - area sample.

P - personal sample.

Table 2-12. Other metals industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	
Nonspecific	58	IL LA	1(a) 1(b)	1P 1P	1					The sample was 0.80 fibers/cc
Mobile transport	58	AR	4(c)	5A	3		2			The two measurable samples were 0.10 and 0.20 fibers/cc
Crushing, grinding, and sizing	58	IL AR	1(a) 3(c)	1P 8A	5		2	1		The highest sample was 6.0 fibers/cc
Concentrating and finishing	58	LA	1(b)	1P	1					

A - area sample.

P - personal sample.

(a) manganese mill.

(b) alumina processing plant.

(c) aluminum ore pits.

Table 2-13. Limestone industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	
Drilling - surface	1,809	IL	4	5P	3	1			1	
		OK	1	2P	1		1			
		TX	2	6P	2	4				
Drilling - underground	104	IL	1	1P					1	
Drilling - unknown		IL	4	5A	2	1			2	
		MI	1	1A					1	
		NY	1	1A	1					
		TX	1	5A					5	
Cutting and boring - unknown		MI	1	1A					1	
		MN	1	2A			1	1		
		NY	1	1A			1			
		OK	1	2A						2
		VT	1	1A		1				Concentrations of 2.6 and 4.5 fibers/cc
Production - surface	1,809	SD	1	1P					1	

(Cont.)

Table 2-13. Limestone industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	>2.0	
Mobile transport - surface		FI	1	2P	2	2					
		IL	2	2P			2				
		OK	1	1P			1				
		WI	1	2P	1	1					
Mobile transport - underground	104	IL	3	3P	1		2				
		TX	1	1P	1						
Mobile transport - unknown		IL	3	7A	1	3	3				
		PA	1	10A		1	4	5			
		TX	1	2A					2		
Crushing, grinding, and sizing - surface	1,809	IL	8	13P	5	2	2	1	2	1	Highest fiber count was 5.8 fibers/cc
		OK	1	2P	2						
		WI	1	4P	2	2					

(Continued)

Table 2-13. Limestone industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Comments
					0	<0.1	0.10-0.49	0.50-1.00	1.00-1.99	
Crushing, grinding, and sizing - underground	104	IL	2	2P	1	1	1	1	1	
Crushing, grinding, and sizing - unknown		CT	2	4A	1	1	1	2	1	Highest fiber count was 2.3 fibers/cc
		IL	4	10A	1	1	5	1	1	Highest fiber count was 5.8 fibers/cc
		KS	2	5A			4	1		
		KY	1	3A		1	2			
		ME	3	4A	2		1	1		
		MA	3	5A				1	4	Highest fiber counts were 2.4-4.4 fibers/cc
		MI	2	6A		2	1	1	2	Highest fiber count was 2.0 fibers/cc
		MN	3	8A	2		4	1	1	Highest fiber count was 7.5 fibers/cc
		MO	1	2A			1			
		NJ	2	4A				4		
		NY	11	25A	15	1	4	2	1	Highest fiber count was 3.2 fibers/cc
		NC	6	21A	4	4	11		2	Highest fiber count was 3.1 fibers/cc

(Continued)

Table 2-13. Limestone industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	>2.0	
Nonspecific - surface	PA		1	5A				4	1		
	TN		16	51A	9	6	32	3			
	TX		1	6A					3	3	Highest fiber counts were 3.3-3.7 fibers/cc
	VT		1	1A		1					
	WI		4	8A	4		1	2	1		
	IL		2	3P		2				1	Highest fiber count was 3.7 fibers/cc
	OK		1	1P	1						
	TX		2	10P	3	1	6				

A - area sample.
P - personal sample.

Table 2-14. Other stone industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	
Drilling - surface	832	OK	1	2P	1		1			
		WI	1	1P					1	
Drilling - underground	15	TX	1	1P			1			
Drilling - unknown		MD	1	3A			1	2		
		MA	2	2A					2	
		MN	2	4A	2				2	
		NC	5	15A	3	1	6		1	Highest fiber count was 5.1 fibers/cc
		TN	2	5A	2	1	2			
		TX	1	10A	1				3	Highest fiber count was 9.3 fibers/cc
		VT	1	1A		1				
		VA	3	12A	2		10			
		CT	1	1A					1	
		MA	1	2A	1			1		
		NH	2	4A	1		3			
		NY	3	4A	1		3			
Cutting and boring - unknown		NC	3	7A		3	4			
		OK	1	1A					1	
		SC	1	3A			3			
		VT	6	11A			8	1	2	

(Continued)

Table 2-14. Other stone industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments			
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	>2.0				
Mobile transport - surface	832	OK	2	2A	2									
				2P										
				3P										
				6P										
Mobile transport - unknown		PA	1					2						
		SC	1						4					
		AR	3											
		MD	1											
		NC	3											
		PA	1											
Haulageway maintenance - unknown		SC	1											
		TX	1											
VA	5													
VT	1													
VT	1													
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Table 2-14. Other stone industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0->2.0	
Crushing, grinding, and sizing - surface	832	MN	1	2P				1	1	Highest fiber count was 3.44 fibers/cc
		OK	2	3P		2	1			
		PA	1	1P				1		
		SC	1	7P		3	4			
		WI	1	2P					1	Highest fiber count was 2.97 fibers/cc
Crushing, grinding, and sizing - unknown		AR	4	7A		2		3	1	Highest fiber count was 2.4 fibers/cc
		CT	2	2A					1	Highest fiber count was 2.4 fibers/cc
		ME	2	2A		1			1	Highest fiber count was 5.2 fibers/cc
		MD	1	8A			4	1	2	Highest fiber count was 2.0 fibers/cc
		MA	5	7A					7	
		MI	1	2A			1			Highest fiber count was 2.0 fibers/cc
		MN	2	3A				2		
		NH	1	2A			1		2	

(Continued)

Table 2-14. Other stone industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-	0.50-	1.0-	>2.0	
						0.49	0.99	1.99			
		NJ	2	3A	1				1	1	Highest fiber count was 2.0 fibers/cc
		NY	2	10A	3		2	1	1	3	Highest fiber count was 5.0 fibers/cc
		NC	26	87A	37	5	31	8	4	2	Highest fiber count was 7.3 fibers/cc
		PA	1	8A			3	2	3		
		RI	1	1A					1		
		SC	1	3A			3				
		TN	1	3A			3				
		TX	2	6A					2	4	Highest fiber count was 9.5 fibers/cc
		VT	3	11A	4	2	5				
		VA	4	16A	1		14	1			
		WI	2	8A				2	2	4	
Concentrating and finishing - surface	832	TX	1	1P					1		
		WI	1	1P						1	Highest fiber count was 2.49 fibers/cc

(Continued)

Table 2-14. Other stone industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-	0.50-	1.0-	>2.0	
						0.49	0.99	1.99			
Nonspecific - surface	832	MN	1	1P				1			Fiber concentration of 2.41 and 2.84 fibers/cc
		WI	1	2P					2		

A - area sample.
P - personal sample.

Table 2-15. Asbestos industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	>2.0	
Drilling - surface	3	VT	1	3P			1	1	1		
Drilling - underground	1	AZ	1	1P			1				
Mobile transport - surface	3	CA	2	6P			3	3			Highest fiber count was 4.53 fibers/cc
		VT	1	9P			4	3	1	1	
Mobile transport - underground	1			8P			8				
Crushing, grinding, and sizing - surface	3	CA	1	7P			4		2	1	Highest fiber count was 7.6 fibers/cc
		VT	1	16P			2	5	6	3	Highest fiber count was 4.6 fibers/cc
Crushing, grinding, and sizing - underground	1	AZ	1	2P				1	1		

(Continued)

Table 2-15. Asbestos industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	>2.0	
Crushing, grinding, and sizing - unknown		MD		5P				1	2	2	Highest fiber count was 2.2 fibers/cc
Concentrating and finishing - surface	3	AZ	1	6P					5	1	Highest fiber count was 2.5 fibers/cc
		CA	2	8P			3	4		1	Highest fiber count was 2.9 fibers/cc
		VT	1	23P				5	8	10	Highest fiber count was 11.61 fibers/cc
Concentrating and finishing - underground	1	AZ	1	1P						1	
Nonspecific - surface	3	AZ	2	29P				5	4	2	Highest fiber count was 2.8 fibers/cc
		CA	1	9P					1		Highest fiber count was 8.3 fibers/cc
		VT		19P					4	6	Highest fiber count was 9.64 fibers/cc

(Continued)

Table 2-15. Asbestos industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-	0.50-	1.0-	>2.0	
						0.49	0.99	1.99			
Nonspecific - underground	1	AZ		22P	14	1	2	5			Highest fiber count was 3.1 fibers/cc

A - area sample.
P - personal sample.

Table 2-16. Clay/shale industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	
Drilling - unknown		NY	1	3A			1			
Mobile transport - surface	421	MN OK	1 1	1P 2P			1			Highest fiber counts were 4.6 and 9.4 fibers/cc
Mobile transport - unknown		AR	1	1A			1			
Crushing, grinding, and sizing - surface	421	MN	1	1P			1			
Crushing, grinding, and sizing - unknown		AR	3	5A	1		1	1	2	Highest fiber counts were 7.0 and 7.3 fibers/cc
		ME MN	2 1	4A 2A			2 1			

(Continued)

Table 2-16. Clay/shale industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-	0.50-	1.0-	>2.0	
						0.49	0.99	1.99			
Crushing, grinding, and sizing - unknown		NH	1	1A						1	Highest fiber count was 3.6 fibers/cc
		NY	2	6A	1	1	1	1	1	1	Highest fiber count was 5.6 fibers/cc

A - area sample.
P - personal sample.

Table 2-17. Talc industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	
Drilling - surface	25	NY	1	1P					1	
		TX	1	4P	4					
Drilling - underground	8	VT	1	4P			2	1	1	
Drilling - unknown		NY	1	1A		1				
		VA	1	5A			1		4	Highest fiber counts were 5.1, 6.0, and 9.4 fibers/cc
Production - surface	25	VT	1	2P	1	1				
Production - underground	8	NY	1	3P			2		1	
		VT	3	10P	1	2	2	2	3	
Production - unknown		NY	1	1A					1	
Mobile transport - surface	25	NY	1	2P				1	1	
		TX	2	9P	1			8		

(Cont.)

Table 2-17. Talc industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	>2.0	
Mobile transport - underground	8	NY	1	2P			2				
		VT	3	13P	3	3	5	1	1		
Mobile transport - unknown		AR	1	1A	1						Highest fiber count was 3.7 fibers/cc
		NC	1	2A					1	1	
		TX	3	23A	1	1	1	2	4	14	Highest fiber count was 8.9 fibers/cc
Crushing, grinding, and sizing - surface	25	NJ	1	2P			2				
		NY	2	3P				2	1		
		VT	2	3P	1	1	1				
Crushing, grinding, and sizing - underground	8	NY	1	3P			1	1	1		

(Continued)

(Continued)

Table 2-17. Talc industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	>2.0	
Crushing, grinding, and sizing - unknown		NY	3	10A		1					
		NC	3	9A	1		7	1			Highest fiber count 7.8 fibers/cc
		TX	3	22A				1	6	15	Highest fiber count 8.4 fibers/cc
		VT	3	4A				1	2	1	Highest fiber count 2.4 fibers/cc
Concentrating and finishing - surface	25	NJ	1	4P		1	3				
		NY	1	3P			2		1		
		TX	1	3P			2	1			
		VT	4	8P	1	3	3	1			
Nonspecific - surface	25	MT	1	2P		1	1				
		NJ	1	4P		1	2	1			
		NY	1	3P			2		1		
		TX	1	5P		2	3				
		VT	4	4P	1	1	1	1			

(Cont.)

Table 2-17. Talc industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Comments
					0	<0.1	0.10-	0.50-	1.0- >2.0	
						0.49	0.99	1.99		
Nonspecific - underground	8	VT	1	3P		1	1	1	1	

A - area sample.
P - personal sample.

Table 2-18. Sand/gravel industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)						Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	>2.0	
Nonspecific - surface	3,351	NH	3	3A					3		
		NJ	3	3A	3						
		NY	12	16A	10	1	3		2		
		VT	5	8A	7		1				
		WI	17	36A	2	1	5	2	13	13	Highest fiber count 4.8 fibers/cc
Mobile transport - unknown		TX	3	6P	4	1	1				
		NM	1	1P		1					
		AR	3	5A	1		4				
		IL	1	2A	1		1				
		ME	2	2A					2		
		MN	1	1A			1				
		NM	3	7P	2	3	2				
		OH	1	1P		1					
		TX	3	8P	4	2	2				
		WA	1	1P		1					
Mobile transport-surface		WI	1	4A			4				
		IL	1	1P		1					
Concentrating and finishing - surface		WI	1	1P			1				
		WI	1	1P					1		

A - area sample.

P - personal sample.

Table 2-19. Other nonmetal industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Highest fiber count 4.7 fibers/cc	Comments
					0	<0.1	0.10-	0.50-	1.0-	>2.0	
Drilling - surface	284	MT	1	5P			3	1	1	1	
Drilling - underground	62	IL TX	3 1	7P 1P	4		1 1	2			
Production - underground	62	NM	2	3P		1			2		
Mobile transport - surface	284	FL IL MT SC	1 1 1 1	2P 1P 31P 4P	1		2		6	2	
Mobile transport - underground	62	IL TX	1 1	1P 1P	1 1						
Mobile transport - unknown		NC SC VA	1 2 1	3A 4A 8A					3 1 4		

(Cont.)

Table 2-19. Other nonmetal industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Comments
					0	<0.1	0.10-	0.50-	1.0-	
							0.49	0.99	1.99	
Haulageway maintenance - unknown		AR	1	1A					1	
Crushing, grinding, and sizing - surface	284	IL	4	5P	2	3				
		MT	1	16P			6	7	3	
		OK	1	1P				1		
Crushing, grinding, and sizing - underground	62	IL	1	1P			1			
Crushing, grinding, and sizing - unknown		AR	1	1A			1			
		CT	1	3A				1	2	
		KS	1	2A			1	1		
		MO	3	8A	1		5	1	1	
		NY	1	6A					2	
		NC	6	20A	5		14	1		
		SC	1	2A	2					
		VA	1	11A			11			
										Highest fiber count 9.3 fibers/cc

(Cont. from page 2-62)

Table 2-19. Other nonmetal industry airborne mineral fiber concentrations.

Operation	No. of active sites in 1980	State	No. of facilities sampled	No. and type of samples	Fiber count distribution (fibers/cc)					Comments
					0	<0.1	0.10-0.49	0.50-0.99	1.0-1.99	
Concentrating and finishing - surface	284	MT	1	9A			1	5	3	
		NM	1	3P	1		1	1		
		OK	2	4P	2		2			
		SC	2	16P		9	7			
Nonspecific - surface		IL	1	1P		1				
		MT	1	28P		1	11	8	4	Highest fiber count 4.7 fibers/cc
		OK	1	1P	1					
		SC	2	16P		5	11			
Nonspecific - underground		IL	1	2P					2	

A - area sample.

P - personal sample.

NIOSH performed the fourth survey in March 1978. Five full-shift area samples were taken in the sample preparation room and assay office. Results of sample analyses showed no detectable asbestos fibers in two of the samples. The remaining three samples had mineral fiber counts of 0.01 (twice) and 0.02 fibers/cc. These concentrations were much lower than the average concentrations observed in the previous studies and were below the lowest alternate PEL of 0.1 fibers/cc. The difference can be accounted for by the fact that the samples taken in 1978 were area samples taken in the assay office. The previous surveys collected personal samples from employees working in production operations, which would be expected to be dustier than the assay office.

Iron (Table 2-8)--

In addition to the personal exposure fiber data from MIDAS and the MSHA fiber survey, electron microscopy results for two area samples from an iron mine in Minnesota were available. The mineral fiber count for these two samples was 15 fibers/cc. The fibers were identified as 19 percent amosite in one sample and 31 percent amosite in the other. The remaining fibers were not asbestos.

The exposure data from production operations are more representative of the mines in the Lake Superior region than of the entire iron industry group. Fiber dust levels vary widely even from one establishment to another in the Lake Superior region. In the mobile transport category, the fiber count from area samples is higher than the count from personal samples. This should not be interpreted as a difference between area concentrations and time-weighted personal exposures; rather, the selection criteria for the area samples (described in Section 2.1.1) tends to skew the distribution toward higher fiber counts.

Lead and Zinc (Table 2-9)--

Eight area samples were available in this industry group. Most of the samples had fiber counts of less than 0.5 fibers/cc.

Molybdenum (Table 2-10)--

The data for this industry group consist of two personal samples from an underground mine in Colorado. One of the samples shows a fiber count above 2.0 fibers/cc.

Uranium (Table 2-11)--

The nine samples for the uranium industry were personal samples collected on the same day from a mill in Colorado.

Other Metals (Table 2-12)--

The data for this diverse group comprise 4 personal samples and 13 area samples taken from a manganese mill in Illinois, an alumina processing plant in Louisiana, and aluminum ore (bauxite) pits or alumina mills in Arkansas.

Limestone (Table 2-13)--

The data for this industry group include 64 personal samples from MIDAS, and 205 samples from the MSHA fiber survey. Electron microscopy analyses of five samples from five establishments were available. These five samples included one sample each from two quarries for crushed limestone, one in Pennsylvania and one in New Jersey, and three cement plants, all in Pennsylvania. The fibers from the quarries and two of the cement plants were determined not to be asbestos minerals. The area sample from the third cement plant had a mineral fiber count of 8.1 fibers/cc and was identified as consisting entirely of asbestos minerals: 8.3 percent chrysotile (1 fiber of 12 analyzed) and 91.7 percent crocidolite (11 fibers of 12 analyzed).

The distributions of the MIDAS and MSHA fiber data suggest that

- Establishments in Illinois have a mineral fiber control problem.
- The region including Pennsylvania, New Jersey, New York, and lower New England has some establishments with mineral fiber levels near 2.0 fibers/cc.
- Establishments in Tennessee may be able to meet the current PEL or the highest alternate PEL more easily than facilities in the other states.

Other Stone (Table 2-14)--

Samples from the other stone industry group show no strong patterns, and the limited data are widely distributed. North Carolina has the most samples and sampled establishments, but the fiber counts are generally lower than those in the total data set.

Electron microscopy results were available for only one sample, taken from a crushed sandstone quarry in Pennsylvania. This sample had a mineral fiber count of 4.3 fibers/cc. None of the fibers were identified as asbestos minerals.

Asbestos (Table 2-15)--

The MIDAS data from asbestos establishments consisted of 169 samples. Results of electron microscopy analyses were available for 12 samples from four mines and mills in California and Arizona. Chrysotile was the only asbestos mineral identified; it constituted a high percentage of the fibers in each sample. The lowest chrysotile content was 82 percent; six samples were

100 percent chrysotile. The fiber counts in these samples ranged from 2.1 to 10.7 fibers/cc.

Clay and Shale (Table 2-16)--

Few data were available on mineral fiber dust in the clay and shale industry. Seven of the 22 area samples, taken from four establishments in New York, Arkansas, and New Hampshire, had mineral fiber counts greater than 1 fiber/cc. These results, although limited, indicate that clay and shale operations are a potential source of significant levels of occupational exposure to mineral fiber dust.

Talc (Table 2-17)--

Although the talc industry group is relatively small, it has been considered as a separate group because of the special problem of mineral fibers in talc. However, these mineral fibers are not necessarily asbestos fibers. Electron microscopy results were available for samples from five establishments in four states. Six samples taken at two mills in Montana and one mill in North Carolina showed no asbestos minerals. Of three samples taken at a California mill, two showed no asbestos; the other had a fiber count of 232 fibers/cc, of which 7 percent were analyzed as tremolite. Of four samples taken at a mine and mill in New York, three had asbestos minerals of the following percentages and types:

<u>Fiber count (fibers/cc)</u>	<u>Mineral</u>	<u>Percent of fibers</u>
2.4	Anthophyllite	9
2.8	Anthophyllite	13
1.98	Chrysotile	17
	Anthophyllite	8

These results for the New York facility differ from those reported in a NIOSH study of health hazards in talc mines and mills (Lemen and Dement 1979). The study included personal sampling and mineralogic assays of talcs produced at a mine and mill in upper New York State. Personal breathing zone samples were collected and analyzed by optical and electron microscopy. Results of the optical microscopy analysis showed TWA exposures to mineral fibers ranging from 0.8 to 9.8 fibers/cc in the mine and 0.2 to 16.0 fibers/cc in the mill. Approximately 70 percent of all operations had TWA fiber exposures exceeding the current MSHA asbestos standard of 2.0 fibers/cc.

Results of the electron microscopy analysis of samples collected at the mine showed concentrations of asbestiform mineral fibers (all lengths) ranging from 9.5 to 17.5 fibers/cc. Analysis by electron microscopy of samples collected at the mill showed concentrations of fibers ranging from 9.9 to 70.6 fibers/cc. The concentrations determined by electron microscopy exceeded

those determined with optical microscopy, because the electron microscopy results included fibers less than 5 micrometers in length.

The results of the study indicated excessive exposure to airborne fibers. More than 50 percent of the mineral fibers were positively identified by electron microscopy as asbestiform amphiboles (38 to 45 percent anthophyllite, 12 to 19 percent tremolite).

Oil Shale--

There were no data on mineral fibers from oil shale establishments.

Sand and Gravel (Table 2-18)--

For the sand and gravel industry group, there were 37 personal samples and 180 area samples for mineral fiber counts. The samples show that sand and gravel operations in the New England states and the Lake Superior region (Michigan, Minnesota, and Wisconsin) are likely to have mineral fibers in airborne dust.

Electron microscopy results were available for only four samples from three establishments. One pit and mill operation in California had a sample with a fiber count of 5.6 fibers/cc. None of the fibers were identified as asbestos minerals. Another establishment in California was the source of two samples with fiber counts of 3.2 and 3.3 fibers/cc. In one of the samples, none of the 11 fibers analyzed were asbestos minerals. In the other sample, one fiber of the 11 analyzed (9.1 percent) was identified as tremolite; the other 10 fibers were not asbestos minerals. A sample from a Michigan sand pit had 4.4 fibers/cc, but none of the fibers tested were asbestos.

Other Nonmetals (Table 2-19)--

Of 161 personal samples recorded in MIDAS for the other nonmetals industry group, 126 came from six establishments producing vermiculite. Of the 20 electron microscopy analyses, 18 were done on samples from two vermiculite establishments. Two of these were from a site in Virginia. One sample showed no asbestos minerals (fiber count of 23.9 fibers/cc); the other sample was 8 percent actinolite and 92 percent nonasbestos minerals (fiber count of 11.8 fibers/cc). The remaining 16 samples were collected from one site in Montana. In two samples, no fibers were identified as asbestos minerals. In the other 14 samples, tremolite fibers were identified; in two of these, chrysotile was also present. The fiber counts of these 14 samples ranged from 2 to 4.8 fibers/cc, with a geometric mean of 2.8 fibers/cc. The percentage of tremolite ranged from 8.3 to 30.8 percent, with a geometric mean of 14.6 percent. In the two samples that contained fibers identified as chrysotile, the chrysotile fibers were 7.7 and 6.3 percent of all fibers.

The electron microscopy results also included a sample from a gilsonite mine. This sample had a fiber count of 32.3 fibers/cc, but none of the six analyzed fibers were asbestos minerals. The other sample came from a gypsum mine in Montana. The fiber count was 41.6 fibers/cc, but none of the eight analyzed fibers were from asbestos minerals.

3. DUST CONTROL TECHNOLOGIES

3.1 INTRODUCTION

This chapter summarizes the existing and developing technology for reducing worker exposure to airborne dust in the mining industry. The material for this chapter is based on JRB's Task 2 report, which presented a comprehensive literature review of dust control technology in the mining industry. All quantitative data that are used to assess the feasibility of the alternative silica and asbestos permissible exposure limits (PEL's) appear in this chapter.

As described in the previous chapter, operations commonly used in the mining industry were divided into 14 basic operation categories that are used to characterize dust exposures and strategies for reducing airborne dust. In this chapter, operation categories that use similar dust control methods have been combined to facilitate discussion of dust control methods and options. The two nonspecific operation categories are excluded in this chapter since dust exposure in these operations could not be well characterized, and a new category, storage operations, is added to ensure that the specific dust control methods applicable to storage operations are discussed. However, since there were no exposure data for storage operations, the feasibility of achieving the alternative PEL's was not assessed for this operation.

3.2 GENERAL INFORMATION ON DUST CONTROL METHODS

3.2.1 Existing Versus Potential Technology

This report defines technological feasibility as it has been used in recent court decisions affecting the Occupational Safety and Health Administration (OSHA) and the Mine Safety and Health Administration (MSHA). "Existing control technology" includes methods and technology currently used in the mining industry. "Potential control technology" includes methods that require only a predictable course of research and development to become applicable under typical industry conditions.

3.2.2 Dust Control Methods According to Line of Control

The dust control situation in any particular mining or milling operation is unique in its details. But a general assessment of dust control technology can be based on two principles for the systematic identification and control of the sources of airborne dust. First, if each dust source is identified and controlled, the dust level in the operation will be controlled. Second, a system of dust control methods can be designed to provide several lines of

control for the dust from each source. Dust that escapes the first line of control can then be reduced by another control method that operates between the point at which dust is formed and the point at which it is inhaled by a worker. These lines of control can be identified as dust formation control, point source control, ambient source control, and worker isolation control. Figure 3-1 shows typical methods applicable at each of the four lines of control. In general, a complete control system should incorporate one or more methods from each of the four lines of control. In this figure and others like it that appear in this report, control methods that are connected in series generally can be combined; control methods on parallel paths are usually alternatives. If methods at the same line of control may be used either in combination or as alternatives, they appear in these figures on the same level and have a crosslinking path between them. Control methods that represent potential technology are presented in a box drawn with broken lines.

The following discussion summarizes methods of dust control that are generally applicable in a variety of mining or milling operations. Table 3-1 shows the operations to which specific control methods can be applied.

Dust Formation Controls--

The first line of control comprises methods to reduce the formation of dust. These methods are either modifications of the mining process or alternative mining processes. Some process modifications that reduce the amount of dust formed by abrasion accomplish this by reducing the amount of dust dislodged from ore surfaces. Among the generally applicable modifications of this kind are methods that reduce ore drop distances, reduce the number of transfers, control load size, or eliminate spillage. Because these methods work primarily by decreasing the entrainment and dispersion of dust that is already formed, they have been treated as point source controls in this report.

Modifying an ore breakage process can also reduce the amount of dust that is formed. While it is unlikely that a blasting operation or drilling pattern in use at a mining operation will be changed solely for reasons of dust control, modifications that are more efficient in producing only the needed amount of fragmentation may also produce less dust. The formation of fines and respirable dust during an ore fragmentation process represents wasted energy, unless the small size is a process requirement and the fines are not lost during material transport (Wills 1979). More important even than energy loss is the cost of controlling the dust after it is formed. Because dust control is an indirect cost of a process, the amount of airborne dust produced is an economic consideration in the evaluation of alternative methods or process modifications.

Point Source Controls--

If the formation of dust cannot be prevented, the next line of control is to contain the dust near the point at which it is formed. A point source control should prevent entrainment and dispersion of dust into the work area

Dust formation controls

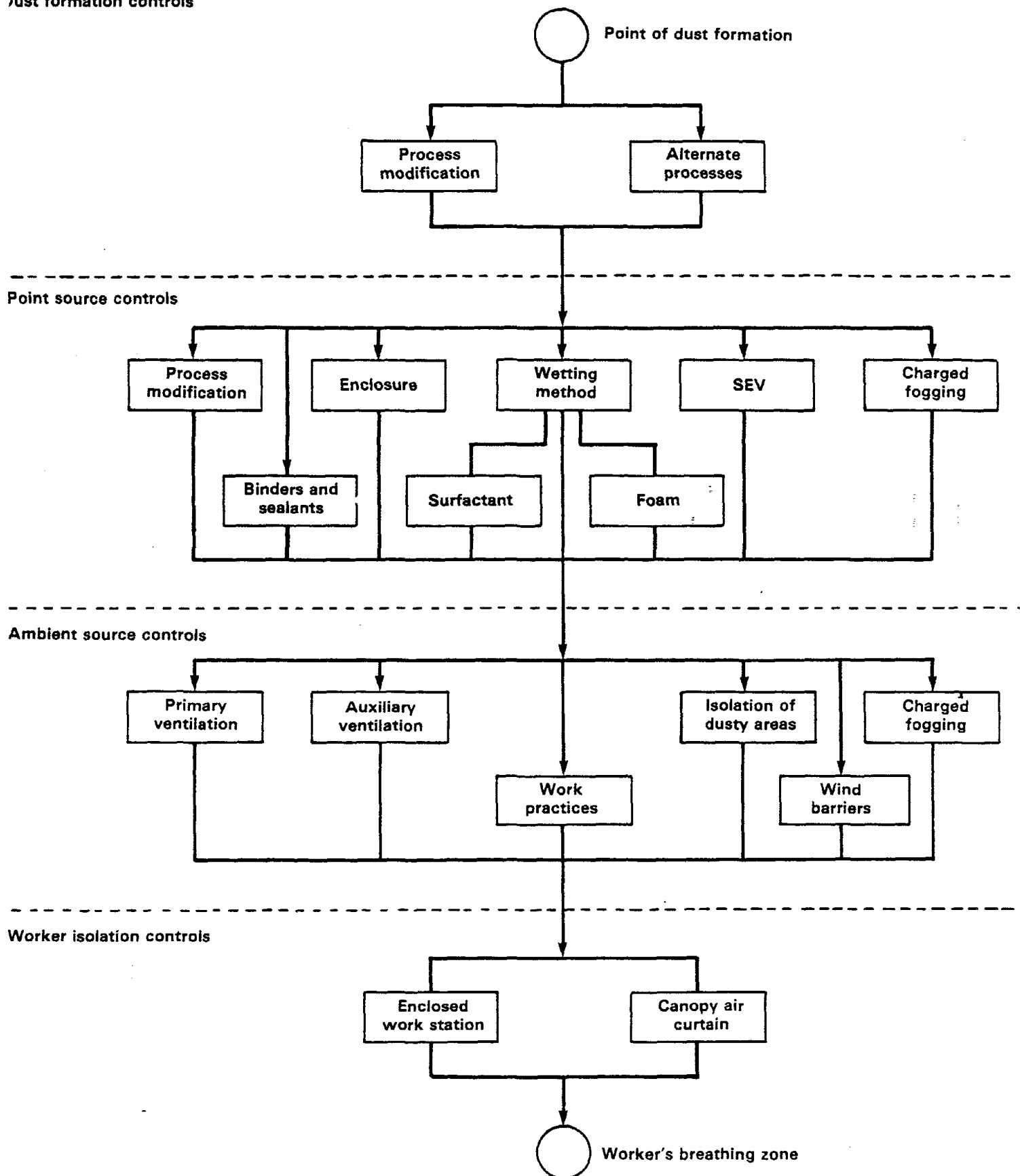


Figure 3-1. Dust control methods at various lines of control.

Table 3-1. Applicability of dust control methods by operation category.

Dust control methods	Operation categories									
	Surface drilling	Underground drilling	Blasting	Cutting and boring	Surface production, mobile transport, and haul- ageway maintenance	Underground production	Underground transport and haul- ageway maintenance	Storage	Crushing, grinding, and sizing	Concentrating and finishing
<u>Dust formation controls</u>										
Process modifications	X	X	X	X	X		X			
Alternative processes		X								
<u>Point source controls</u>										
Process modifications										
Alternative processes										
Enclosure and collection:										
Enclosure only										
(skirts, shrouds, and covers)										
Enclosure and collection										
(secondary exhaust ventilation)	X	X		X						
Wetting methods:										
Wet processes	X	X	X	X	X					
Water sprays										
(foggers, wetting agents, and foam)	X	X	X	X	X					
Binders and sealants					X		X	X	X	X
Charged foggers					X	X	X	X	X	X

Table 3-1. Applicability of dust control methods by operation category.

Dust control methods	Operation categories									
	Surface drilling	Underground drilling	Blasting	Cutting and boring	Surface production, mobile transport, and haul-ageway maintenance	Underground production	Underground transport and haul-ageway maintenance	Storage	Crushing, grinding, and sizing	Concentrating and finishing
<u>Ambient source controls</u>										
Primary ventilation		X	X	X		X	X		X	X
Isolation of dusty areas			X						X	X
Wind barriers					X			X	X	X
Housekeeping	X							X	X	X
Charged fogging	X							X	X	X
<u>Worker isolation controls</u>										
Enclosed work stations (cabs, booths, etc.)	X	X		X	X	X	X	X	X	X
Canopy air curtain				X		X				

air. It should also prevent the spread of small fragments into wider areas of the work environment where the movement of equipment, workers, and material may break or abrade the fragments into respirable dust.

Some methods of point source control are process modifications or alternative methods of production. These methods fall under two general headings: decreased drop distance and control of load size. Decreasing the distance that ore falls when it is dumped or transferred reduces both the entrainment of dust on ore surfaces and the formation of dust. The momentum of the falling ore, which increases as the distance of the drop increases, may break the ore into pieces, resulting in formation of dust. Also, the abrasion of the surfaces of ore fragments as they rub against other fragments or hard surfaces is increased when movement increases. As ore falls, it displaces the air below it and creates a negative pressure area above it, which draws in surrounding air. These air movements increase the entrainment and dispersion of dust that is already present on the ore, in addition to dispersing dust that is formed by the fall. The air displacement can also entrain and disperse dust that has settled previously (Schutz et al. 1980a; Rodgers 1974).

In some cases, an ore drop can be completely eliminated by modifying the process or using an alternative process. Dust levels in a limestone mine in eastern Pennsylvania were reduced when truck haulage was eliminated. Rubber-tired Clark tractor shovels were used for both mucking and transporting the quarry rock from the face to the primary crusher. This eliminated the dumping of ore into haul trucks (Rock Products 1978c). An ore drop can also be eliminated with process equipment that performs several functions without transfers.

Control of load size to prevent spillage is another important way to contain dust. When a transport vehicle or a conveyor system is overloaded, ore spillage increases during transport. Most of the respirable dust in the spill comes from dust adhering to the surface of large ore fragments. In addition, larger fragments can be ground into dust by abrasion. Spillage on heavily traveled haulage roads or drifts creates a steady source of new dust. Spillage from overloaded conveyors may be ground into dust by rollers and pulleys. When spills occur in milling operations, a much larger fraction of the resulting dust may be of respirable size.

Control of load size to prevent spillage involves other factors that increase its cost efficiency. Equipment may function better and require less maintenance if it is not overloaded. Decreasing the number of spills near moving parts can decrease wear and increase the lifetime of costly equipment. The decreases in maintenance, repair, and housekeeping costs that result from careful control of load size can offset decreases in productivity when the weight per load is kept to a proper size. Because load control is in part a work practice, appropriate training, supervisory responsibility, and management support are important factors in attaining the best results.

Wet processes can be substituted for dry processes in some operations (e.g., wet drilling or wet screening). The situations in which these processes are used depend on commodity type, milling operation, end products desired, and other factors.

Water sprays and fogs can be effective in wetting surface dust to prevent the entrainment and dispersion of dust. These methods are less effective in removing airborne dust. Each method can be used as a point source control or to reduce dust from ambient sources.

Wetting agents and surfactants improve water spray efficiency by lowering the surface tension on water drops and decreasing the size of droplets produced by a nozzle. Therefore, the addition of a surfactant to a water spray can significantly reduce the amount of water required to operate an effective water spray system.

Surfactants can be used to generate foams, which consist of stable, uniform bubbles formed by carefully regulated mixtures of water, surfactant, and air. Dust particle wetting is increased when particles penetrate and break the bubbles, and are thereby moistened.

Deliquescent materials absorb moisture from the air and retard evaporation. They are used primarily in haulageway maintenance and mobile transport operations.

Point sources can be enclosed to contain airborne dust in small areas. Enclosing a point source with a hood, shroud, skirt, or similar barrier prevents the dispersion of airborne dust from the enclosed space to the surrounding air. As a dust control method, enclosure used alone has limited value unless the dust source can be completely enclosed. Wherever the enclosure is incomplete, airborne dust from inside the enclosure will be dispersed by any outward air movement. Most mining processes involve mechanical systems with moving parts. These moving parts typically create oscillating air pressure differentials or air velocity changes that tend to disperse dust through bolt holes, cracks, or any other openings in the enclosure.

If the enclosure is open at one or more points, adding a means of collecting the airborne dust inside the enclosure will increase the effectiveness of enclosure as a dust control. The escape of dust from the enclosure openings can be reduced or eliminated by creating airflow into the enclosure. This airflow, or indraft, results from the negative pressure in the enclosure. The negative pressure is produced by exhausting air from the enclosure after the dust has been removed by a collector. Any control method that encloses and collects airborne dust in this way can be called secondary exhaust ventilation (SEV). In general industry, the term "local exhaust ventilation" is also used.

A typical SEV system for point source dust control consists of four components:

- The enclosure, which surrounds the dust source
- The ductwork, which connects the enclosure to the collector
- The collector, which separates dust from the air before the air is exhausted from the system
- The fan, which creates an airflow into the enclosure and from the enclosure through the ducts to the collector.

The dust reduction efficiency of a SEV system as a point source control depends on three factors:

- The efficiency of the enclosure and ductwork in containing the airborne dust from the enclosed source
- The efficiency of the collector in removing the respirable dust from the air, if the air is exhausted through a work area
- The relative contribution to the dust level in the work area of the enclosed point source. (Dust from other sources will still be present.)

SEV systems are commonly used in milling operations and in some extraction operations, such as surface drilling. Machine-mounted fan-scrubbers or SEV systems represent a relatively new technology used in coal mining that may be applicable in other mining operations.

Charged fogging is a relatively new technology now being used in field applications, although investigations on its effectiveness are still continuing. This method removes dust from the air by electrostatic attraction. As dust is formed, it acquires an electrostatic charge. The charge on fine particles (8 micrometers and smaller) is usually negative (Hoenig 1977). A charged fogger produces a fog of fine water droplets that carry a charge opposite to the charge of the dust particles. Dust is attracted to the droplets, agglomerates rapidly, and settles out of the air (Mathai et al. 1981).

In some applications, this control method can also be considered an ambient source control. Charged fogging may prove to be much more efficient than water sprays for controlling respirable dust. It provides a means for reducing dust levels without significantly increasing humidity in the mine atmosphere. Reduced water use is particularly important in the mining of water-soluble ores or in areas where water supplies are limited.

Binders and sealants are another category of point source control. They are useful in reducing entrainment and dispersion of haul road dust. Many dust-suppressing chemicals are available for use, but data on their effectiveness are limited.

Ambient Source Controls--

Once dust is dispersed away from the point at which it is formed, the next line of control is to reduce the respirable dust level in the work area air. The following are the major methods for ambient source control:

- Preventing by wet methods or dry methods the entrainment and dispersion of dust that adheres to or forms from larger materials
- Controlling the general airflow through work areas (primary ventilation)
- Isolating dusty areas from routine work areas.

Settled dust and smaller ore fragments from spills contribute to the ambient air dust level in any operation. Respirable dust from this dispersed material is easily entrained in moving air. A number of control methods, including water spraying, enclosures, and wind barriers, can be used to reduce dust entrainment after the dust has been moved away from its point of formation. These applications are specific to individual operation categories.

Primary ventilation is the use of a mechanical ventilating system to circulate fresh air through an enclosed work area. This is the most common method of reducing dust levels in underground or milling operations. Primary ventilation reduces dust levels by displacing or diluting the dust-laden air in a work area with fresh air. Some of the methods of point source control, including area water spraying and charged water fogging, can also be used to remove dust from ambient air in the work area. In general, however, these methods are more effective as point source controls or as controls in localized areas with high dust levels than as controls for entire work areas.

The primary ventilation system includes all of the active and passive elements that are used to circulate fresh air through an enclosed work area. The active elements include fans and dust collectors; passive elements may be ducts, airways, and stoppings. In a mill building, the primary ventilation system is equivalent to the "general ventilation" of other industrial facilities, but circulating fresh air through an underground mine presents a set of special problems. In an underground mine, the primary ventilation system has many functions, including removal and dilution of gases, fumes, and particulates created by mining operations, replenishment of the oxygen supply, and control of temperature and humidity.

Another general approach to controlling ambient dust levels is to isolate particularly dusty areas so that workers are not exposed. As used in this report, this approach does not include the use of "administrative" controls,

such as assigning workers to dusty areas only for limited periods to maintain their time-weighted-average (TWA) exposure below the PEL, because this technique is considered a poor industrial hygiene practice. Instead, worker access to high dust areas should be limited as much as possible. When work must be performed in these areas, the use of appropriate personal protective equipment should be mandatory. Since worker rotation and the use of personal protective devices are not recommended control methods, they are not considered as control options in this report.

Worker Isolation Controls--

If methods to reduce dust in the work area air are not sufficient to control the dust to acceptable levels, one last line of control can be used. The worker's breathing air can be isolated from the general area air by an enclosure, such as an enclosed cab. Worker isolation controls create a barrier that prevents dust from reaching the worker's breathing zone while allowing adequate exchange between the air supply and expired air. (Although not considered in this report, personal protective equipment also operates by imposing a barrier between worker and contaminant.)

Engineering controls that function at this line of control include enclosed work stations such as vehicle cabs or operator booths. Enclosed cabs are typically provided on mobile equipment, such as dump trucks, front-end loaders, bulldozers, and drills. Control booths are constructed near stationary operations, such as crushing and grinding. For maximum effectiveness in controlling dust, cabs and booths should be airtight, and positive pressure should be maintained with a filtered air system. A high-efficiency particulate arrestor (HEPA) filter is recommended. Frequent vacuuming is required to eliminate dust that may be stirred up by motion within the enclosure. Good visibility and a comfortable temperature should be maintained so that the operator does not have to leave the enclosure or open windows, vents, or doors (Schutz et al. 1980a). When enclosed work stations are well maintained and properly used, they can be very effective as dust controls.

A variation on the enclosure method of control is the canopy air curtain. This recent development in worker protection consists of a machine-mounted, hydraulically operated fan and filter assembly, an air duct, and a canopy-mounted air diffuser that provide a flow of clean air to the worker's breathing zone (Bureau of Mines 1977a). The canopy air curtain is designed for employees who work on stationary or slow-moving machines or at other fixed locations. Its primary advantage over personal protective equipment is that it is not worn, carried, or in any way connected to the worker (ACGIH 1978). The device provides unrestricted freedom of movement and vision and imposes no comfort or communication problems on the user.

3.2.3 Work Practices in Dust Control

Good work practices are essential to maintaining adequate dust control in mining and milling operations. Major improvements in dust levels are possible if in-place engineering controls are used in conjunction with proper

procedures for operation, maintenance, and housekeeping. Table 3-2 lists work practices that can be generally applied in mining and milling processes. In assessing the expected performance of individual control methods or combinations of controls, this report assumes that all applicable good work practices are being implemented.

3.3 DUST CONTROL METHODS FOR EACH OPERATION

Information developed from the assessment of specific control methods applicable to each of the operations is summarized in Sections 3.3.1 through 3.3.10. In each section, the processes involved, dust formation and dispersion mechanisms, and dust controls are briefly discussed. Then, tables summarizing the results of the literature review of the applicable control methods are provided. Data given in each table include reported efficiencies, test settings, equipment costs, data sources, and comments.

3.3.1 Surface Drilling

Drilling is the process of driving small-diameter holes into rock. Holes are drilled to obtain rock core samples, to create places of weakness along which rock will break, and to place explosives. The appropriate length and diameter for a drill hole are determined by production requirements and rock fragmentation characteristics. Drilling procedures depend on the required size and depth of the holes, the hardness of the rock, the choice of drill equipment, the blasting pattern, the presence of groundwater, and other factors.

Dust is formed in surface mechanical drilling operations from the mechanical energy used to break and penetrate rock. The dust is ejected from the hole as part of the cuttings when the hole is bailed. The air velocity required to clear the drill cuttings away from the bit varies with rock hardness and the fragment sizes created by the drill bit. If water is present in the drilled material, the required bailing velocity increases. The compressed air for bailing is forced through holes in the drill bit and escapes out the drill hole, ejecting cuttings and dust. The heavier material is deposited around the drill hole. Because high air velocities are used to bail the hole, the airborne respirable dust can be widely dispersed.

Wind currents and the movement of drill rigs or other heavy equipment can disperse the material deposited around the drill holes; this material then becomes an ambient dust source. Depending on the mining method and production schedule of a mine, the cuttings may be disposed of, used for blast-hole stemmings, or simply left at the hole. Dry dust collection units mounted on drill rigs either discharge collected dust into plastic sacks attached to the unit or allow material to fall directly on the ground. Dust deposited on the ground then becomes an ambient dust source.

Thermal drilling operations create combustion gases that blow dust and coarse material out of drill holes or channels at high velocities. Dust levels will vary considerably according to the direction and force of wind in

Table 3-2. Generally applicable work practice procedures.

- (1) Implement a program of regular maintenance and inspection of ventilation equipment. The program should include repairing collectors, replacing bags in baghouses, unplugging and repairing ductwork, and balancing collection systems.
 - (2) Institute an inspection and maintenance program to detect the causes of leaks and spills in all production and processing areas.
 - (3) Inspect and maintain enclosed work stations, such as booths and cabs, so that they remain airtight and under positive pressure. Enclosures should be cleaned regularly to eliminate dust that would be stirred up by walking and to maintain good visibility so that the operator rarely has to leave the booth. Filters should be changed as required.
 - (4) Replace or close inspection plates, and clean out ports and skirting that are missing or left open.
 - (5) Clean surfaces where dust collects, such as floors and the tops of beams, machinery, and ductwork. Vacuum units or central vacuuming systems should be used to avoid re-dispersing settled dust. (Cleaning with compressed air or dry sweeping should be avoided.)
 - (6) Clean up spills and leaks quickly. Vacuuming should be used to clean up fine material.
 - (7) Provide proper disposal facilities for dust that is collected in ventilation systems or during housekeeping.
 - (8) Inspect water lines, pumps, and nozzles to detect and eliminate clogs and leaks so that adequate water pressure can be maintained. Strainers in water lines that are used to filter impurities out of the water should be cleaned regularly.
 - (9) Avoid overloading conveying and mobile transport equipment.
 - (10) Position workers upwind from dust sources when possible.
-

the drilling location. Because of the high temperature and large quantity of gas produced by thermal drilling, it is not feasible to control the dust produced by this method with water sprays or exhaust ventilation systems (Gerhardsson et al. 1977).

Table 3-3 lists the applicable control technologies, with information on their efficiency and their unit costs.

3.3.2 Underground Drilling

In underground mines, drilled holes are used for placing explosives, inserting roof bolts, draining water, and boring pilot holes prior to driving raises.

In underground drilling operations, dust is formed from the use of mechanical energy to break and penetrate rock. Cuttings from small hole drilling and collaring are usually removed by water flushing. With pneumatic percussion drills, compressed air may leak past the piston, resulting in dust dispersion at the drill face (Rodgers 1974; MSA Research Corporation 1974). During drilling operations, it may be necessary to dislodge large chips or clean debris from drill holes. Compressed air, which may be used to clean the holes after they are drilled, can cause dust dispersion.

Information on specific methods for reducing dust levels in underground drilling operations is summarized in Table 3-4.

3.3.3 Blasting

Explosives or blasting agents are used to displace rock from the working faces of mineral deposits. When the blasting pattern is efficient, the rock breaks into pieces that require minimal secondary breakage before they can be loaded and hauled.

When an explosive detonates, the released energy takes four forms that produce or disperse dust:

- Rock fragmentation
- Rock displacement
- Ground vibration
- High-velocity combustion gases (DuPont 1969).

Dust can also be produced when explosives are loaded into blast holes. Ammonium nitrate and fuel oil (ANFO) is often injected into the blast hole with a pressure feed system. The high-velocity air that is used to draw the ANFO from its container and convey it through a hose to the blast hole may blow dust out of the hole. Augers can also be used to load ANFO. This loading procedure produces less dust than pressure injection.

Table 3-3. Dust control technology for surface drilling.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Decreasing rotary drill speed		National Academy of Sciences 1980	General		Drills that are made with special steels and alloys can withstand the stresses from low-speed drilling.
Drilling larger holes					Less drilling is required and less dust is therefore generated.
Using water jet drilling		JRB Site Visit Report No. 4 1982	Field, rock		Potential technology.
Installing water injection in flushing airstream (wet drilling)	98	Rodgers 1974	Field, noncoal	\$1,000 for system on rig drilling 6-1/2 in. holes, includes hydraulic-driven piston water pump, belt drive, valves, water injected at 3 gal. per min., 500 psi (personal communication Mission Megamatic, Nov. 1982)	Wet drilling cannot be used efficiently in cold weather or for water-soluble ores.
Using wetting agents		Kothari and Gerstle 1980; Given 1973	Field, rock	Deter Pressure Foam®, \$3.50 per gal. (manufacturer's data, Deter Co., Inc., July 1982)	When injected into the flushing airstream, detergents are reportedly less effective in controlling dust than synthetic foaming agents.

(Continued)

Table 3-3. Dust control technology for surface drilling.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Mounting SEV systems on the drill rig	100	Rock Products 1977b; Pit and Quarry 1976	Field, limestone, rock		The SEV system does not affect drill bit life or increase the frequency with which rods and bits hang up in the hole.
Enclosing the cab	65	Volkwein et al. 1979	Field, salt, coal	\$3,000-\$10,000 (personal communication, Wilbar and Arnold, Inc., Oct. 1982)	Efficiency data were based on two cabs with doors and windows open, and no ventilation system.
Using charged water fogging	60-70*	ACGIH 1978	Field, various dusts	Ritten Fogger III®, \$5,660 (personal communication, Ritten Corporation, Ltd., Nov. 1982)	Equipment can be mounted on large drill rigs only.

*These reduction efficiencies are not specific to an operation category and apply only to general field conditions.

Table 3-4. Dust control technology for underground drilling.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Decreasing rotary drill speed		National Academy of Sciences 1980	General		Drills that are made with special steels and alloys can withstand the stresses from low-speed drilling.
Drilling holes with larger diameters		Sisselman 1978	Field, general		In-the-hole drills can be used to drill 15 to 20 inch blast holes. Better ventilation is achieved, reducing the need for secondary blasting and associated dust.
Using water to flush blast holes	98	Rodgers 1974; MSA Research Corporation 1974	Field, noncoal		Using an insufficient amount of water is the major reason that a 98% efficiency is rarely attained in the field.
Equipping drill rigs with SEV systems	99.9	Mason 1976; manufacturer's data, Donaldson Company 1982; Rock Products 1977b	Field, limestone		To provide SEV with pressure in drill steel to enclose the area surrounding the drill hole.
Enclosing cabs	70-90*	Volkwein et al. 1979	Field, salt, coal	\$3,000-\$10,000 (personal communication, Wilber and Arnold, Inc., Oct. 1982)	Enclosed cabs generally cannot be used in underground work areas because of space limitations.

Table 3-4. Dust control technology for underground drilling.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Canopy air curtains	70*	Bureau of Mines 1977a	Field, coal	\$1,479, includes blower, filter element, connecting hose, generator (personal communication, Donaldson Co., Inc., Oct. 1982)	Effectiveness in protecting workers depends on amount of time the worker is under the canopy.

*These reduction efficiencies are not specific to an operation category and apply only to general field conditions.

Table 3-5 lists the control technologies and provides information on cost and efficiency where possible. Because of the variability in blasting procedures, efficiency data are limited. However, it is technologically feasible to keep workers out of a blast area until ventilation has reduced the dust level to the ambient source level for that part of the mine.

3.3.4 Cutting and Boring

In conventional mining, the ore body is broken up by a cycle of drilling, blasting (shooting), and ore removal. As an alternative to the drilling and shooting sequence, special machines can be used to cut, bore, shear, or gouge the ore or mineral from the face being worked. Operations that use machines such as continuous miners, longwall miners, augers, and roadheaders are included in the cutting and boring category. Dust control methods that can be used with this specialized machinery are particularly important, because these operations involve the formation of large amounts of dust and require workers to be near the ore face while the dust is being generated. The control methods that have been developed for use with the different machines are generally similar, although special adaptations are needed for each.

Dust is formed when the machine cutting head makes contact with the material to be excavated. This dust is entrained and dispersed in the high-velocity air currents typical of face ventilation. The impact of the cutting bits or the mined ore falling to the floor of the heading can disperse larger particles and fragments. These fragments become sources of dust when surface dust adhering to them is dislodged or when they are broken up or abraded by vehicle movement.

Studies of continuous miners (Courtney et al. 1978; Black et al. 1978) and roadheaders (Burnett et al. 1981) show that the sumping step accounts for a majority (60 to 70 percent) of the dust formed by continuous mining equipment. Although the shearing step, in which the cutting head traverses the face, produces more of the ore or mineral, it forms less than half of the dust.

Most continuous mining machines include some means of mucking the broken ore and transferring it to a discharge point. The transfer and conveying of ore increases dust levels by dislodging and entraining surface dust and by forming dust through abrasion and fragmentation.

The primary airflow through a heading where a cutting or boring machine is operating is an important dust control method but can also be a source of dust. First, if the intake air is not a clean split and has entrained dust in passing through haulageways, even the best system for point source control at the cutting face will not protect the worker. Second, unless the pattern of airflow through the heading is carefully controlled, air currents may pick up dust at the face and carry it into the area where workers are stationed before it is exhausted. The work area includes not only the machine operator's stations but also other areas where workers are present in the heading.

Table 3-6 lists the dust control technologies applicable to cutting and boring operations. As is typical of other operations, sprays are primarily used as point source controls in cutting and boring to wet surface dust and to

Table 3-5. Dust control technology for blasting operations.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Using correct amount of explosive to fragment and displace material		DuPont 1969			Excessive amounts of explosive can cause increased dust formation and dispersion.
Wetting down the blast area before and after blasting					This is the most common method to control dust generated and dispersed from a blast.
Wet-stemming blastholes	30-50	Gerhardsson et al. 1977	Field, general		Used infrequently in mines.
Delaying reentry into blast area after blast; using ventilation systems to disperse dust generated by blast					This is the most effective worker protection method for blasting operations. Ventilation system must be able to dilute and displace dust before workers reenter.

Table 3-6. Dust control technology for cutting and boring.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Reducing drum speed on a continuous miner from 51 to 18 or 9 RPM	77	Black et al. 1978	Field, coal		No decrease in productivity was noted using this technique. Changing cut depth did not change dust levels significantly.
Installing wetheads on longwall shearers	0-33	Bureau of Mines 1977a	Field, coal	Ventura® spray system, approx. \$1,500 for unit and 16-20 hours labor costs to install (personal communication, Fairchild, Inc., Nov. 1982)	Dust reduction was measured on 3 different machine types. Dust reduction efficiencies compare the use of the wethead versus conventional water sprays.
	46-60	Bureau of Mines 1977a	Field, coal		Dust reduction efficiencies shown were for auger type miners and provide comparison of wetheads and conventional water sprays
Installing wetheads on roadheader	30	Burnett et al. 1981	Field, coal		Dust reduction efficient, is comparison of wethead versus conventional water spray. High-pressure sprays have operational problems.

Table 3-6. Dust control technology for cutting and boring.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Installing wetheads that spray directly onto ore	50	Burnett et al. 1981	Field, coal		Dust reduction efficiency is comparison of wethead versus conventional water spray. High-pressure sprays have operational problems.
Using wet bar methods	0-66	Page et al. 1981	Field, salt		Front spray wet bar systems performed in the range of 41-66 percent efficiency.
Installing water sprays on continuous miners	33	Matta 1976	Field, coal	Full cone nozzles (stainless steel): 1/32 in. \$8.35 to 15/64 in. \$28.31. Nozzle bodies (stainless steel): 1/8 in. \$7.50 to 1/2 in. \$12.03. Pipeline valve (stainless steel): \$52.05. Check valves (nylon): 1/2-3/4 in. \$21.28. Liquid strainer (stainless steel): 3/8 in. \$70.08 (manufacturer's data, Spraying Systems Co., Oct. 1981)	Nozzles mounted on the boom were not effective. Reduction was achieved during sumping.

Table 3-6. Dust control technology for cutting and boring.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Installing water sprays on continuous miners (continued)	12	Courtney et al. 1978	Field, coal		The dust reduction test was performed during sumping using only sprays.
Using auxiliary ventilation on continuous miners	60	Courtney et al. 1978	Field, coal	\$866.80 Lamb Air-Mover® Ventilator 10 in. diameter (personal communication, MSA, Oct. 1982)	Dust reduction value was obtained during shearing and loading. This source provided design criteria and that auxiliary ventilation was effective, but provided no numerical dust reduction efficiency data.
Locating operator of a double-drum shearer on the upstream side of the lead drum		Taylor and Jankowski 1982	Field, coal		
Using unidirectional cutting sequence for double-drum shearers		Bureau of Mines 1981	Field, coal		Allows trailing drum to freewheel on the head-to-tail pass.

(Cont.)

Table 3-6. Dust control technology for cutting and boring.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Installing water sprays on longwall system	20-30	Kost et al. 1979	Laboratory, coal	Full cone nozzles (stainless steel): 1/32 in. \$8.35 to 15/64 in. \$28.31. Nozzle bodies (stainless steel): 1/8 in. \$7.50 to 1/2 in. \$12.03. Pipeline valve (stainless steel): \$52.05. Check valves (nylon): 1/2-3/4 in. \$21.28. Liquid strainer (stainless steel): 3/8 in. \$70.08 (manufacturer's data, Spraying Systems Co., Oct. 1981)	Dust reduction efficiency compares water sprays facing upwind versus spraying downwind.
Directing water sprays downwind and toward the face	70	Taylor and Jankowski 1982	Field, coal		Efficiency varies with distance from the shear
Increasing the water flow rate to 45 to 65 gal/min using a 3-stage filter system		Bureau of Mines 1981	Field, coal		This system prevents clogging of the spray nozzles.

Table 3-6. Dust control technology for cutting and boring.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Installing point source controls on a roadheader		Burnett et al. 1981	Field, coal		This study provides data on dust concentrations, but does not compare the concentrations to a "no control" situation.
Installing shearer clearer	97	Kissell et al. 1981	Laboratory, coal		Preliminary field data showed an efficiency of 40-60 percent.
Using conveyor belt screens		Bureau of Mines 1981	Coal		Confines dust to the side of the shearing machine.
Installing a brattice curtain on the gob side of the shearer		Bureau of Mines 1981	Coal	Damage-resistant brattice roll 6 ft. by 50 yd., \$400. Self-sealing brattice 24 ft. diameter, \$650 (Thimons and Kissell 1981)	Decreases air leakage in the gob and raises air flow along the face.
Using a machine-mounted SEV on longwall miners	60	Courtney et al. 1978	Field, laboratory, coal		Field and laboratory test results were in agreement with 80% reduction predicted in lab tests.

Table 3-6. Dust control technology for cutting and boring.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
	50	Courtney et al. 1978	Field, coal		The SEV system studied used wet fan dust collectors.
Mounting a diffuser fan or canopy air curtain on continuous miners		Bleilckl et al. 1975	Laboratory, coal	SQ Blower®, no accessories, belt driven, does not include motor: 8 3/4 in. \$400, 36 in. \$1,800 (personal communication, American Fan Co., Oct. 1982). Canopy air curtain: \$1,479, includes blower, filter element, connecting hose, generator (personal communication, Donaldson Co., Inc., Oct. 1982)	A diffuser fan is more effective than a canopy air curtain.
Using a sideboard on continuous miner		Murphy 1980	Laboratory, coal		Serves as an extension the line brattice.

(Cont.)

Table 3-6. Dust control technology for cutting and boring.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Installing air-moving water sprays on continuous miners		National Academy of Sciences 1980	Coal	Full cone nozzles (stainless steel): 1/32 in. \$8.35 to 15/64 in. \$28.31. Nozzle bodies (stainless steel): 1/8 in. \$7.50 to 1/2 in. \$12.03. Pipeline valve (stainless steel): \$52.05. Check valves (nylon): 1/2-3/4 in. \$21.28. Liquid strainer (stainless steel): 3/8 in. \$70.08 (manufacturer's data, Spraying Systems Co., Oct. 1981)	Sprays create an airflow along the machine to the working face and across the face to the exhaust line brattice or tubing.
Using high-pressure shrouded sprays		Murphy 1980	Coal		Used to move air and typically operates at 1,200 ft ³ /min.
Installing steam spray systems	68-90	Burnett et al. 1981	Field, coal		Dust reduction efficiencies compare steam spray to conventional water systems. Steam systems use much less water.

Table 3-6. Dust control technology for cutting and boring.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Using high-expansion foam (HEF)	50	Wojtowicz et al. 1974	Field, coal	Ultrafoam® concentrate 55-gal. drum, \$625.95 (manufacturer's data, MSA, Feb. 1981)	Dust reduction effi- ciencies were for total dust and compared HEF to conventional water
	15-20	Wojtowicz et al. 1974	Field, coal	Mine Model Foamaker® generator, Foam output = 3,000 cfm.; \$7,790	Dust reduction effi- ciencies were for respir- able dust and compared to conventional water sprays.
	25-60	Hiltz 1975	Field, coal		Dust reduction effi- ciencies were for respirable dust and compared HEF to conven- tional water sprays.
Installing a canopy air curtain	70-90	Bureau of Mines 1977a	Laboratory, field, coal	\$1,479, includes blower, filter element, connect- ing hose, generator (personal communica- tion, Donaldson Co., Inc., Oct. 1982)	Dust reduction of 70 per cent was based on field tests.
Installing a canopy air curtain on gathering-arm loader	40-60	Bureau of Mines 1977a	Field, coal		Effectiveness in reducing dust levels depends on the amount of time is stationed under

*These reduction efficiencies are not specific to an operation category and apply only to general field conditions.

capture dust at its source. Research into methods of increasing the effectiveness of auxiliary ventilation for bedded deposits has also shown that water sprays are useful as air impellers to confine dusty air along the face and prevent it from blowing into the breathing zones of equipment operators. As indicated, most of the research and field studies of these applications have centered on coal dust control. While the methods of coal dust control in cutting and boring operations are generally applicable to similar noncoal operations, specific parameters, such as drum speed, depth of cut, bit geometry, water spray location, and auxiliary ventilation airflows, may vary for operations in different ore deposits. Field tests may be required to determine the best operating parameters for these mining operations.

3.3.5 Surface Production, Mobile Transport, and Haulageway Maintenance

For the purpose of assessing dust control methods, production operations at surface mines include removing overburden, mucking and loading materials at the working face, mobile transport, and haulageway construction and maintenance. The first step in surface production is to remove overburden by using various types of excavating equipment. After the overburden has been removed and disposed of, the ore or rock is loosened from the deposit by ripping, blasting, or splitting. The loosened material is then loaded into haul trucks or railcars and transported to a mill for further processing or to storage or waste piles. Haulage road construction and maintenance occur at the same time as the process steps listed above.

During surface production operations, dust can be dispersed or entrained during each major process step. Some process steps also form dust. The sources of dust for each process step are

- Loading - Sources of dust from loading processes at the working face include
 - Loose dust that blows off moving excavation equipment
 - Dust that is entrained and dispersed as ore is dumped from loading equipment into haulage vehicles
 - Spillage from loading equipment as it travels or rotates from the muckpile or waste rock heap to haulage vehicles or the waste pile.
- Mobile Transport - During ore and waste rock transport, dust can become entrained or dispersed from the load on the vehicles or from the roads on which the vehicles travel. Dust can be formed from spillage on the haul roads or from deteriorating road surfaces. The silica or fiber content of the dust from roads differs greatly from that of the ore being hauled. The amount of dust resulting from transport on unpaved haul roads was given by Kothari and Gerstle (1980) as 3.7-9.8 pounds per vehicle mile on a dry day. Specific sources of dust in surface mobile transport operations include
 - Roadway materials or spilled ore and waste rock that are crushed by vehicle tires

- Material that falls from overloaded trucks or material that accumulates on tailgates, sideboards, or tires
- Small particles dislodged from ore surfaces by wind currents or by jarring and shifting of the loaded ore during transport on rough roads.
- Conveying - In conveying and material transfer, the most dust is emitted at transfer points. The following design and maintenance factors increase dust levels (Schutz et al. 1980a):
 - Spillage from conveyors
 - Throw-off from dirty conveyor belts
 - Inadequate belt sizes
 - Uncontrolled air currents
 - Belts that are uneven or poorly aligned.

Table 3-7 presents information on applicable control methods. Properly constructed roadbeds will enhance the performance of sealants, binders, or wetting agents. These agents can help prevent dust entrainment and dispersion from ore when it is loaded or transported and suppress dust emissions from surface roads. Enclosed cabs are a generally applicable worker isolation control in surface mining, and in large, highly mechanized open pit or strip mines, enclosed cabs could become the principal method of dust control. However, the cabs in current use are inadequate as the sole line of control, even in operations where all workers are stationed in vehicles. The cabs are often poorly maintained, with numerous openings to the outside and little or no filtration of intake air.

3.3.6 Underground Production

After the ore has been broken by drilling and blasting, the underground production cycle begins. This cycle requires the use of heavy equipment to load the ore for transport to crushing and grinding operations.

In production operations, airborne dust results from moving broken ore or waste material. Moving a shovel or loader bucket into a muckpile and dumping the loaded bucket into a haulage vehicle dislodges and entrains the respirable dust already formed by blasting, cutting, or boring operations. Slusher dip-pers may pass through a muckpile for long distances before dumping the material through draw holes into orepasses, mine cars, or trucks. Dust can be dispersed anywhere along the slusher route.

Accumulations of fine material and settled dust can be crushed by the tires or tracks of the vehicles used in production operations. This crushing movement can form dust or disperse existing dust in production areas.

The movement of ore down an orepass or finger raise is another major dust source. According to one recent review of dust control in mining, most airborne dust in production operations is dispersed when the load is dumped

Table 3-7. Dust control technology for surface production, mobile transport, and haulage maintenance operations.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Constructing roadbeds properly		Bohn and Zeller 1981	Field, general		Includes use of quality aggregate, careful compaction of subgrade, and provisions for drainage.
Applying gravel to roads	50	Brookman and Martin 1981	Field, general	Gravel, #57 bluestone, \$13 per ton (personal communication, Sand and Gravel, Nov. 1982)	Gravel particles applied should be from 200 micrometers to 5 centimeters in diameter.
Paving roads		Schultz 1980a Watt 1974	Field, rock Field, silica sand	Asphalt \$26 per ton (personal communication, Newton Asphalt Co., Inc., Nov. 1982)	Permits periodic cleaning with vacuum road cleaner.
Geotextiles		Belongia 1981	Field, general	Fabric, \$10.56 to \$32.08 per ft.; granular backfill, \$15.68 to \$18.25 per ft. (Belongia 1981)	Used with gravel or on roads built on soft sediment.
Maintaining roadbeds properly		Bohn and Zeller 1981	Field, general		Includes grading, replacement of aggregate, repairing and cleaning ditches, and maintenance of rails.

(Continued)

Table 3-7. Dust control technology for surface production, mobile transport, and haulage maintenance operations.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Reducing the number of material transfers		JRB Site Visit Report No. 6 1982	Field, potash		Use of larger tractor shovels and portable primary crushers, and elimination of surge bins This control method may cause production delays.
Reducing drop distance		Schutz et al. 1980a	Field, general, noncoal		
Reducing spillage		Schutz et al. 1980a Evans 1977	Field, general, noncoal, asbestos		Accomplished by avoiding overloads, cleaning trucks, repairing holes haulage equipment, and repairing suspension systems to avoid vibration. May use auto matic truck-washing stations.

Table 3-7. Dust control technology for surface production, mobile transport, and haulage maintenance operations.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Using water sprays to wet ore prior to and during loading and unloading operations	20-60* (30% average)	Tomb et al. 1972a; Bureau of Mines 1977a; Schultz et al. 1980a; Roggers 1974; Evans 1975	Field, coal Field, coal Field, noncoal Field, noncoal Field, rock	Full cone nozzles (stainless steel): 1/32 in. \$8.35 to 15/64 in. \$28.31. Nozzle bodies (stainless steel): 1/8 in. \$7.50 to 1/2 in. \$12.03. Pipeline valve (stainless steel): \$52.05. Check valves (nylon): 1/2-3/4 in. \$21.28. Liquid strainer (stainless steel): 3/8 in. \$70.08 (manufacturer's data, Spraying Systems Co., Oct. 1981)	Amount of water needed ranges from 5 to 8 gal by weight of the ore. Effectiveness depends on many factors. Depends on water availability and solubility of ore.
Using wetting agents in water sprays	50-60*	Cole 1981; Schultz et al. 1980a	Field, asbestos, silica sand Field, noncoal		
Installing windscreens and windbreaks	80	Harwood and Blaszk 1974; Julius Koch Co., Inc. 1981	Field, asbestos Manufacturer		Used to reduce fugitive emissions from roads and tailings and at unloading areas.

Table 3-7. Dust control technology for surface production, mobile transport, and haulage maintenance operations.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Using tarpaulins to cover ore prior to loading and during transport		Schutz et al. 1980a	Field, noncoal	Tarpaulins 5 ft., 3 in. by 7 ft., 5 in. \$15; 18 ft., 5 in. by 29 ft., 2 in. \$187.40 (manufacturer's data, SHD, 1982)	Requires supervision to ensure consistent use.
Treating the roadway with: --Calcium chloride	40-60	Dow Chemical 1981 Levene and Drehmel 1981	Manufacturer Field, general	\$20.85 per 100 lbs. (personal communication, Potomac Chemicals, Nov. 1982)	Less cost-effective than water spray. Helps control ice and snow accumulation.
--Magnesium chloride	60-95	Kaiser Chemicals	Manufacturer	\$21.00/short ton (manufacturer's data, Kaiser Chemicals, April 1981)	Good for 5-month period.
--Calcium lignosulfate		Bohn and Zeller 1981 Dow Chemical 1981	Field, general Manufacturer	\$2,400-\$10,000/mile (manufacturer's data, Dow Chemical Co., Sept. 1981)	Less expensive than calcium chloride, but lasts only half as long. Costs may decrease after first application.
--Elastomeric asphalt emulsion	56-86	Larson et al. 1981	Field, general		

Table 3-7. Dust control technology for surface production, mobile transport, and haulage maintenance operations.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
--Geotextiles w/aggregate	30-70 (40% average)	Levene and Drehmel 1981 Belongia 1981	Field, general	Fabric, \$10.56 to \$32.08 per ft.; granular backfill \$15.68 to \$18.25 per ft. (Belongia 1981). Gravel, #57 bluestone, \$13 per ton (personal communication, Sand and Gravel, Nov. 1982)	More cost-effective than gravel used alone.
--Oil and emulsified oil	50-98	Levene and Drehmel 1981 Dow Chemical 1981	Field, general Manufacturer		Lasts about 6 weeks.
--Oil-latex emulsion	18-80 (Average greater than 50%)	Larson et al. 1981	Field, general		
--Paving	85	EPA 1977		>\$20,000 per mile (Kothari and Gerstle 1980)	Cost given for 3-inch bituminous surface.
--Petroleum emulsion	99, 7 days 37, 12 days	Union Carbide 1982 Rodgers 1974	Manufacturer Field	\$6,177 per mile (Nevada Moly Project, Anaconda Minerals Co., May 1982)	More cost-effective than most wetting agents.

Table 3-7. Dust control technology for surface production, mobile transport, and haulage maintenance operations.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
--Soll-Sement®	95	Midwest Industrial Supply 1981	Manufacturer	\$0.025/ft ² (\$.098/gal.) (average) (manufacturer's data, Midwest Industrial Supply, Oct. 1981)	Lasts 2-3 weeks in heavy traffic.
--Surfactants	50-60*	Cole 1981	Field, asbestos, silica sand	MR 2040 Super Concentrate® 55-gal. drum = \$5.75 per gal; 3,500-gal. tank = \$5.25 per gal; MR® 55-gal. drum = \$4.25 to \$6.75 per gal., depending on quantity, (personal communication, Johnson-March Corp., Nov. 1982)	

Table 3-7. Dust control technology for surface production, mobile transport, and haulage maintenance operations.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
--Water sprays	40	Levene and Drehmel 1981 Union Carbide 1982	Field, road Manufacturer	Full cone nozzles (stainless steel): 1/32 in. \$8.35 to 15/64 in. \$28.31. Nozzle bodies (stainless steel): 1/8 in. \$7.50 to 1/2 in. \$12.03. Pipe- line valve (stainless steel): \$52.05. Check valves (nylon): 1/2-3/4 in. \$21.28. Liquid strainer (stainless steel): 3/8 in. \$70.08 (manufacturer's data, Spraying Systems Co., Oct. 1981)	More cost-effective than calcium chloride. Close to zero efficiency after 24 hours. Enough water must be used to give the surface a moisture of 10 percent.
--Dustbinder polymer concentrate	90-95 for 12 days, 57% after 21 days	Union Carbide 1982	Manufacturer	\$500,000-\$600,000 (National Academy of Sciences 1980)	Cost is for single water truck.

(Continued)

Table 3-7. Dust control technology for surface production, mobile transport, and haulageway maintenance operations.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Controlling vehicle speed:		EPA 1977	General, noncoal		Average speeds in stone industry range 10 to 20 mph. Data given for and light-duty trucks traveling on unpaved roads.
Reduction to 30 mph	25				
Reduction to 20 mph	65				
Reduction to 15 mph	8				
Enclosing cabs:					Data from field tests of surface production equipment. Cab on front-end loader was well enclosed with good seals. open on scraper and bulldozer.
On front-end loader	65	Schutz et al. 1980a	Field, noncoal	\$3,000-\$10,000 (personal communication, Wilbar and Arnold, Inc., Oct. 1982)	
On elevating scraper	82	Volkwein et al. 1979	Field, salt, coal		
On bulldozer	56				
Using a helmet air curtain	99	Treafftis et al. 1981	Laboratory, silica sand, coal	3M Airhat® \$375 (manufacturer's data, Direct Safety Company, 1982)	This is personal protective equipment.

*These reduction efficiencies are not specific to an operation category and apply only to general field conditions.

(National Academy of Sciences 1980). Finger raises are vertical or inclined openings that are driven upward from one level to another. Orepasses are vertical or inclined passages constructed to transfer ore from a production level to a haulage level. The simplest orepass is a vertical hole, often with a concrete lining, between a production level and a haulage level directly beneath it. In mining systems with multiple production levels and one haulage level at the bottom, the orepass may extend from the uppermost production level all the way to the haulage level. Dump raises at each production level feed into the main orepass.

The control of ore movement down a raise or orepass is an important consideration, both for dust control and to avoid structural damage from heavy ore masses that gain too much momentum during the fall. Because these openings connect two or more levels, they often create a problem for primary ventilation controls. In particular, if a pressure difference exists between two levels connected by a raise or an orepass, any dust that is dislodged and entrained during an ore fall will be displaced by airflow toward the opening with the lowest pressure.

Three process steps may be involved in underground production: mucking with a loading vehicle, slushing, and moving ore through a chute (such as an orepass or finger raise). Efficiencies and cost estimates for applicable control methods are given in Table 3-8.

3.3.7 Underground Mobile Transport and Haulageway Operations

This category comprises all of the operations that occur on haulage levels and in main haulageways between underground workings and the surface. Mobile transport operations begin when ore or waste rock is loaded into transport vehicles and end when the vehicles are unloaded at a mill, stockpile, or waste pile. This assessment category also includes the construction and maintenance of haulageways.

Dust sources that affect the main haulage operations in haulageways include dust formed from the roadbed by movement of equipment; spillage from overloaded transport vehicles; entrainment and dispersion of dust from roadways, muckpiles, and loads; and airborne dust carried into haulageways from other operations (e.g., production operations) or from the surface (contaminated intake air). In addition, haulageway construction and maintenance operations may involve the following specific sources of dust:

- Entrained dust from the dumping and spreading of crushed stone during roadbed or railbed construction
- Dust that is formed or dispersed by leveling roadways with graders
- Mucking operations at development headings during the driving of haulage drifts
- Dust that is dislodged and dispersed from debris as it is cleaned up by pick and shovel crews
- Silica sand dust that originates from materials used in haulageways.

Table 3-8. Dust control technology for underground production.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Modifying work processes					
Using water sprays at ore transfer operations	20-60	Bureau of Mines 1977a	Laboratory and field, coal	Full cone nozzles (stainless steel): 1/32 in. \$8.35 to 15/64 in. \$28.31. Nozzle bodies (stainless steel): 1/8 in. \$7.50 to 1/2 in. \$12.03. Pipeline valve (stainless steel): \$52.05. Check valves (nylon): 1/2-3/4 in. \$21.28. Liquid strainer (stainless steel): 3/8 in. \$70.08 (manufacturer's data, Spraying Systems Co., Oct. 1981)	Reducing ore discharges and controlling load size on haulage vehicles.

Table 3-8. Dust control technology for underground production.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Using foams and surfactants		Rodgers et al. 1978	Field, copper	Ultrafoam® concentrate, 55-gal., \$625.95 (manufacturer's data, MSA, Feb. 1981). Mine Model Foamaker® generator, foam output = 3,000 cfm., \$7,790. Surfactants: MR 2040 Super Concentrate® 55-gal. drum = \$5.75 per gal.; 3,500-gal. tank = \$5.25 per gal.; MR® 55-gal. drum = \$4.25 to \$6.75 per gal., depending on quantity (personal communication, Johnson-March Corp., Nov. 1982)	Author concluded that foam when applied into the ore chute does not reduce dust levels.
Installing auxiliary ventilation for slusher drifts		Rodgers et al. 1978 Given 1973 Marshall 1982	Field, noncoal, general	Lamb Air Mover® ventilator, 10 in. diameter, \$866.80 (personal communication, MSA, Oct. 1982)	Designed to improve distribution by supplementing an existing primary ventilation system.

Table 3-8. Dust control technology for underground production.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Installing ventilation systems in orepasses and raises					Design ventilation to maintain negative pressure inside the pass or raise relative to the work area.
Using helmet air curtains	99*	Treaffis et al. 1981	Laboratory, silica sand, coal	3M Airhat®, \$375 (manufacturer's data, Direct Safety Company, 1982)	Not an engineering control.
Using canopy air curtains	60-70*	Bureau of Mines 1977a	Laboratory, and field, coal	\$1,479, includes blower, filter element, connecting hose, generator (personal communication, Donaldson Co., Inc., Oct. 1982)	Effectiveness depends on amount of time worker spends under canopy; applicable for stationary work stations only.
Installing machine-mounted wetted fan scrubbers	70-100	Divers and Janosik 1978, 1980; manufacturer's data from Donaldson Company 1982	Laboratory, field, coal	Strata® Scrubber, includes fan, mini-cyclones, motor, mounting base, 2,000 cfm, approx. \$3,400 (personal communication, Donaldson Company, Inc., Nov. 1982)	Performance of fan scrubbers depends on sources to be controlled and the relation of the unit's exhaust airflow to the airflow near the worker.

*These reduction efficiencies are not specific to an operation category and apply only to general field conditions.

Table 3-9 summarizes the information on efficiencies and costs of control methods for mobile transport and haulageway construction and maintenance.

3.3.8 Storage

Several types of storage operations occur at mines and mills. Some materials are placed in long-term storage or in disposal areas, while others are held for short periods before further processing or shipping. The material stored may be run-of-mine ore, a processed product, or waste. Storage for ore and mill products is typically short term. Storage of wastes from mining or processing is long term. Most short-term storage occurs at mills; disposal piles of waste rock, uneconomic low-grade ore, or overburden are located near mining sites.

The primary source of dust from outside storage operations is windblown dust from stockpile and waste pile surfaces. Other dust sources include

- Dust entrained during dumping of material from trucks or conveyors into storage areas
- Dust carried by displaced air during bin or silo loading
- Dust dispersed during unloading at stockpiles by front-end loaders and similar equipment
- Dust entrained and dispersed at transfer points from storage to conveyors.

During storage operations, dust can be controlled by modifying the material handling processes, adding moisture to stored materials, enclosing the storage area, or protecting stored materials from wind erosion. Isolation of workers from dust-laden air can also control their exposure to dust.

Table 3-10 presents information on the available control technologies. Short-term storage operations can be eliminated as dust sources if they can be completely enclosed between the process step of transferring material into storage and the step of removing it. SEV capacity that is adequate for the enclosure and the rate of material addition is required. To the extent that enclosure is incomplete, dust reduction becomes more difficult. The details of the particular storage situation should be considered in selecting the best and most applicable methods.

3.3.9 Crushing, Grinding, and Sizing

This operation category includes the process steps that generally constitute the first phase of milling metal ores and some nonmetal minerals. Milling is used to fragment ores so that economic minerals can be separated from waste material. The initial breaking and crushing steps are also used in processing crushed stone and nonmetal minerals that do not require additional grinding for separation and concentration. The five major process steps are crushing, grinding, sizing or screening, conveying, and material transfer.

Table 3-9. Dust control technology for underground mobile transport and haulage operations.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Modifying work processes and procedures					Process modifications as reducing the number of transfer events, decreasing drop distances, and controlling load size inhibit dust formation.
Trimming and reducing load size					The supervision necessary to enforce control procedures may reduce productivity.
Controlling traffic with signals		Press and Johnstone 1976	Field, copper		This system kept the number of vehicles in the airway to a minimum.
Covering haulage loads				Tarpaulins, 5 ft., 5 in. by 7 ft., 5 in. \$15; 18 ft., 5 in. by 29 ft., 2 in. \$187.40 (manufacturer's data, SHD, 1982)	Covering haulage loads reduce productivity.
Installing ventilation systems				Lamb Air Mover® ventilator, 10 in. orifice diameter, \$866.80 (manufacturer's data, MSA, Feb. 1981)	Primary ventilation systems are common in haulageways; secondary ventilation systems are common in dead-end corridors.

Table 3-9. Dust control technology for underground mobile transport and haulage operations.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Installing automatic doors		Given 1973			Automatic doors are used to direct ventilation air
Mulrex 925®		Quilliam and Van Wyk 1977	Field, gold		The low dust reduction efficiency for the 2.5 percent solution was attributed to sweeping the haulage way with the sampling period.
1.7 percent solution	87				
2.5 percent solution	35				
10.0 percent solution	88				
Using surfactants and binders		JRB Site Visit Report No. 1 1982	Field, general	MR 2040 Super Concentrate® 55-gal. drum = \$5.75 per gal.; 3,500-gal. tank = \$5.25 per gal.; MR® 55-gal. drum = \$4.25 to \$6.75 per gal., depending on quantity (personal communication, Johnson-March Corp., Nov. 1982)	Nalco 8808® and calcium chloride were in use at sites visited. Calcium chloride may corrode vehicles.
Enclosing cabs on haulage vehicles		Volkwein et al. 1979	Field, salt, coal	\$3,000-\$10,000 (personal communication, Wilbar and Arnold, Inc., Oct. 1982)	Cabs on all vehicles only partially enclosed and cab ventilation systems were not operating.
Dump truck	44				
Dump truck	11				
Front-end loader	-4.5*				

Table 3-9. Dust control technology for underground mobile transport and haulageway operations.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Using canopy air curtain	70**	Bureau of Mines 1977a	Laboratory, field, coal	\$1,479, includes blower, filter element, con- necting hose, generator (per- sonal communica- tion, Donaldson Co., Inc., Oct. 1982)	High velocity venturi air distorts the air curtain downdraft and reduce its effectiveness
Using foams	90 98	Selbel 1976 Cole 1981	Field, coal Field, asbestos, silica sand	Ultrafoam® con- centrate, 55-gal., \$625.95 (manu- facturer's data, MSA, Feb. 1981). Mine Model Foamaker® generator, foam output = 3,000 cfm., \$7,790	Data derived from studies of the application of directly on haulage prior to transport. No data dust reduction when foam was applied earlier in production process was contained in these authors' studies.

*A negative value for dust reduction efficiency results when dust exposure in the absence of dust controls is lower than exposure during the application of a dust control.

**These reduction efficiencies are not specific to an operation category and apply only to general field conditions.

Table 3-10. Dust control technology for storage operations.

Control Technology or Technique	Efficiency %	Data Source	Type of Data	Cost Data	Comments
Using reclaim tunnel instead of a front-end loader		EPA 1976			Substitutes for front-end loader. Not feasible at all facilities. This is currently in use at large crushing facilities.
Reducing drop distance		Graesser 1976 Schutz et al. 1980a	Field		May be accomplished by using stacking conveyors, telescoping chutes, or drop socks, or by ensuring that machine operators reduce drop distance.
Recycling dust		Rodgers 1974	Field		Value of recycled dust paid for equipment at one copper mill. Not if dusts are too fine-grained.
Using water sprays	20-60* (30% average)	Baur 1981 Tomb et al. 1972a Bureau of Mines 1977a	Field	Full cone nozzles (stainless steel): 1/32 in. \$8.35 to 15/64 in. \$28.31. Nozzle bodies (stainless steel): 1/8 in. \$7.50 to 1/2 in. \$12.03. Pipeline valve (stainless steel): \$52.05. Check valves (nylon): 1/2-3/4 in. \$21.28. Liquid strainer (stainless steel): 3/8 in. \$70.08 (manufacturer's data, Spraying Systems Co., Oct. 1981)	Effective for stockpile loading operations and to control wind erosion. Effective on finished piles unless spraying is continuous or frequent.

Table 3-10. Dust control technology for storage operations.

Control Technology or Technique	Efficiency %	Data Source	Type of Data	Cost Data	Comments
Using water sprays (continued)					
		O'Brien and Soderberg 1981	Field, Coal		Control of dust from coal stockpiles required 210-250 liters of water per ton of coal.
		Rodgers et al. 1978	Field		Sprays directed at mouth of ore dumping pockets reduced dust cloud during dumping; visible dust still escaped.
Using surfactant DC-7	50-60*	Apollo Technologies 1982; Cole 1981	Manufacturer Field	\$0.0015-0.03 per ton (manufacturer's data, Apollo Technologies, 1982)	Cost based on use in rotary car dumping.
Using water spray/surfactant	50-60*	Castelline 1981 Cole 1981	Field Field	Full cone nozzles (stainless steel): 1/32 in. \$8.35 to 15/64 in. \$28.31. Nozzle bodies (stainless steel): 1/8 in. \$7.50 to 1/2 in. \$12.03. Pipe- line valve (stainless steel): \$52.05. Check valves (nylon): 1/2-3/4 in. \$21.28. Liquid strainer (stainless steel): 3/8 in. \$70.08 (manufacturer's data, Spraying Systems Co., Oct. 1981)	High-pressure spray system for rotary car dump activated only when dumper is operating. More cost-effective than enclosures or SEV.

Table 3-10. Dust control technology for storage operations.

Control Technology or Technique	Efficiency %	Data Source	Type of Data	Cost Data	Comments
Using foam	95	Apollo Technologies 1982	Manufacturer, Coal	Ultrafoam® concentrate, 55-gal., \$625.95 (manufacturer's data, MSA, Feb. 1981). Mine Model Foamaker® generator, foam output = 3,000 cfm., \$7,790	Application rate of 0.09 liters per ton of coal reduced water consumption by 88 to 92 percent.
Enclosure with SEV	80-90*	Rodgers 1974 ACGIH 1978	Field	FABRI-pulse® pulse jet fabric dust collector, 3,079 sq. ft. of filter media, 12 gauge, approx. \$26,000 (personal communication, American Air Filter Co., Inc., Nov. 1982)	Many SEV systems on storage enclosures have insufficient capacity during dumping cycle to adequately control dust.
Enclosed conveyor, covered bin, and bin filter system with a capacity of 88 ft ³ /min had a dust collection efficiency of 99.9 percent. Efficiency of reducing dust in ambient air was not reported.		Schutz et al. 1981	Field		

Table 3-10. Dust control technology for storage operations.

Control Technology or Technique	Efficiency %	Data Source	Type of Data	Cost Data	Comments
Installing air curtains		Castelline 1981	Field		Enclosure of truck dumps, railcar dumps, and clam-shell discharge points interfere with operation. Dump stations require SEV for adequate dust control
		O'Brien and Soderberg 1981	Field		
Using binders and sealants		Powlesland 1974	Field	Air Curtain, 11 ft. by 4 ft. 6 in., 3,000 cfm, \$515 (manufacturer's data, Arrow Star, Inc., 1982)	Used at the mouth of the crusher pit. The curtain decreased SEV exhaust requirements. Air curtains are applicable to dump stations.
		Baur 1981 Cross 1980	Field, Coal Field	MR 2040 Super Concentrate® 55-gal. drum = \$5.75 per gal.; MR® 55-gal. drum = \$4.25 to \$6.75 per gal., depending on quantity (personal communication, Johnson-March Corp. Nov. 1982)	Used on outdoor stockpiles; may be polymers, petroleum resins, water emulsions, or cement coatings. Water sprays used on active piles. Crusts from binders last from several months to a year, depending on weather conditions.
Using Soll-Sement® acrylic		Manufacturer's data, Midwest Industrial Supply, 1982		\$431.25 per acre (manufacturer's data, Midwest Industrial Supply, 1982)	Applied to tailings, per manufacturer's use.

(Continued)

Table 3-10. Dust control technology for storage operations.

Control Technology or Technique	Efficiency %	Data Source	Type of Data	Cost Data	Comments
Enclosing cabs	65-99*	Fish 1977c Rodgers et al. 1978 Volkwein et al. 1979	Field Field Field	\$3,000-\$10,000 (personal communication, Wilbar and Arnold, Inc., Oct. 1982)	Automatic remote control systems are available to permit operators to inside cabs during and unloading.

*These reduction efficiencies are not specific to an operation category and apply only to general field conditions.

Dust is formed during each of the process steps. When ore or rock is broken up during crushing and grinding, dust is produced. In addition, the decrease in the size of ore fragments during milling increases the total surface area that is exposed to abrasion. The processes of conveying, sizing, and material transfer involve continuous movement of the fragments, which also increases dust formation. The dust is not always entrained and dispersed at the point in the process where it is formed. Transfer points and dry screening operations may be especially dusty if they follow a crushing or grinding step.

Dust levels are affected by the distance of the drop at the feed and discharge points, the moisture content of the ore, the type of ore being processed, and the type of crushing and grinding equipment used. Impact crushers produce more uncontrolled dust per unit of ore processed than other crushers. Jaw crushers produce more airborne dust than gyratory crushers of the same size because the jaws act as bellows in dispersing particles (Kothari and Gerstle 1980).

In sizing processes that use dry screening, dust is produced as the screens vibrate and ore fragments rub against each other and the screen (Schutz et al. 1980a). Most of the airborne dust escapes at the points where ore is fed onto or discharged from the screens (Kothari and Gerstle 1980).

In conveying and material transfer, most of the dust is emitted at transfer points. The amount of uncontrolled dust emissions depends on the size of the ore being transported and transferred, the conveyor belt speed, and the distance of the drop (Kothari and Gerstle 1980).

Table 3-11 summarizes the cost and efficiency data available for specific control technologies.

3.3.10 Concentrating and Finishing

After ore is crushed, ground, and sized, concentrating and finishing operations are performed to yield a product that is ready for shipping. The process steps included in this category are

- Classification processes that sort ore particles of various sizes and densities as they settle in a fluid
- Separation and concentration by which economic minerals are removed from gangue and agglomerated
- Water removal if the material has been separated and concentrated in a wet process
- Heat treatment to refine ore concentrates by exposing them to high temperatures in furnaces or kilns
- Bulk loading in which the material is fed from a storage hopper directly into railcars or trucks

Table 3-11. Dust control technology for crushing, grinding, and sizing.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Reducing drop distance, belt loading conveyor speeds, using 45° inclined chute at transfer point	80	Cheng 1973a	Laboratory, coal		Increasing bed thickness on the conveyor for heavy loads and increasing speed for light loads reduced the amount of respirable dust generated at a given production rate. The 45° chute at the transfer point reduced the amount of dust generated at a given production rate by 80 percent.
Using a drop distance of less than 6 feet		Rodgers 1974	Field, noncoal		If conveyor speed was less than 250 ft/min, the dust level was consistently below 0.2 mg/m ³ .
Using a deep center trough in conveyor belt and closely spaced rollers		Graesser 1976	Field, asbestos		This control prevents material from reaching the edge of the belt and falling onto the work floor.
Reducing the number of transfer points		Willis 1979	Field, general		Aerofall® crusher crushes, grinds, and classifies in one circuit, thus reducing the number of transfer points.

(Continued)

Table 3-11. Dust control technology for crushing, grinding, and sizing.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Installing canopy hoods		Vatavuk and Nevert 1980c			Canopy hoods over low-speed conveyors should have in-draft velocities of 100-200 ft/min.
Enclosing control booths	96-99	Rodgers et al. 1978	Field, iron		An average respirable dust concentration of 0.18 mg/m ³ was achieved inside the booth, which was under positive pressure.
Enclosing work stations		Trabant and Spear 1980 Weems and Spear 1981	Field, cement Field, sand		MSHA has specifically recommended installing station enclosures at a clay mill and a sand screening process.
Using charged water fogging	98 (respirable dust) 87 (total dust)	Hoenig 1977	Field, silica sand	Ritten Fogger III®, \$5,660 (personal communication, Ritten Corp., Ltd., Nov. 1982)	More effective at removing small particles that are more highly charged.
	20 (9 micrometer particles) 75 (1 micrometer particles)	Hoenig 1977	Field, cement		Data from a cement plant quarry surge building.
	65.4	Hoelng 1977	Field, copper		Data from a conveyor drop box at a copper mine.

(Continued)

Table 3-11. Dust control technology for crushing, grinding, and sizing.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
	58.9 (total dust)	Mathai et al. 1981	Field, clay		Data from a bentonite mine.
	66.3 (fine particles)				
	42.7 (coarse particles)				
Non-charged water fogging	30 (total dust)	Mathai et al. 1981	Field, clay	Sonic Dry Fog®, approx. \$4,000 for atomizing nozzles, compressed air source, sequencing circuit, linear actuators, controls; electric cost = \$2,160/year (manufacturer's data, Sonic Development Corp., Oct. 1981; personal communication, Sonic Development Corp., Nov. 1982)	
Ritten Fogger IV®	65-70	Mining Engineering 1981	Field, rock	\$8,800 (personal communication, Sonic Development Corp., Nov. 1982)	Data from a primary rock crusher for dust particles smaller than 15 or 30 micrometers.

(Continued)

Table 3-11. Dust control technology for crushing, grinding, and sizing.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
	40	Brookman and Kelley 1982	Field, coke		Data from a coke screening operation. Charged fog was 29 percent more effective when compared to non-charged fog.
Ritten Fogger III®		Sonic Development Corp. 1982	Manufacturer, field	\$5,660 (personal communication, Ritten Corp., Ltd., Nov. 1982)	Field tests reported that fugitive emissions were well contained.
Enclosing the screens	83-99	Hutcheson 1971	Field, asbestos		Efficiency calculated by JRB from Hutcheson's data.
Using elastomeric dust sealing system		Watt 1974	Field, silica sand		System was successful for reducing dust in an Ontario silica mill.
Using water sprays	20-60* (30% average)	Baur 1981 Tomb et al. 1972a Bureau of Mines 1977a	Field, coal Laboratory, coal Field, coal	Full cone nozzles (stainless steel): 1/32 in. \$8.35 to 15/64 in. \$28.31. Nozzle bodies (stainless steel): 1/8 in. \$7.50 to 1/2 in. \$12.03. Pipeline valve (stainless steel): \$52.05. Check valves (nylon): 1/2-3/4 in. \$21.28. Liquid strainer (stainless steel): 3/8 in. \$70.08 (manufac- turer's data, Spraying Systems Co., Oct. 1981)	Sprays should be equipped with activators, for maximal performance.

Table 3-11. Dust control technology for crushing, grinding, and sizing.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Using a conveyor belt washing system	48 (respirable dust) 78 (total dust)	Bureau of Mines 1977a	Field, coal		Belt washing system reduced respirable dust by 48% and total dust by 78%. Belt scrapers of pulleys and hoppers were most effective.
Using water sprays on underside of belt	50-60	Bureau of Mines 1977a	Field, coal	Full cone nozzles (stainless steel): 1/32 in. \$8.35 to 15/64 in. \$28.31. Nozzle bodies (stainless steel): 1/8 in. \$7.50 to 1/2 in. \$12.03. Pipeline valve (stainless steel): \$52.05. Check valves (nylon): 1/2-3/4 in. \$21.28. Liquid strainer (stainless steel): 3/8 in. \$70.08 (manufacturer's data, Spraying Systems Co., Oct. 1981)	Were more effective than a dust spray.

(Continued)

Table 3-11: Dust control technology for crushing, grinding, and sizing.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Using surfactant spray system	43 (3-nozzle system) 82 (5-nozzle system)	MSA Research Corporation 1974	Field, copper	MR 2040 Concentrate® 55-gal. drum = \$5.75 per gal. 3,500-gal. tank = \$5.25 per gal. MR® 55-gal. drum = \$4.25 to \$6.75 per gal. depending on quantity (personal communication, Johnson-March Corp., Nov. 1982)	The 5-nozzle system without surfactant reduced dust 62 percent.
Spraying foam at chain feeder transfer point	43-91	Selbel 1976	Field, coal	Ultrafoam® concentrate 55-gal. \$625.95 (manufacturer's data, MSA, Feb. 1981). Mine Model Foamaker® generator, foam output = 3,000 cfm., \$7,790	Use of foam was 43% more efficient than water sprays and 91% more efficient than no controls.
Using wet processing		Given 1973 EPA 1976	Field Field, noncoal		
Installing vacuum systems		Canadian Mining Journal 1980			Vacuum systems are used to prevent reentrainment of dust. A fixed and portable system was used in a silica milling facility.

(Continued)

Table 3-11. Dust control technology for crushing, grinding, and sizing.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
	99.5-99.97	Nillfisk of America Inc. 1982	Manufacturer	\$800-\$5,000 (manufacturer's data, Nillfisk of America, Inc., 1982)	Reported collection efficiencies of the filters.
Using enclosure/product isolation		Fish 1977c	Field, asbestos		Area within enclosure is kept at negative pressure to prevent escape of fibers.
Installing solid floor on second level		Weems and Schutz 1979	Field, silica		Installation of solid floors prevents dust from being transferred from one area to another.

*These reduction efficiencies are not specific to an operation category and apply only to general field conditions.

- Bagging, which generally involves piping the product from a bin or hopper through a spout or nozzle into bags that are then stacked in pallets
- Finishing operations at dimension stone facilities, involving sawing, sandblasting, or polishing.

Because of the fine size of the ore particles that are processed in concentrating and finishing operations, dust entrainment and dispersion can be a significant problem in several process steps. Many classifying, separating, and concentrating processes are performed wet, which reduces problems of dust entrainment. The most significant sources of dust in this operation category are bagging and bulk loading processes. Dust is also likely to be a problem at the feed and discharge points of water removal and heat treatment equipment and along conveyors that transport material between the process steps. Oil shale retorting processes present a special dust control problem, which is particularly significant because oil shale has a substantial silica content. Studies have shown that respirable dust concentrations around retorting operations are often above the current MSHA PEL (Rudnick et al. 1980).

Table 3-12 gives the available information on efficiency and cost for specific control technologies. Not all of these options are applicable to each process step.

Table 3-12. Dust control technology for concentrating and finishing.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Minimizing transfer points		Thomas 1977	Field, general		Use equipment designed to perform two or more process steps, i.e., drying and calcining.
Using drop socks during dumping		Stearn 1979	Field, limestone, cement	Fabric telescope spout over covered hopper car, 4,000 to 5,000 cu. ft. capacity, 2 ft. diameter, automatic retracting spout, free flowing, \$7,000-\$8,000 (personal communication, Dynasteel Corp., Nov. 1982)	
Using telescoping spout on bins		Stearn 1979	Field, limestone, cement		The bin studied by this author was equipped with SEV system.
Using pneumatic conveying systems					Alternative to conventional bulk loading methods.
Modifying bagging machines to delay bag release from pressure packing machine until material stops flowing into bags		ACGIH 1978	Field, silica sand		Also improves tightness of seal.

(Continued)

Table 3-12. Dust control technology for concentrating and finishing.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Using auger-type bagging machines		Schutz et al. 1980a Weems et al. 1980	Field, general Field, silica sand		Avoids overfilling and excessive air pressure.
Improving bag quality to minimize spillage		ACGIH 1978 LI 1975 Weems and Schutz 1979	Field, silica sand Field, asbestos Field, silica sand		Stronger adhesive for bag seams. Use of tear-resistant plastic instead of paper. Use of air relief slits in staggered patterns.
Disposing of damaged bags properly		Weems et al. 1980	Field, silica sand		Dump bags in spill hopper rather than mill yard.
Removing sharp objects from mill areas		ACGIH 1978	Field, silica sand		Prevents bags from being cut open and releasing dust.
Using large bags for semi-bulk shipments		Schutz and Weems 1979	Field, silica sand		Replaces open tote boxes, which permit dust to escape.
Using automatic palletizing machines		Schutz et al. 1980a Canadian Mining J. 1977	Field, silica sand Field, asbestos		Encases pallets in bags, reducing spillage.
Using enclosure and or SEV at feed and discharge points.	85-90*	Schutz et al. 1980a Lawall 1978 Schutz and Weems 1979 ACGIH 1978	Field, general Field, limestone Field, silica sand Field, silica sand	FABRI-pulse® pulse jet fabric dust collector, 3,079 sq. ft. of filter media, 12 gauge, approx. \$26,000 (personal communication, American Air Filter Co., Inc., Nov. 1982)	Used at kilns and ovens, at stone finishing facilities, and during sandblasting performed to cut fine designs.

(Continued)

Table 3-12. Dust control technology for concentrating and finishing.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Using enclosure/SEV at bagging operations	89	Schutz et al. 1980a Bureau of Mines 1977b ACGIH 1978	Field, general Field, silica sand Field, silica sand		Exhaust head mounted on fluidized bagging machine. SEV systems can also be used at spill hoppers placed under bagging machines.
Using enclosure/SEV at palletizing and bulk loading stations	85-90*	ACGIH 1978 Lawrie 1970 Weems and Schutz 1979 Kothari and Gerstle 1979 Harris 1978	Field, silica sand Field, general Field, silica sand Field, rock Field, general		
Using wet methods					Cannot be used for dust control after mineral concentrates have been dried or heat-treated.
Using water spray/surfactant		JRB Site Visit Report No. 4 1982	Field, rock		Surfactant reduces amount of mist released during rock sawing in dimension stone finishing.
Using water spray at bagging machine: -Fogging -Water injection -Fogging and water injection	-4** 50 28	Volkwein et al. 1982a	Field, silica sand		Small amount of water may be injected directly into bag. Fogger is used to wet outside of bag.

(Continued)

Table 3-12. Dust control technology for concentrating and finishing.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Using water spray during loading of bags into railcar:					
-External spray	15	Volkwein et al. 1982a	Field, silica sand	Full cone nozzles (stainless steel):	
-Water injection	23			1/32 in. \$8.35 to	
-External spray and water injection	48			15/64 in. \$28.31.	
				Nozzle bodies	
				(stainless steel):	
				1/8 in. \$7.50 to	
				1/2 in. \$12.03.	
				Pipeline valve	
				(stainless steel):	
				\$52.05. Check valves	
				(nylon): 1/2-3/4	
				in. \$21.28. Liquid	
				strainer (stainless	
				steel): 3/8 in.	
				\$70.08 (manufac-	
				turer's data,	
				Spraying Systems Co.,	
				Oct. 1981)	
Using water spray and microfoam	98	Cole 1981	Field, silica sand		Data from field tests with water and microfoam during bulk loading of silica sand in railcar.
Housekeeping - using vacuums for spillage cleanup		Schutz et al. 1980a	Field, general		Particularly important around feed and discharge points. May require shut-down times between shifts.

(Continued)

Table 3-12. Dust control technology for concentrating and finishing.

Control technology or technique	Efficiency %	Data source	Type of data	Cost data	Comments
Isolating loading, bagging, and palletizing stations with walls and partial enclosures		Schutz et al. 1980a Weems and Schutz 1979	Field, general Field, silica sand		Used to control primary ventilation.
Enclosing work stations and booths for automatic equipment	65-99*	Rodgers et al. 1978 Volkwein et al. 1979	Field, copper Field, salt, coal		
Using charged fogger	86*	Hoening 1977	Field, silica sand	Ritten Fogger III® \$5,660 (personal communication, Ritten Corp., Ltd., Nov. 1982)	Efficiency for total dust. Used at transfer points, bagging stations, and bulk loading stations.
Wearing helmet air curtain	99	Treattis et al. 1981	Laboratory, silica coal	\$375 (manufacturer's data, Direct Safety Company, 1982)	Personal protective equipment.

*These reduction efficiencies are not specific to an operation category and apply only to general field conditions.

**A negative value for dust reduction efficiency results when dust exposure in the absence of dust controls is lower than exposure during the application of a dust control.

4. DERIVATION OF DUST REMOVAL EFFICIENCY VALUES

4.1 INTRODUCTION

Chapter 3 summarized currently available and potential technologies for dust control in the mining industry. It contained a brief description of applicable dust controls that can be used in each operation, and focused on the performance data for these methods. This chapter summarizes the data reported by various investigators on those dust control methods that are applicable in two or more operations and assigns an expected dust reduction efficiency for each method. The expected dust reduction efficiency established for a particular method is used in the feasibility determinations included in Chapter 5.

Because the silica dust and asbestos fibers of concern are those particles or fibers in the respirable range, dust control methods have been selected on the basis of their effectiveness in removing respirable dust and asbestos fibers from the worker's breathing zone. Expected dust reduction efficiencies assigned to a method in this report are the method's efficiency in reducing ambient respirable dust concentrations. Only those efficiencies reported in the literature that pertain to the reduction of respirable dust are referenced in this report. Studies in which particle sizes were not specifically mentioned are so identified in this report. Because of differences among studies in the literature, JRB chose efficiency values to use in the analyses according to the following order of preference:

- Typical values for respirable noncoal dust reported in well-documented scientific studies
- Lowest value for respirable noncoal dust reported in well-documented scientific studies, in which a typical value was not reported
- Lowest value for respirable noncoal dust in published trade and manufacturer's literature, published conferences and proceedings, and bulletins
- Lowest reported value for respirable coal dust when the difference in chemical properties between coal and noncoal dust would have little effect on the dust removal efficiency
- Lowest value for total dust removal efficiency reported in literature.

It is also assumed that any control method reduces respirable dust (or silica dust) and asbestos fibers with equal efficiency. The equivalent aerodynamic diameter of a fiber increases as a function of its aspect ratio (ratio of length to diameter) and is always larger than the aerodynamic diameter of a spherical particle of the same density and diameter (Burke and Esmen 1978).

The critical range of asbestos fiber diameters that may induce biological changes is reported to be from 2.5 micrometers to 0.5 micrometers (Lemen and Dement 1979). Since only those fibers larger than 5 micrometers are counted for MSHA sample analysis, asbestos fibers with diameters of 0.5 micrometers must therefore have an aspect ratio of at least 10 to be counted. The equivalent aerodynamic diameter of a fiber 0.5 micrometers in diameter and an aspect ratio of 10 would be 1.3 micrometers, according to the study by Burke and Esmen (1978). Based on the same study, the aerodynamic diameter of an asbestos fiber with a diameter of 2.5 micrometers and an aspect ratio of 3 (which is required for the particle to be counted) is 5.2 micrometers. Therefore, aerodynamically, asbestos fibers can be expected to behave in the same way as respirable dust particles that have diameters ranging from 1 to 10 micrometers.

As discussed in Chapter 3, dust exposures can be reduced by applying control techniques at successive stages of dust formation and release. These successive lines of control include

- Dust formation controls
- Point source controls
- Ambient source controls
- Worker isolation controls.

Although some control methods are applicable to several lines of control, most are used only in one line of control. The discussion of control methods and dust reduction efficiencies will therefore follow the sequence of these successive lines of control.

4.2 DUST FORMATION CONTROLS

The first line of control comprises methods to reduce the amount of dust formed. These methods involve either modifying the mining or milling process or using alternative mining processes. Modifying the mining or milling process can reduce dust either by decreasing the amount of dust dislodged from ore surfaces or by reducing the amount of dust that is formed when the ore is broken. Some process modifications that reduce the amount of dust generated by abrasion act as dust controls primarily by reducing the dislodgment of dust from ore surfaces and subsequent dispersion. Among the generally applicable modifications are methods that will reduce ore drop distances, minimize the number of transfers, control the load size, and eliminate spillage. These methods work mostly by decreasing the entrainment and dispersion of dust that is already formed and are treated as point source controls; they are therefore discussed below, in connection with point source controls.

4.3 POINT SOURCE CONTROLS

Once dust has been formed, the best line of control is to contain the dust close to the point at which it forms; controls that accomplish this are called point source controls. A point source control should prevent the entrainment and dispersion of dust into the work area air. Generally applied point source controls include equipment enclosure, with or without wetting; secondary exhaust ventilation; wetting methods; and process modifications. These controls are discussed below.

4.3.1 Equipment Enclosure

Equipment enclosure is defined as the use of skirts, shrouds, hoods, or other coverings to prevent dust inside an enclosed space from dispersing into the surrounding air. As a dust control method, enclosure used alone has limited value unless the dust source can be completely enclosed; if the enclosure is incomplete, airborne dust from inside the enclosure will be dispersed by the outward movement of air. Most mining processes involve mechanical systems with moving parts. These moving parts typically create oscillating air pressure differentials that tend to disperse dust through bolt holes, cracks, or any other opening in the enclosure.

Therefore, equipment enclosure is often used in combination with other methods such as exhaust ventilation or wetting. Equipment enclosure is used alone to cover conveying systems, equipment dumping and charging points or other locations where point source control methods cannot be applied or are difficult to use. JRB found no quantitative data on the efficiency of equipment enclosure. Theoretically, a complete enclosure on equipment will eliminate 100 percent of the dust released from that equipment. However, it is not possible to achieve this degree of efficiency since openings in the enclosure are needed to permit equipment loading, discharging, and inspection, or breaks may occur due to wear and tear. Since no data are available on the effectiveness of equipment enclosure, no efficiency value is assigned in this report.

4.3.2 Secondary Exhaust Ventilation

As discussed above, any opening in an equipment enclosure allows dust to escape. The amount of dust escaping can be reduced or eliminated by creating an airflow into the enclosure. This indraft of air can be achieved by exhausting air from the enclosure. The dust withdrawn with the airflow can then be directed away from the work area or removed from the air stream by a dust collector. As discussed in Chapter 3, such a method is called secondary exhaust ventilation (SEV).

A typical SEV system for point source control consists of four components: an enclosure, ductwork, a collector, and a fan. In general, a point source enclosure should be as complete as the process allows, because the volume of air that must be exhausted through the SEV system is a function of the total area of all the openings leading into the enclosure. A recommended

minimum indraft velocity is 150-200 ft/min through all openings (ACGIH 1980). In applications where surges of air are periodically expelled from the enclosure, as in dumping an ore load, the indraft velocity must be large enough to handle the outward surges of air to provide a net 200 ft/min minimum requirement (MSA 1974). The ductwork connects the enclosure to the collector or exhaust port and serves as the conduit for dust-laden air. The most important factor in properly functioning ductwork is to maintain the air velocity inside the ductwork at or above the minimum necessary to keep dust particles from settling in the duct and causing clogging and loss of indraft air velocity. Weems and Schutz (1981a) recommended a minimum transport velocity of 3,500 to 4,000 ft/min.

If discharge air of a SEV system is allowed to recirculate through a work area, the effectiveness of the dust collector in the system would be an important factor in reducing dust levels in that work area. Four types of dust collectors are commonly available: dry mechanical collectors, wet collectors, fabric filters, and electrostatic precipitators. The applicability, dust removal efficiency, and cost effectiveness of different types of collectors vary. Data on collector efficiencies were compiled in one EPA report (1977). As a rule, the efficiency of any collector decreases as the size of the dust particle decreases. In addition, a dust collector can only function at its expected efficiency if it is properly designed, operated, and maintained. Thus, regular inspection and maintenance are essential.

The dust reduction efficiency of SEV as a point source control depends on the effectiveness of the enclosure and ductwork in containing the dust, the contribution of dust from the enclosed point source to the dust level in the work area, and the efficiency of the collector in removing respirable dust if the air is exhausted through a work area. For a source that is the major contributor to the airborne dust in a work area, the indraft air velocity is the most important factor if the exhausted air is not recirculated. If the indraft air velocity is high enough to overcome any outward movement of dust particles, the dust reduction efficiency will be very high. Bureau of Mines (BOM) researchers reported that SEV systems on continuous coal mining machines reduced the respirable dust concentration at the operator's station 80-90 percent and that the dust cloud capture efficiency of a SEV is 80 percent (ACGIH 1978). A SEV system for silica flour bagging operations provided a dust reduction efficiency of 85-95 percent (ACGIH 1978). Although these data were reported for two different types of operations, they are in agreement. Thus, a well-designed and well-maintained SEV system can be expected to achieve at least an 80 percent reduction efficiency for respirable dust concentrations.

4.3.3 Wetting Methods

Wetting methods for point source control (primarily water sprays) involve wetting the surface of ore fragments, thus preventing the adherent dust particles from becoming airborne and capturing airborne dust particles close to their source. The effectiveness of reducing dust using water sprays therefore depends on the degree to which ore surfaces are wetted and on the capture efficiency of the water droplets. Courtney and Cheng (BOM 1979a) reported that coverage on impact reaches a maximum for a water droplet with a diameter

of 500 micrometers, while the optimum capture of airborne coal dust particles in the respirable range occurs with droplets 200 micrometers in diameter. Manufacturers' data can be used to select nozzles that provide the best combination of droplet size and velocity for a specific operation.

Tomb and coworkers (1972a) reported that BOM studies estimated that water spray systems used in mines achieved a 25 percent efficiency in suppressing respirable dust in underground coal operations. However, these authors also reported that a maximum suppression efficiency of approximately 80 percent in removal of respirable coal dust was achieved using this method in a laboratory study of cutting operations. In a review of dust control methods, the National Academy of Sciences (1980) concluded that a reduction in respirable dust concentration of 60-70 percent was achievable at coal mine working faces. Courtney and Cheng (BOM 1977a) reported that water sprays generally have a respirable coal dust reduction efficiency of 20-60 percent, with an average efficiency of 30 percent. They also reported that dust suppression can be improved by the proper selection of nozzles, incorporation of nonclogging devices, and better placement of nozzles; this also reduces the amount of water needed. It can therefore be assumed from these data that a respirable dust reduction efficiency of at least 30 percent is achievable by using water sprays at a dust source, such as at the cutting face and at loading and transfer points.

The data cited here are derived from test results on hydrophobic coal dust. When applied on noncoal dust particles (which are hydrophilic), water spray can be expected to be at least as effective in reducing ambient noncoal dust levels as in reducing ambient coal dust concentrations.

Another method of improving the dust reduction efficiency of water sprays is to add surfactants such as wetting agents or foams to the water. Surfactants lower the surface tension on water droplets, which allows dust particles to be wetted more easily. Casteline (1981) reported that plain water can wet only about 50 percent of a particle that is less than 7 micrometers in diameter, and 0 percent of hydrophobic particles such as coal dust. By adding a surfactant to the water spray, the author found that 100 percent of particles of all sizes and physical properties could be readily wetted. Reducing the surface tension of the droplets also reduces droplet size, which permits less water or lower line pressures to be used.

At a transfer point in a copper ore processing plant, adding surfactant to the water spray increased the dust (probably total dust) reduction efficiency from 62 to 82 percent (MSA 1974). Cole (1981) reported that water and surfactant used together reduced dust concentration (probably total dust) by 50-60 percent in operations at a silica sand processing plant; however, no supporting evidence was given. Other investigators (manufacturer's data, Apollo Technologies, 1982; Casteline 1981) have reported the use of wetting agents to reduce dust, but no reduction efficiencies were given in these studies. According to the MSA (1974) report, the dust reduction capability of water sprays was enhanced by about one-third when a surfactant was added. Assuming that respirable dust concentrations can be reduced as effectively as those discussed in the MSA report, and since water sprays used alone are

assumed to have a dust reduction efficiency of 30 percent, adding surfactants to water sprays will increase their efficiency by about one-third, or an expected dust reduction efficiency of 40 percent.

Foaming agents can be added to water to generate foam, which increases particle wetting when dust particles penetrate and break the foam bubbles and are moistened. Three types of foams are commercially available: low-expansion foam, high-expansion foam, and Microfoam. Foams can be layered onto moving conveyor belts, sprayed into free falling materials, injected into the input throats of crushers, or applied to incoming shipments at mills.

Once applied, foams may continue to suppress dust through several mining processes. Cole (1981) recommended that foam be sprayed on materials just before the material is dumped. Seibel (1976) investigated the effectiveness of low-expansion foams and water sprays in reducing respirable dust at an underground coal transfer system that involved transferring coal from the shuttle cars to the section belt and then from the section belt to the main belt. Applying foam at the chain feeder while coal was transferred from shuttle cars onto the section belt reduced the respirable dust at the chain feeder by 89 percent; by 92, 60, and 69 percent at the first, fifth, and last crosscut outby, respectively; and by 45 percent at the belt-to-belt transfer. With water sprays, the corresponding dust reductions were 66, 63, 0, 0, and 3 percent. Cole (1981) reported, without documented test results, that Microfoam reduced dust (probably total dust) by 98 percent during the bulk loading of a railcar at a sand processing plant, while water sprays reduced the dust only by 50-60 percent. High-expansion foam was tested at a coal mine cutting operation and was found to be 15-20 percent more effective in reducing respirable dust than water sprays (Wojtowicz et al. 1974). Based on the report by Cole (1981), it would seem that the dust reduction efficiency of water sprays for suppressing silicas and dust was increased from 60 to 98 percent, or a 63 percent increase in dust removal efficiency, by adding a foaming agent to the water. Since water sprays were assumed to have a dust reduction efficiency of 30 percent, adding a foaming agent should increase this efficiency by 63 percent, resulting in an expected dust reduction efficiency of 50 percent. This estimate is in agreement with the values reported for coal dust, as mentioned above.

4.3.4 Charged Fogging

Charged fogging is a method of removing dust from the air by electrostatic attraction. As dust is formed, it acquires an electrostatic charge. The charge on fine particles 8 micrometers or smaller is usually negative (Hoenig 1977). A charged fogger produces a fog of fine water droplets that carries a charge opposite to the charge on the dust particles. Dust is then attracted to the droplets, agglomerates rapidly, and settles out of the air. Charged fogging is more efficient than water sprays in controlling respirable dust, both at point sources and in ambient air. Because of the increased efficiency, this technique requires less water and may therefore provide a means of reducing dust levels without significantly increasing the humidity.

Most tests of charged foggers under actual operating conditions have focused on their use as point source controls for indoor loading, unloading, conveying, and transfer operations. Research on the performance of charged fogging is still being conducted, and the dust reduction efficiencies reported by various investigators to date are shown in Table 4-1. It appears that charged fogging removes smaller sized particles (those of respirable size) more effectively than larger particles. Since the lowest reported efficiency for removal of ambient respirable dust was 63.3 percent, JRB has assigned a reduction efficiency of 65 percent (after rounding) to charged fogging that is used as a point source control for aboveground applications. Because of the safety hazards associated with creating static charges in the potentially gassy environments in underground mines and mills and the more rugged conditions prevailing in underground operations, charged fogging may not be applicable in certain underground locations.

Table 4-1. Dust reduction efficiencies of charged foggers.

Mine and operation	Dust reduction efficiency	Source
Silica sand unloading	87% (total dust) 98% (respirable dust)	Hoenig 1977
Quarry surge conveying	75% (1 micrometer particles) 20% (9 micrometer particles)	Hoenig 1977; Hoenig in ACGIH 1978
Copper conveyor drop box	65.4% (respirable dust)	Hoenig 1977
Bentonite hopper	63.3% (fine fraction) 58.9% (total dust)	Mathai et al. 1981
Coke screening	40% (particles smaller than 16 micrometers)	Brookman and Kelley 1982

4.3.5 Steam and Water Sprays

Applying steam and water sprays in sequence enhances the dust removal efficiency that is achievable with water sprays used alone. When steam condenses on dust particles, the particles increase in size, making them easier to be captured by spray droplets. If small diameter particles were increased to 10-20 micrometers in diameter, they could be removed by conventional water sprays at an efficiency of nearly 100 percent (Schowengerdt and Brown 1976).

In a study by Cheng et al. (1974) on coal dust, the reduction efficiency for all particles smaller than 6 micrometers was at least 20 percent higher using steam and water sprays in sequence compared to using water sprays alone. Since water sprays are assumed to be at least 30 percent efficient in removing respirable dust, JRB has assigned a dust reduction efficiency of 50 percent to the method of using steam and water sprays in sequence. As reported by Cheng et al. (1974), the effective use of steam and water spray in reducing respirable dust requires a large amount of ventilation air to condense the steam rapidly.

4.3.6 Roadbed Construction

Proper construction of roadbeds can reduce the formation of dust and increase the efficiency of chemical dust suppressants that are applied to road surfaces. This control method is important in production operations in which ore movement over road surfaces is required. Roads that wear down more rapidly produce more dust for a given traffic load than roads that resist wear (Bohn and Zeller 1981). Incorporating the use of quality aggregate, carefully compacting the subgrade, and providing for adequate drainage when designing and constructing a new road will help prevent the formation of cracks, pot holes, and other surface irregularities that contribute to dust formation. Existing roads can be improved and dust formation reduced by adding gravel or paving materials to road surfaces.

The addition of gravel is especially applicable to road surfaces that are easily fractured into dust-sized particles by vehicular traffic. The gravel should be well graded, angular, hard, and resistant to weather (Bohn and Zeller 1981). Brookman and Martin (1981) reported that the application of gravel to unpaved roads reduces dust levels by 50 percent.

Paving road surfaces virtually eliminates the formation of dust from the roadbed; however, paving is very costly, particularly for temporary roads. No studies were found that compare dust levels arising from paved and unpaved road surfaces. EPA (1977) predicted a dust reduction efficiency of 85 percent with road paving, although no supporting data were provided. Since dust formation is virtually eliminated by paving, this efficiency would appear to be the minimum that can be achieved.

4.3.7 Chemical Dust Suppressant

Numerous dust-suppressant chemicals are available for use on mine roads. These chemicals control the emission of dust particles from road surfaces by binding the particles together to form a thin crust that adheres to the road surface. The materials that can be used include oil, petroleum resins, oil-latex emulsion, calcium lignosulfonate, ammonium lignin sulfonate, calcium chloride, sodium chloride, magnesium chloride, bituminous materials, waxes, tars, and pitch products. Many of these materials and some specially prepared

formulations are marketed under various brand names. Over 30 dust suppressants are currently being marketed (Bohn and Zeller 1981). Among these, only a few have been carefully tested for dust suppression efficiencies. These are listed in Table 4-2 along with their reported dust reduction efficiencies.

Obviously, the dust reduction efficiency of a chemical dust suppressant varies with the type of chemical used, the concentration applied, and the lapse time since the treatment. Generally speaking, an efficiency of at least 50 percent can be achieved, and JRB has assigned this value to the use of chemical dust suppressants.

4.3.8 Reducing Vehicle Speed

One source of dust from haulage roads is the dust particles that are entrained in the air turbulence caused by moving vehicles. Slower moving vehicles produce less air turbulence, and thus disperse less dust into the air. Therefore, speed reduction should reduce dust levels on or near haulage ways. Kothari and Gerstle (1980) reported that average haulage vehicle speed in the crushed and broken stone industry ranged from 10 to 20 miles per hour. The authors also reported that reducing haulage vehicle speed from an average of 15 miles per hour to an average of 10 miles per hour will reduce dust emissions (probably total dust) by an estimated 65 percent. Based on that report, it is assumed that a reduction in haulage vehicle speed will reduce the nearby dust concentrations by 65 percent.

4.3.9 Process Modifications

Two general types of process modifications are commonly adopted: reducing the number of ore drops and the drop distances, and controlling load sizes. These modifications are applicable to controlling dust emissions at material conveying and transporting operations. Decreasing the distance that ore falls when it is being dumped or transferred reduces both the entrainment of dust on ore surfaces and the formation of dust. Courtney and Cheng (BOM 1977a) reported from a laboratory study using coal that about 30 percent less dust is dislodged by reducing the drop height by half or by slowing the belt by a factor of 2 at a belt transfer operation. Eliminating a drop point eliminates that point as a dust source. The increase in dust reduction efficiency achieved depends on the number of drop points eliminated. By changing to different processing equipment, drops may be totally eliminated (Rock Products 1978c).

Controlling the load size to prevent spillage is another important method of containing dust. When a transport vehicle or a conveyor system is overloaded, ore spillage during transport increases, thus increasing the number of dust sources.

Only the report cited above (BOM 1977a) described the dust reduction efficiency achievable by reducing drop height and conveyor speed. JRB therefore assigns this reported 30 percent reduction in respirable dust concentration to the method of reducing the drop distance or slowing the conveyor speed

Table 4-2. Summary of dust reduction efficiencies of chemical dust suppressants.

Chemical	Dust reduction efficiency	Source	Comments
Calcium chloride	40-60%	Dow Chemical, USA 1981 Levene and Drehmel 1981	Amount needed depends on relative humidity of air. Needs water to work.
Magnesium chloride	60-95% for a 5-month period	Nevada EPA 1982	Marketed as Dustop® or Dustgard®. Needs water to work.
Elastomeric asphalt emulsion	56-86%	Larson et al. 1981	
Oil and emulsified oil	50-98%	Levene and Drehmel 1981	Difficult to work with. Very slippery when wet.
Oil-latex emulsion	18-80%, average 50%	Larson et al. 1981	
Petroleum resins	99% for first 7 days 37% by 12th day	Union Carbide 1982	Marketed as Coherex®. More cost effective than water spray, wetting agents, and calcium chloride.
Soil Sement®	95%	Midwest Industrial Supply 1981	Lasts 2-3 weeks under heavy traffic.
Dustbinder Concentrate 124®	99% on 1st day 90-95% on 10th day 57% on 21st day	Union Carbide 1982	
Mulrex 925®	84% after 19 days	Quilliam and Van Wyk 1977	10% solution.

by one half. No reports of the dust reduction efficiency of controlling conveyor or vehicle load size were found in the literature.

4.4 AMBIENT SOURCE CONTROLS

Once dust is dispersed from the point at which it forms, the next line of control is to reduce the respirable dust level in the work area. Primary ventilation, which uses a mechanical ventilation system to circulate fresh air through an enclosed work area, is the most common method of reducing ambient dust levels in underground mines or in mills. The recirculated fresh air disperses or dilutes the dust-laden air, thus reducing dust levels in the work area. Other ambient source control methods that can be used include charged fogging, isolation of dusty areas, and proper work practices.

4.4.1 Primary Exhaust Ventilation

A primary ventilation system generally performs a number of functions in an underground process, including

- Removing and diluting naturally occurring hazardous gases
- Removing and diluting hazardous gases and fumes generated by equipment
- Replenishing the oxygen supply depleted by combustion engines or other processes
- Controlling temperature and humidity
- Removing and diluting explosive dusts or dusts that may affect visibility or interfere with equipment function
- Removing and diluting airborne respirable dust.

In general, circulating fresh air into and through the mine workings accomplishes all of these functions. In particular circumstances, however, improving one function may be detrimental to the others. For instance, increasing the air velocity to remove more respirable dust can entrain more of the settled non-respirable dust that affects visibility, equipment life, and physical comfort (National Academy of Sciences 1980). Therefore, a properly designed system should represent optimized performance among all functions.

Because primary ventilation is necessary to solve immediate safety and health problems such as explosions and oxygen deficiency, it is used routinely in mining and milling operations. Since it is already a standard practice in the industry, primary ventilation cannot be considered an additional method of dust control. Furthermore, except in inadequately designed, installed, operated, or maintained systems, only minor improvements in the reduction of respirable dust may be possible without affecting the performance of other functions. JRB has therefore assumed that the dust reduction efficiency of

primary ventilation is the baseline level of control, and no efficiency has been assigned to it. It is also assumed that the air supplied to a work area by the primary ventilation system will not contribute a significant amount of respirable dust to the area.

However, the effectiveness of primary exhaust ventilation in removing airborne dust can be enhanced by the use of auxiliary ventilation. Auxiliary ventilation is defined as an exhaust ventilation system without source enclosure. It works as SEV but it exhausts dust from a source at a distance or blows dust away from the source. Because of the distance from the source, it is not as effective as SEV. As with SEV systems, auxiliary ventilation systems can be connected with a dust collector that exhausts the discharge to the outside or through work areas to an exhaust drift. No reports of the dust reduction efficiency achievable using an auxiliary ventilation system were found in the literature. However, studies have shown that exhausting air out is more effective in reducing airborne respirable dust than blowing air in, especially when the exhaust inlet can be placed close to the source (Courtney et al. in ACGIH 1978; National Academy of Sciences 1980). Because no data were available on the dust removal efficiency of auxiliary ventilation, JRB has not assigned an expected efficiency for this method.

4.4.2 Charged Fogging

As discussed in Section 4.3.4, charged fogging is also an applicable ambient source control. Studies conducted at a cement plant conveying area indicated that 5 minutes of charged fogging reduced the concentration of 1 micrometer particles from 10 to 5 mg/m³, or by 50 percent, and that of 6 micrometer particles from 1.4 to 0.6 mg/m³, or by 57 percent (Hoenig 1977; ACGIH 1978). After 30 minutes of charged fogging, the concentration of 6 micrometer particles was reduced from 1.4 to 0.2 mg/m³, or by 86 percent. Based on these data, JRB has attributed a 50 percent reduction in respirable dust concentration to charged fogging used as an ambient source control in surface locations.

4.4.3 Isolation of Dusty Areas

Isolating a dusty area can reduce a worker's dust exposure, in that restricting worker access to these areas prevents or reduces exposures to high dust concentrations. Examples of areas to which access may be restricted are conveyor belt galleys, exhaust air drifts, and areas in which automated dry sizing equipment is used. Theoretically, a completely tight seal can be maintained between the dusty area and the cleaner work area; in reality, however, a certain amount of leakage occurs, especially when employees enter the dusty area. Since the effectiveness of the area isolation method will depend on how often a worker must enter the area and what type of protection is used, no expected reduction efficiency will be assigned to this method.

4.4.4 Work Practices

Good work practices are essential in maintaining adequate dust control in mining and milling operations. Reductions in dust levels can often be achieved by instituting proper procedures for housekeeping, maintenance, and operations (Rodgers 1974; Rodgers et al. 1978; MSA 1974). Dust exposure in an operation is the result of exposure to dust released from the processes (primary sources) involved and from the incidental sources such as spills, dust releases from enclosure breaks, and fugitive dust. Dust control methods applicable to primary sources will not control dust from incidental sources. Theoretically, implementation of proper work practices can eliminate dust from these incidental sources. However, the effectiveness of work practices is highly variable, depending on the degree of training, supervisory enforcement, and management support present in a particular operation. The relative contribution of incidental dust sources to overall exposure can therefore not be estimated. In addition, since no single value can be assigned to the dust reduction efficiency of work practices in general, JRB has not assigned such a value to these practices. Not attributing a reduction efficiency to work practices when calculating achievable levels of dust control will add to the conservative nature of JRB's feasibility assessments because any reduction in ambient dust concentrations achieved by using proper work practices has not been included in assessing the feasibility of the alternative PEL's for silica and asbestos.

4.5 WORKER ISOLATION CONTROLS

If methods to reduce the dust level at the source and in the work area air are not sufficient to reduce the dust to acceptable levels, one last line of control can be used, i.e., worker isolation. The worker can be isolated from the general air by an enclosure, such as an enclosed cab or work station. Such enclosures provide a barrier that prevents dust from reaching the worker's breathing zone while allowing for an adequate exchange between the supply air and the expired air.

4.5.1 Enclosed Work Stations

An enclosed work station, either a vehicle cab or an operator booth, must limit the exchange of air through the dust barrier between the work station inside and the ambient air outside. Typically, the cab or booth has its own air supply and an exhaust system that will produce a positive pressure within the enclosure relative to the ambient air pressure. This positive pressure minimizes the leakage of dust-laden air into the enclosure. The air supply should pass through a well-maintained filter or bag house that effectively removes respirable dust particles. In addition, adequate temperature and humidity control is needed to ensure proper use of the enclosure. Enclosure can be very effective in controlling dust. Rodgers and coworkers (1978)³ found that the average respirable dust concentration was reduced from 4.2 mg/m³ outside the operator's booth to 0.18 mg/m³ inside (a 96 percent reduction) at

an iron ore primary crusher. From these data, it appears that a 95 percent reduction in respirable dust concentration can be expected using a well-designed and maintained operator's booth.

Volkwein and coworkers (1979) investigated the dust reduction efficiencies of cabs on various surface and underground mine machinery. The study was conducted at actual field sites, and many of the cabs were not totally enclosed, had no air circulation or air conditioning equipment, or were in need of repairs. Respirable coal dust reduction efficiencies ranged from 56 to 82 percent, depending on the condition of the cab, the direction of airflow, and the proximity of the cab to the dust source. It was also reported that total dust concentrations in the cabs on dump trucks and front-end loaders at a salt mine varied from 4.5 percent more to 44 percent less than the ambient dust concentration outside the cabs. Of the cabs studied, the one with a well-enclosed and operating air-filtering system achieved a respirable dust reduction efficiency of 65 percent. Therefore, JRB has assigned a respirable dust reduction efficiency of 65 percent to enclosed cabs.

4.5.2 Canopy Air Curtain

Another worker protection method that has recently been developed and is available commercially is the canopy air curtain. It consists of a machine-mounted, hydraulically operated fan and filter assembly, an air duct, and a canopy-mounted air diffuser that provides a flow of clean air to the worker's breathing zone (BOM 1977a). The canopy air curtain is designed for employees who work on stationary machines or at fixed locations. It provides unrestricted freedom of movement and vision and poses no comfort or communication problems such as those associated with respirators. The canopy air curtain has been approved by MSHA as an engineering control for both above- and below ground metal/nonmetal applications (personal communication, MSHA inspectors).

In field tests, the air curtain reduced personal respirable dust concentrations by as much as 70 percent (BOM 1977a). In the BOM study, the air curtain was found to be more effective when the cross flow was horizontal, with the diffuser located upwind from the worker in relation to the airflow produced by the general ventilation. In another test at a gathering-arm loader in an underground salt mine, the dust level under the air curtain was 72-84 percent lower than the ambient dust level measured with a Real-Time Monitor (Volkwein et al. 1982b). However, a sampling probe at the operator's lapel only recorded a 59 percent reduction. When sampling with and without the air curtain was done at the worker's lapel, the difference in dust concentration was 43 percent. The authors therefore concluded that the canopy air curtain can achieve a 50 percent reduction, and JRB will use this efficiency.

4.6 SUMMARY

The generally applied methods of dust control used in mining and milling operations are summarized in Table 4-3. The table includes dust reduction efficiencies reported by various authors, expected efficiencies used in this assessment study, and descriptions of the applicability and limitations of

Table 4-3. Summary of generally applied control methods.

Control method	Dust reduction efficiency*	Source	Expected dust reduction efficiency**	Applicability and limitations
Point source controls:				
Enclosure			Not assigned	Covers on vehicles, conveyors, railcars, and at loading or dumping points
SEV	80-90% on coal continuous mining machines 85-95% on silica flour bagging machines	ACGIH 1978 ACGIH 1978	80%	With effective enclosure of the source, operating with indraft air velocity of 150-200 ft/min and a duct velocity of 3,500 ft/min
Wetting	25% in underground coal operations 80% in a laboratory study of a coal cutting operation 20-60% with an average of 30% for coal dust 60-70% expected at a coal mine working face	Tomb et al. 1972a Tomb et al. 1972b Courtney and Cheng in Bureau of Mines 1977a National Academy of Sciences 1980	30%	At cutting, loading points, transfer points using 500 micrometer droplets for surface wetting, 200 micrometer droplets for airborne dust
Wetting with surfactants	32% improvement over water spray at a copper ore transfer point	MSA 1974	40%	Water spray plus surfactant, transfer points

(Continued)

Table 4-3. Summary of generally applied control methods.

Control method	Dust reduction efficiency*	Source	Expected dust reduction efficiency**	Applicability and limitations
	50-60% at a silica sand rail-car loading	Cole 1981		
Wetting with foam	45-90% in coal transfer operations 98% (particle size not defined) in silica sand railcar loading	Seibel 1976 Cole 1981	50%	Material transfer point, conveyor belt
Reduced drop distance	30% when drop distance (or belt speed) is reduced by one-half for coal dust	Courtney and Cheng in Bureau of Mines 1977a	30%	Reduced drop distance, belt speed, and load size; transport by vehicle or conveyor
Charged fogging	98% in sand unloading at a silica flour mill 63% at a hopper at a bentonite plant 20% (9 micrometer particles) 75% (1 micrometer particles) in conveying operations at quarry 40% (16 micrometer particles and smaller) at a coke screening operation	Hoenig 1977 Mathai et al. 1981 Hoenig in ACGIH 1978 Brookman and Kelley 1982	65%	Used at material transfer points in surface locations
Steam and water spray	20% higher than water sprays alone for coal particles smaller than 6 micrometers	Cheng et al. 1974	50%	

(Continued)

Table 4-3. Summary of generally applied control methods.

Control method	Dust reduction efficiency*	Source	Expected dust reduction efficiency**	Applicability and limitations
Good roadbed construction	50% when applying gravels to unpaved road 85% paving of road surface	Brookman and Martin 1981 EPA 1977	50% 85%	Spreading gravel on road surface paving road surface only
Chemical dust suppressant	40-98% depending on the type of chemical used and the time elapsed since application	various (see Table 4-2)	50%	Suppression of dust emissions from road surfaces
Reduced vehicle speed	65% haulage vehicle speed reduced from 15 to 10 MPH in crushed and broken stone industry	Kothari and Gerstle 1980	65%	
Ambient source controls:				
Primary exhaust ventilation			Not assigned	Standard practice in mining and milling industries; considered the control baseline rather than an additional control
Auxiliary exhaust ventilation	75% higher than air blowing at coal mining face	Courtney et. al. in ACGIH 1978	Not assigned	Entrance hood should be as close to the source as possible
Isolation of dusty area			Not assigned	For areas not in frequent use

(Continued)

Table 4-3. Summary of generally applied control methods.

Control method	Dust reduction efficiency*	Source	Expected dust reduction efficiency**	Applicability and limitations
Charged fogging	50% for 1 micrometer particles and 57% for 5 micrometer particles 5 minutes after spraying in a cement plant 86% for 6 micrometer particles 30 minutes after spraying in a cement plant	Hoenig 1977 ACGIH 1978	50%	For use in surface locations
Worker isolation controls:				
Enclosed work station	96% at a copper ore primary crusher	Rodgers et al. 1978	95%	Equipped with positive-pressure air-filtering system
Enclosed cab	56-82% on various mobile coal mining machines -4.5-44% total dust on dump trucks and front-end loaders for salt mines***	Volkwein et al. 1979	65%	Totally enclosed with air conditioning and air-filtering system

(Continued)

Table 4-3. Summary of generally applied control methods.

Control method	Dust reduction efficiency*	Source	Expected dust reduction efficiency**	Applicability and limitations
Canopy air curtain	70% in coal cutting operations 59% in a personal sample 43% difference in dust concentrations when the air curtain was on and off, measured with a realtime air monitor in a salt mine	Bureau of Mines 1977a Volkwein et al. 1982b	50%	Used horizontal airflow concurrent with general ventilation air movement

*Dust reduction efficiency reported for respirable dust unless otherwise noted.

**The typical value reported or the lowest dust reduction efficiency reported in well-documented studies. Values assigned for use in feasibility assessment only.

***A negative value for dust reduction efficiency results when dust exposure in the absence of dust controls is lower than exposure during the application of a dust control.

each method. The expected dust reduction efficiencies chosen are based on a conservative estimate derived from reported data, i.e., a reported typical value or a lowest reported value. However, even these expected efficiencies can only be achieved if the control methods are properly used and the control equipment is properly designed, installed, operated, and maintained. These expected dust reduction efficiencies will be used in the next chapter to provide basic data to determine whether a PEL is feasible in operations in each industry category. In certain operation categories, a higher value than the expected reduction efficiency may be used because of the special circumstances involved. However, in these cases, the specific value used will fall within the range of reported efficiencies for that particular control method, and the special circumstances surrounding the choice of this efficiency value will be discussed.

4.7 DUST REDUCTION EFFICIENCIES OF COMBINED CONTROL METHODS

Depending on the dust reduction requirements for a particular operation in a particular industry, it may be possible to control dust by means of a single technique from one line of control, or it may be necessary to combine methods across several lines of control. Table 4-3 summarizes the expected efficiencies for single methods. Examples are given here to present the methods for computing overall dust reduction efficiencies of combinations of methods.

Assuming a hypothetical control situation in which the generally applied dust control methods can be used, a control option chart can be prepared, as shown in Figure 4-1. Normally, only one method at one line of control may be used, unless two methods are cross-linked on the figure. For example, wetting methods and enclosure can be used together as a point source control method, but enclosure and SEV cannot (SEV would have its own enclosure). A combination of control methods may use one or more methods from each line of control. As shown in Figure 4-1, if one begins at the point source control line and ends at the worker isolation control line, there are $7 \times 4 \times 2$, or 56, combinations of control schemes. However, the number of practical combinations of control techniques may vary depending on the particular requirements for dust control at each mining operation.

When two methods are combined across the lines of control or linked within one line of control, the second method would remove the dust that is not removed by the first method, if the two methods are complementary. Therefore, the combined reduction efficiency of the two methods can be calculated as shown in Equation 1:

$$E_c = E_a + \frac{E_b}{100} (100 - E_a) \quad (1)$$

Where

E_c = dust reduction efficiency of combinations of methods A and B, in %;

E_a = dust reduction efficiency of method A, in %; and

E_b = dust reduction efficiency of method B, in %.

For example, the combination of SEV as point source control and charged fogging as ambient control would result in an overall dust reduction efficiency of

$$80 + \frac{50}{100} (100 - 80) = 90\% \quad (2)$$

When more than two control methods are combined, the dust reduction efficiency of the first two methods can be computed first and this result can then be used as a single efficiency value to be combined with the efficiency value of the third method, and so on. For example, if the result in Equation 2 is added to the efficiency attributed to a canopy air curtain, the combined efficiencies of the SEV, charged fogging, and canopy air curtain controls would be

$$90 + \frac{50}{100} (100 - 90) = 95\% \quad (3)$$

Based on the control methods shown in Figure 4-1, applicable combinations of two or more methods and their computed dust reduction efficiencies are shown in Figure 4-2. This figure illustrates that a wide range of respirable dust reduction efficiencies (from 30 to 99%) can be formulated.

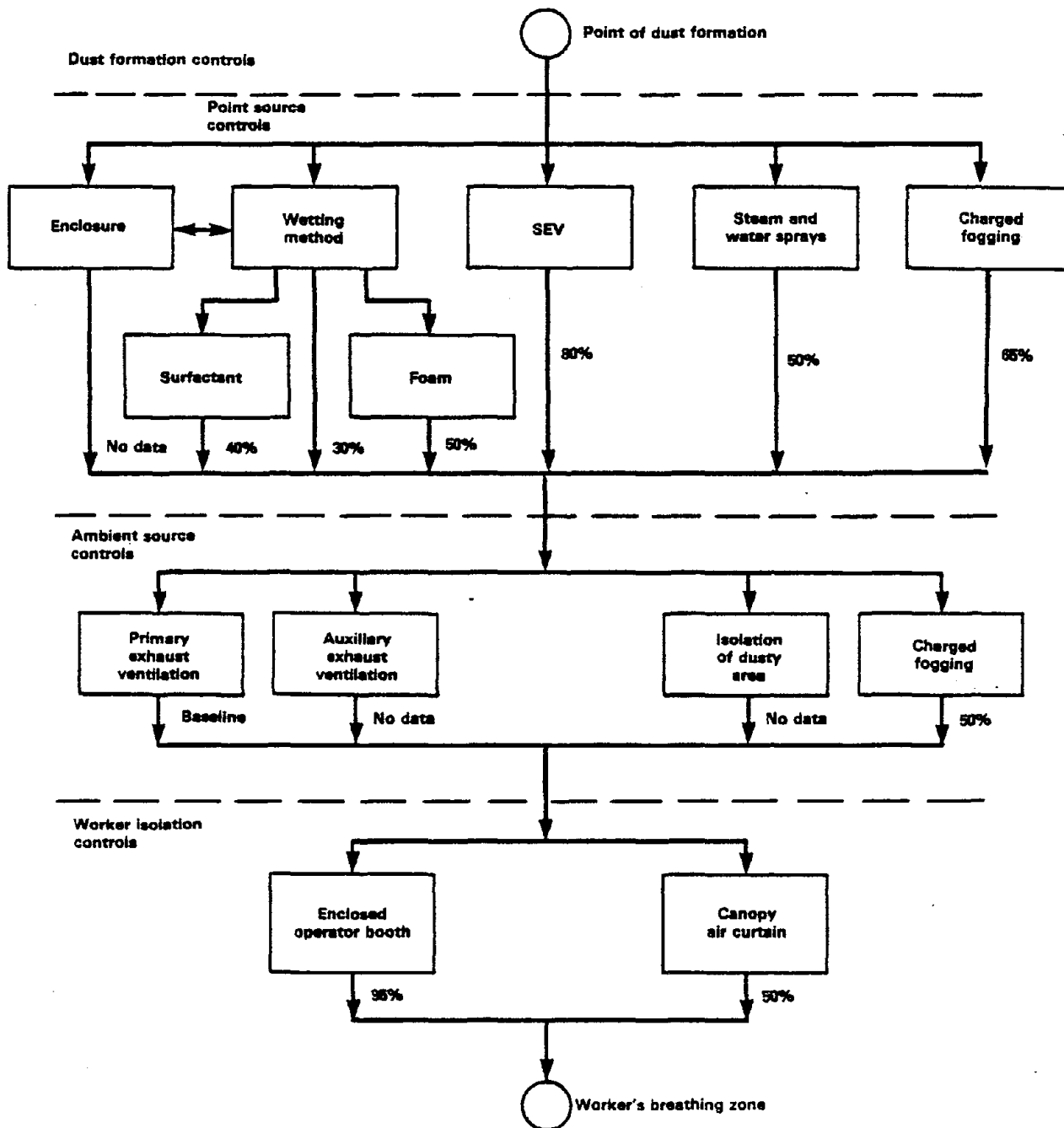


Figure 4-1. Flow diagram of dust control options and applicable reduction efficiencies for a hypothetical operation.

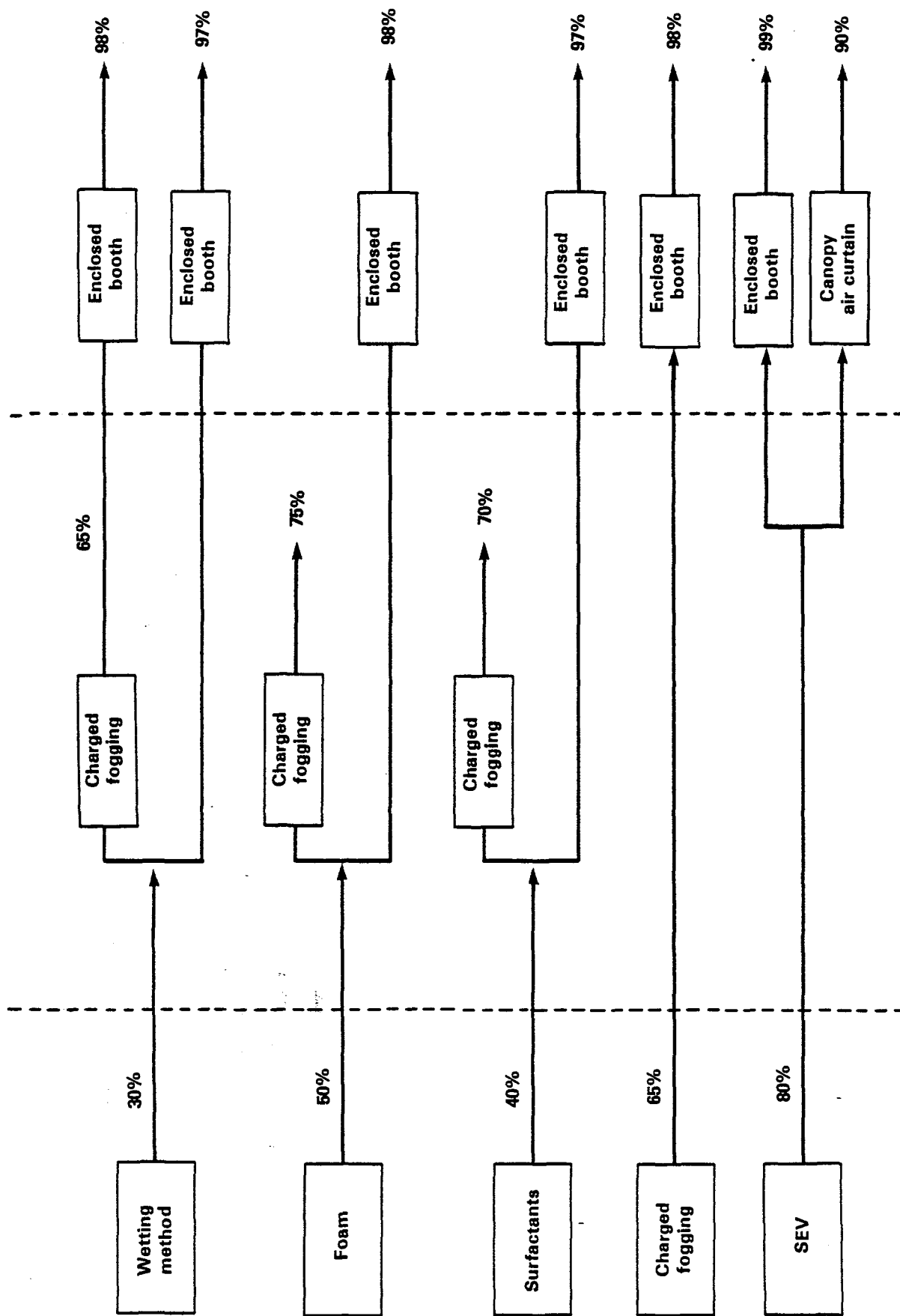


Figure 4-2. Examples of applicable combinations of dust control options and applicable dust reduction efficiencies for a hypothetical operation.

5. FEASIBILITY ASSESSMENT FOR SILICA AND ASBESTOS PEL'S

5.1 INTRODUCTION

This chapter discusses the technological feasibility of reducing silica dust and asbestos fiber exposure in the mining industry to various PEL's, based on the available data described in Chapter 2 and the information concerning dust controls summarized in Chapters 3 and 4. For this feasibility assessment, JRB has evaluated two PEL's for silica dust, 0.05 and 0.075 mg/m³, and three PEL's for asbestos fibers, 0.1, 0.5, and 1.0 fibers/cc. The feasibility of achieving these PEL's is determined for operation categories within each industry group.

In this chapter, the assumptions and procedures used to select an estimate of worse-case exposure, formulate control system options, and determine technological feasibility are discussed in Section 5.2. The feasibility of achieving each of the PEL's is analyzed for each operation category in Sections 5.3 to 5.15. Each of these sections contains the analysis of a single operation category. Within each section, the results of the feasibility assessment, the factors contributing to a judgment of marginal feasibility or infeasibility, and the maximum exposures that can be reduced to the PEL's through applications of controls are presented for each industry group. Each section begins with a brief discussion of the operation and the equipment associated with it. This is followed by a discussion of the MSHA job codes included in that operation category, sources of airborne dust, and the dust control methods applicable to that operation. Schematic illustrations of applicable combinations of control methods are used to show available control scheme options and ranges of achievable dust reductions. At the end of this chapter, tables are provided that summarize the results of the feasibility assessments and list the maximum exposures in each operation that can be reduced to each PEL.

5.2 TECHNICAL APPROACH

5.2.1 Technological Feasibility: The Mine Safety and Health Act of 1977

Any discussion of feasibility as it relates to the major occupational safety and health statutes must clearly distinguish between two meanings or applications of the term. As used in the statutes (MSHA and OSHA) themselves, references to feasibility apply to the standards-setting process carried out by the agencies as they develop mandatory health standards. As used in enforcement proceedings, however, the question of feasibility becomes one of the role of economic factors in an individual employer's ability to comply. Questions arising from the statutes' use of the term focus on whether a standard is feasible for the industry or sector affected by the standard, while those related to enforcement ask to what extent any burden placed on

individual employers by compliance with a standard should be considered in enforcement or abatement issues (Berger and Riskin 1978). Since the technological feasibility analysis that follows was undertaken by NIOSH in the context of possible future rulemaking activity, it is the statutory use of the term feasibility that is of concern here. In the material that follows, therefore, feasible is defined as "capable of being done." Factors such as productivity effects, relative unavailability of control technology, and costs of engineering controls have not been taken into consideration because, although they may affect individual employers, they do not threaten the long-term competitive structure of any industry sector. This interpretation is consistent both with the views expressed in recent court cases and with MSHA's enabling legislation, as discussed below.

Statutory Considerations of Feasibility

The Federal Mine Safety and Health (MSH) Act of 1977 specifies:

The Secretary [of Labor]...shall set standards which most adequately assure on the basis of the best available evidence that no miner will suffer material impairment of health or functional capacity....In addition to the attainment of the highest degree of health and safety protection for the miner, other conditions [on which standards development depends] shall be the latest available scientific data in the field, the feasibility of the standards, and experience gained under this and other health and safety laws (Section 101(a)(6)(A)) [emphasis added].

In the Senate Report (U.S. Congress 1977) that accompanied the MSH Act's passage, the Senate Committee on Human Resources specifically explained:

While feasibility of the standard may be taken into consideration with respect to engineering controls, this factor should have a substantially less significant role [than the latest available scientific data in the field]. Thus, the Secretary may appropriately consider the state of the engineering art in industry at the time the standard is promulgated. However, as the circuit courts of appeals have recognized, occupational safety and health statutes should be viewed as "technology-forcing" legislation, and a proposed health standard should not be rejected as infeasible "when the necessary technology looms on today's horizon" [the Report is quoting the OSHA Vinyl Chloride decision].

The Senate Report continues:

Similarly, information on the economic impact of a health standard which is provided to the Secretary of Labor at a hearing or during the public comment period, may be given weight by the Secretary. In adopting the language of Section 101(a)(6)(A), the Committee wishes to emphasize that it rejects the view that cost benefit ratios alone may be the basis for depriving miners of the health protection which the law was intended to insure. The Committee concurs with the judicial constitution that standards may be economically feasible even though from the standpoint of employers, they are "financially burdensome and affect profit margins adversely." Where substantial financial outlays are needed...to allow industry to reach the permissible limits necessary to protect miners, other regulatory strategies [such as variances, staggered effective dates, phasing in of compliance deadlines] are available to accommodate economic feasibility and health considerations (p. 22) [emphasis added].

These excerpts make clear that the legislature believed that MSHA should not give economic factors overriding consideration during the standards development process. The Congress believed that this reasoning reflected a proper setting of priorities: the miners' health and safety should be given the foremost consideration. As the Senate Report emphasizes, this view is reasonable in light of the Act's other strategies for industry and employer relief, e.g., variances, judicial review of standards, enforcement proceedings review, and phasing in of compliance deadlines.

In fact, MSH Act standards have not specifically been tested in the courts over the issue of feasibility (or its most current manifestation, cost-benefit analysis) as OSHA standards have. On the other hand, the major OSHA cases, ranging from Asbestos (Industrial Union Department v. Hodgson 1972) to Vinyl Chloride (Society for the Plastics Industry, Inc. v. OSHA 1975) to Lead (United Steelworkers of America, AFL-CIO-CLC v. Marshall 1980) to Cotton Dust (American Textile Institute v. Donovan 1981), have rejected the notion that economic considerations should play the decisive role in occupational safety and health rulemaking. It would be reasonable to think that the outcome of judicial review, if the MSHA standards were put to the test, would be no different. At the present time, therefore, the various rulings on the role of feasibility in the standard development process would appear to apply equally to MSHA rulemaking. The major findings of these cases are briefly described below.

- Vinyl Chloride: Ruled that "it remains the duty of [OSHA] to act to protect the working man, and to act even in circumstances where existing methodology or research is deficient....[OSHA] is not

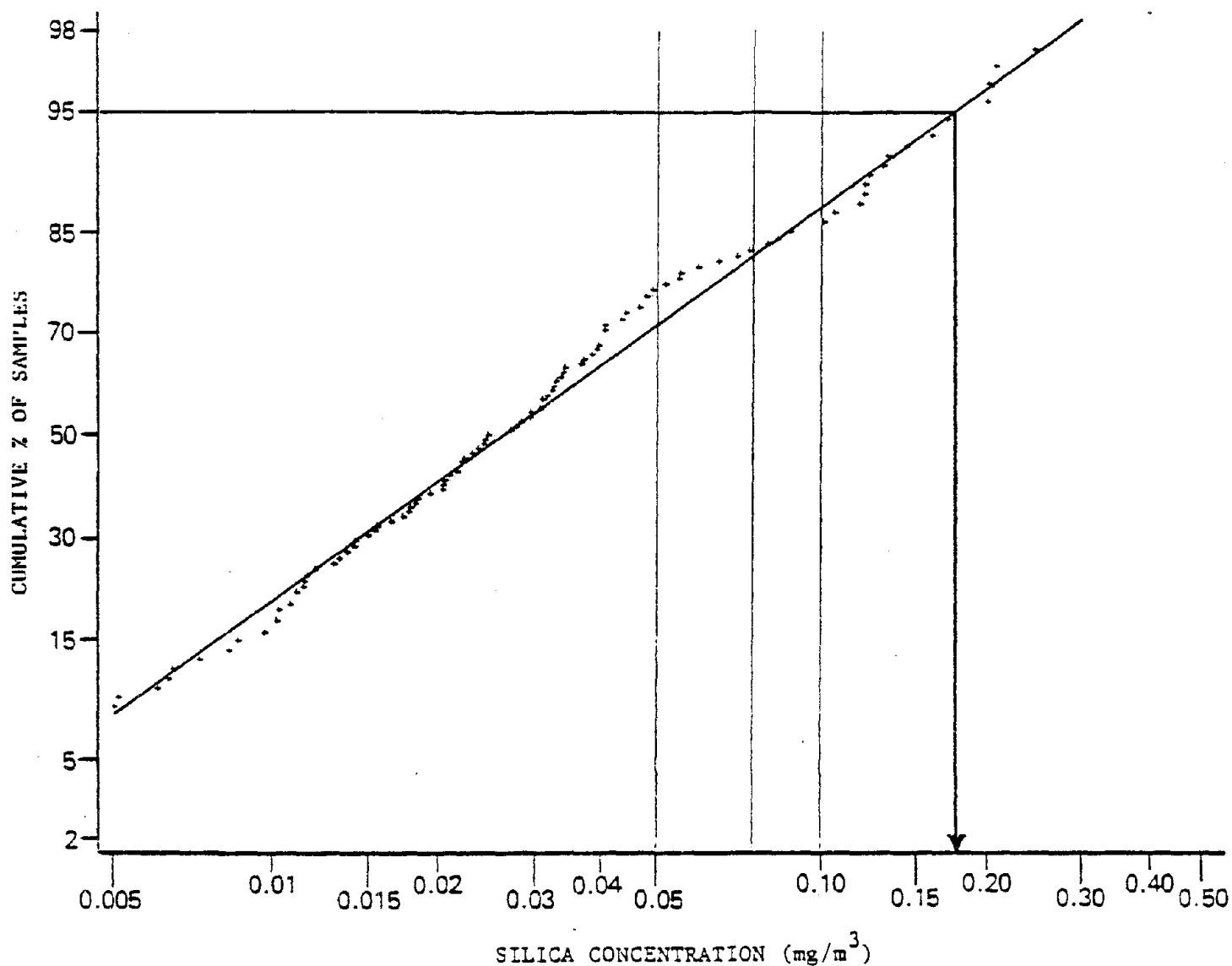
restricted by the status quo...[and] may raise standards which require improvements in existing technologies or which require the development of new technology."

- Lead: Ruled that a standard is not "infeasible solely because OSHA has no hard evidence to show that the standard has been met [in current practice]....OSHA's duty is to show that modern technology has at least conceived some industrial strategies or devices which are likely to be capable of meeting the PEL and which the industries are generally capable of adopting....[OSHA must demonstrate] a reasonable possibility that the typical firm will be able to develop and install engineering and work practice controls that can meet the PEL in most of its operations. OSHA can do so by pointing to technology that is either already in use or has been conceived and is reasonably capable of experimental refinement and distribution within the standard's deadlines....OSHA is not required to prove that marginal firms will not be forced out of business by the costs of complying with a standard, nor is it required to be concerned with their demise unless their extinction would threaten the competitive structure of the industry."
- Cotton Dust: Ruled that cost-benefit analysis to determine a PEL for a health standard is inconsistent with the intent of the OSH Act: "cost benefit analysis [by OSHA] is not required by the statute because feasibility analysis is." Court did not rule out use of cost-effectiveness analysis in standards setting, however.

5.2.2 Selection of Estimated Worse-Case Exposure Concentration

The lead decision (United Steelworkers of America, AFL-CIO-CLC v. Marshall) and other decisions (Vinyl Chloride, Asbestos) have established that a PEL does not have to be achievable in every situation in all affected industries at all times for a PEL to be judged feasible. Consequently, not all of the exposure conditions contained in the MSHA MIDAS file and summarized in Chapter 2 must be controlled to the PEL to conclude that the PEL is feasible in a particular operation. As discussed in Chapter 2, exposure profiles were developed for each industry group and for each operation category. Where an exposure profile is available to give a quantitative measure of the exposure levels in an industry-operation group, a cutoff level, e.g., a certain percentage of all the data points, can be selected as a feasibility threshold.

Based on the MIDAS files (and including MSHA fiber survey results in the case of mineral fiber exposure), exposure profiles that show the cumulative percentage of the samples versus silica or asbestos concentration were developed for each operation and industry group for which at least five data points were available. These profiles for silica dust exposure are included in Appendix A and those for mineral fiber exposure are in Appendix B. As seen in the example shown in Figure 5-1, the horizontal axis represents the concentration in logarithmic scale, while the vertical axis represents the normal probability distribution of the data points, with 50 percent as the median.



No. of samples: 116
 No. of mine ID's represented: 50
 No. of active sites in 1980: 104
 Percent of samples less than 0.05 mg/m³: 76
 Percent of samples less than 0.075 mg/m³: 82
 Percent of samples less than 0.1 mg/m³: 84

Figure 5-1. Example of exposure profile--silica dust concentrations found in underground drilling operations in the limestone industry group.

Generally, the exposure data follow a logarithmic normal distribution; therefore, least square regression analyses were made to determine the best-fit line that describes the data distribution in each exposure profile. Regression analyses were also done for those industry-operation cells for which only three to five data points were available, but for which profiles were not prepared. For those exposure profiles for which regression analyses were made, equations for determining the best-fit lines are provided in Appendix A. In order to estimate the worse-case exposures that are found in the mining industry, JRB used these equations to determine the exposure level that describes the 95 percentile distribution point of the samples for a given industry-operation group. This point is called the 95 percentile exposure level. In Figure 5-1, the best-fit line determined by regression analysis and the 95 percentile exposure level for that industry-operation group are shown. The regression analysis was made only for silica dust exposure data, not for the mineral fiber exposure data, for the reasons explained below.

Since the 95 percentile of the exposure data was selected to provide the best estimate of worse-case exposure, judgments of technological feasibility are based on the ability of the industry to reduce silica and asbestos exposure from the 95 percentile exposure level for a particular operation category to any of the alternative PEL's. If the 95 percentile exposure level can be reduced to a PEL, achieving that PEL is judged to be feasible for that operation and industry. Although data are not available for all mines in any given industry sector, we have assumed that the available data for a given industry sector and operation category represent the highest exposures currently found in each industry sector and operation category. This assumption is reasonable since, for dust sampling, MSHA generally selects those mines and operations that present the highest risk of exposure to silica or asbestos dust (personal communication, MSHA inspectors, 1983). Further, selecting the 95 percentile exposure level will produce a conservative judgment of feasibility because the 95 percentile exposure level will probably be higher than typical exposure levels found in the industry. In practical terms, use of this exposure level as the point of reference for the analysis guarantees that the dust reduction required to meet the PEL's is greater than would be needed in typical industry situations.

Silica dust exposure data were available for most of the industry-operation cells, and in these cases the 95 percentile concentration can therefore be determined. For the industry-operation cells for which regression analyses of the data could not be made (because only one or two data points were available) the only data point available (or the highest in the data set) was used to represent the 95 percentile exposure level. These data are shown in Table 5-1.

Personal exposure data on asbestos fiber counts are very limited compared with the available data on silica dust exposure. Furthermore, available asbestos exposure data are almost entirely in the form of mineral fiber counts rather than asbestos fiber counts. Feasibility assessments are therefore made by assuming that asbestos fiber counts would be the same as the counts reported for mineral fibers. Since not all mineral fibers are asbestos fibers, this assumption will produce conservative results. As discussed in Section 2.3.1, the mineral fiber exposure data are generally derived from short-term sampling

Table 5-1. Overview of 1977-1981 silica dust exposure data collected by MSHA.

Operation Category	Industry Group	Copper	Gold and Silver	Iron	Lead and Zinc	Molybdenum	Uranium	Other Metals	Limestone
Surface drilling		0.27 37(58%)	0.5 14(8%)	0.10 56(42%)		0.02 4(67%)	0.14 11(12%)	0.8 5(9%)	0.09 443(17%)
Underground drilling		0.25 56(42%)	0.11 79(8%)	0.09 15(14%)	0.18 38(29%)	0.22 35(25%)	0.15 76(17%)	0.03 3(8%)	0.17 116(48%)
Blasting		1.2 7(4%)	0.05 3(1%)	0.08 9(5%)	0.01 2(4%)	0.195 5(15%)		0.03 2(8%)	0.165 27(16%)
Cutting and boring									0.075 23(0.5%)
Surface production		0.003 4(3%)		0.05 7(19%)				0.005 1(5%)	0.06 36(2%)
Surface mobile transport		0.36 161(100%)	0.10 47(21%)	0.07 415(77%)	0.14 7(100%)		0.07 106(76%)	0.095 7(18%)	0.078 3,779(58%)
Surface haulage way maintenance		0.005 4(3%)							0.05 20(0.5%)
Underground production		0.28 23(21%)	0.17 44(7%)	0.04 2(29%)	0.20 10(10%)	0.49 44(25%)	0.095 32(11%)	0.078 9(17%)	0.02 3(2%)
Underground mobile transport		0.25 197(63%)	0.11 139(11%)	0.076 14(29%)	0.19 101(39%)	0.18 47(30%)	0.10 216(32%)	0.05 1(17%)	0.10 221(52%)
Underground haulage way maintenance		0.03 10(26%)	0.08 24(4%)		0.16 16(8%)	0.13 40(38%)	0.09 10(3%)		
Crushing, grinding, and sizing		0.27 249(39%)	0.375 106(6%)	0.20 360(48%)	0.26 62(31%)	1.45 17(15%)	0.27 69(9%)	1.32 15(12%)	0.12 2,324(45%)
Concentrating and finishing		0.05 66(22%)	0.175 25(4%)	0.09 375(31%)	0.076 27(23%)	0.03 1(13%)	0.075 40(5%)	0.06 9(12%)	0.17 339(6%)
Number of active sites in 1980		190 31S	1130 73S	70 31S	490 5S	80 3S	1550 34S	120 22S	1040 1,809S

(Continued)

Table 5-1. Overview of 1977-1981 silica dust exposure data collected by MSHA.

Operation Category	Industry Group	Other Stone	Clay and Shale	Asbestos	Talc	Oil Shale	Other Nonmetals	Sand and Gravel
Surface drilling		0.39 796(26%)	0.15 12(2%)		0.07 3(8%)	0.04 3(100%)	0.09 30(7%)	0.10 17(.03%)
Underground drilling		0.197 17(40%)	0.32 56(50%)			0.13 21(9%)	0.08 26(15%)	
Blasting		0.04 7(1%)	0.07 10(1%)				0.01 3(1%)	
Cutting and boring		0.1 151(5%)						
Surface production		0.17 29(2%)	0.34 12(2%)				0.43 4(1%)	0.15 69(1%)
Surface mobile transport		0.215 1,554(44%)	0.20 454(39%)		0.085 8(24%)	0.46 11(100%)	0.19 295(26%)	0.15 2,188(28%)
Surface haulageway maintenance		0.12 6(0.4%)					0.06 3(0.7%)	
Underground production		0.045 8(20%)	0.23 4(14%)		0.02 3(13%)		0.11 13(6%)	
Underground mobile transport		0.29 44(40%)	0.22 80(71%)			0.12 13(18%)	0.12 47(19%)	
Underground haulageway maintenance		0.14 3(7%)	0.11 6(21%)				0.03 5(3%)	
Crushing, grinding, and sizing		0.33 1,513(42%)	0.38 353(29%)		0.14 18(18%)	0.7 2(9%)	0.56 216(15%)	0.29 1,137(19%)
Concentrating and finishing		0.73 549(7%)	0.37 573(18%)		0.135 28(18%)		0.91 289(12%)	0.40 569(3%)
Number of active sites in 1980		15U 832S	14U 421S	1U 3S	8U 25S	11U 0S	62U 284S	0U 3,351S

Note: Within each box, the top number denotes the 95 percentile exposure level in mg/m³, the lower number denotes the number of data points, and the percentage in the parentheses denotes the percentage of active mines where exposure data were available. Underground is indicated by "U" and surface by "S."

and from locations likely to have higher than typical exposures; therefore, available data are assumed to represent worse-case conditions in the particular operation category.

The scarcity of asbestos data means that there are many cells of the industry-operation matrix that have no data, and that even for cells with data, only a few establishments are represented. Only 48 cells of the 180 possible cells of the industry-operation matrix contain personal mineral fiber exposure data. Furthermore, 21 of the 48 cells that have personal exposure data contain no more than three data points. Meaningful regression analyses cannot be made for almost half of the available exposure profiles and therefore were not done for the mineral fiber exposure data. Instead, a best-fit line was drawn on a probability graph where five or more data points in an industry-operation cell were available. The 95 percentile exposure level was then determined from the concentration corresponding to the point where the 95 percentile line intercepts the best-fit line. For industry-operation cells where only one to four data points were available, the highest fiber count was assumed to represent the 95 percentile concentration. An overview of the available 95 percentile data and the number of data points and percentage of sampled mine sites among the industries is shown in Table 5-2. As is the case for the feasibility assessment of silica PEL's, assessments of the technological feasibility of achieving alternate asbestos PEL's are given for industry-operation cells for which exposure data are available.

5.2.3 Selection of Control Options

After establishing a 95 percentile concentration for each industry-operation cell, the reduction efficiency required to meet the lowest PEL is calculated. (Only if the lowest PEL is infeasible is the feasibility of the higher PEL's evaluated.) The required reduction efficiency is the criterion against which the expected reduction efficiency of applicable combinations of control methods is judged to determine the feasibility of reducing dust exposure to the PEL for that particular industry-operation cell.

Dust controls in the mining and milling industry can be achieved by using controls at various stages of dust formation and dispersion. As discussed in Chapters 3 and 4, dust exposure can be reduced at four lines of control: at dust formation, at point source, at ambient source, and at the worker's breathing zone. Several control methods are generally available at each line of control. A method may be used alone or be combined with methods from other lines of control to yield the required level of control. Based on the expected dust reduction efficiency established for each applied control method and using the methods outlined in Chapter 4 for combining the efficiencies of several methods, appropriate control methods are selected to formulate a control system that will provide a dust reduction efficiency high enough to meet the required reduction efficiency. In addition to those methods discussed in Chapter 4, the efficiencies of specific controls applicable only in specific operations are considered and included where appropriate in formulating a control system. Control methods applicable to each operation are shown, with their respective expected dust reduction efficiencies, in a flow chart format in Sections 5-3 through 5-15. These flow charts provide information only for applicable

Table 5-2. Overview of 1977-1981 mineral fiber exposure data collected by MSHA.

Operation Category	Industry Group	Copper	Gold and Silver	Iron	Lead and Zinc	Molybdenum	Uranium	Other Metals	Limestone
Surface drilling				0.01 IP 3% 0.09* 1A 3%					0.1 1.8 13P 12A 0.4% 0.3%
Underground drilling			0.4 IP 3%	0.09* 1A 3%					1.2 1P 1%
Blasting									
Cutting and boring									6.0 7A 0.4%
Surface production				0.2* 17A 5%					1.2 1P 0.1%
Surface mobile transport				0.5 0.9 46P 48A 19% 19%				0.2 5A 7%	0.3 1.8 7P 19A 92% 0.3%
Surface haulage/maintenance									
Underground production		0.5 1A 5%	0.7 3P 0.5%	0.2* 17A 5%	0.3 2A 1%	3.0 2P 9%			
Underground mobile transport		0.02 8P 5%							0.4 1.8% 4P 19A 4% 0.3%
Underground haulage/maintenance									
Crushing, grinding, and sizing		0 1A 5%	0.4 4P 0.5%	0.6 1.0 62P 185A 17% 26%	0.3 6A 4%			0.8 6.0 1P 8A 2% 5%	1.5 3.0 22P 167A 0.5% 3%
Concentrating and finishing				0.1 3P 5%			0.2 9P 10.4%	0 1P 3%	
Number of active sites in 1980		19U 31S	113U 73S	7U 31S	49U 5S	8U 3S	155U 34S	12U 22S	104U 1,809S

(Continued)

Table 5-2. Overview of 1977-1981 mineral fiber exposure data collected by MSHA.

Operation Category	Industry Group	Other Stone	Clay and Shale	Asbestos	Talc	Oil Shale	Other Nonmetals	Sand and Gravel
Surface drilling		1.6 5.0* 3P 52A 0.2% 2%	5.0* 3A 0.2%	1.0 3P 33%	1.7 9.0* 5P 6A 8% 2%		2.0 5P 0.2%	
Underground drilling		0.1 5.0* 1P 52A 0.1% 2%	5.0* 3A 0.2%	0.2 1P 100%	1.1 9.0* 4P 6A 13% 2%		0.5 8P 6%	
Blasting								
Cutting and boring		0.8 33A 2%						
Surface production								1.2* 3A 0.0%
Surface mobile transport		0.6 1.7 13P 90A 0.5% 2%	0.1 3P 0.5%	1.4 15P 100%	0.5 10* 11P 26A 12% 10%		1.6 38P 0.2%	0.17 0.7* 19P 14A 0.3% 0.3%
Surface haulageway maintenance		1.0* 2A 0.1%						
Underground production					2.0 13P 50%		1.3 3P 1%	1.2* 3A 0.0%
Underground mobile transport				0.2 8P 100%	0.5 10* 15P 26A 50% 10%		0 2P 1%	0.7* 14A 0.3%
Underground haulageway maintenance		1.0* 2A 0.1%						
Crushing, grinding, and sizing		2.0 2.5 15P 189A 1% 7%	0.04 10 1P 18A 0.2% 2%	3.0 25P 43%	1.5 7.0 11P 45A 10% 25%		1.1 2.5 22P 53A 2% 3%	2.0 4.3 10P 163A 0.2% 3%
Concentrating and finishing		2.0 3P 0.2%		4.0 38P 43%	0.8 18P 14%		1.6 32P 2%	0.2 1P 0%
Number of active sites in 1980		15U 832S	14U 421S	1U 3S	8U 25S	11U OS	62U 284S	0U 3,351S

Note: Within each box, the top number denotes the 95 percentile exposure level in fibers/cc, the second number denotes the number of data points ("P" for personal sample, "A" for area sample), and the last number denotes the percentage of mines from which samples were taken. Underground is indicated by "U" and surface by "S."

methods at each line of control and do not imply that any method from one line of control can be combined with any method in another line of control to provide additional dust removal. Only compatible methods can be combined, and examples are provided in each section where appropriate.

In formulating combinations of dust controls to determine the technological feasibility of achieving the PEL at a particular operation, only currently available control methods are considered. Control methods still under development but which can reasonably be expected to be available in the future are classified as potential technology and discussed as appropriate in the text. The reduction efficiencies attributed to these controls are discussed in the text and shown in the operation category control flow charts, but their status as potential technology is clearly identified. An example of such a potential control is a water jet drill.

Control methods that are currently available and in use in the mining or milling industry have been classified as existing controls for the purposes of this report, even in cases where their use is not widespread or is still under evaluation. The dust reduction efficiencies attributable to such controls have been included in the calculations on which the feasibility determination for an operation category was made.

Another criterion used to classify a control as existing rather than potential was its applicability, without regard to cost, to an operation category as a whole. For example, charged fogging is a currently available control method that can be used in surface drilling operations, although at present it is not widely applied. Because there are no technological barriers to the use of charged foggers in aboveground operations, feasibility calculations for these categories include the reduction efficiencies assigned to charged foggers. However, JRB does not consider charged foggers applicable controls for underground operations because they generate static charges and may be hazardous in underground mining operations that are contaminated with methane or other explosive gases.

Although work practice controls are critically important in the real world and personal protective equipment may be needed for limited exposures in certain work situations, the dust control efficiencies of work practices and personal protective equipment have not been considered in this analysis.

Since the mining industries are already using certain dust control methods, the dust concentrations and fiber counts obtained in MSHA samples reflect the dust reducing effects of existing controls; therefore, the dust reduction efficiency required to meet one of the alternative PEL's specifies only the additional amount of control required. Existing methods of control that are in routine use throughout the mining and milling industry comprise the current industry practice baseline; baseline controls, such as primary ventilation, are therefore not considered in subsequent calculations of dust reduction efficiencies. Additional baseline controls used in specific operation categories are discussed in specific sections of the report. Information on baseline controls in various industries and operations was obtained from the literature, especially those sources describing common practices in industry or MSHA surveys. Observations made during the site visits conducted

for this project and interviews conducted with various MSHA mine inspectors and officers and Bureau of Mines (BOM) personnel provided additional information.

5.2.4 Determination of Technological Feasibility

If the degree of dust reduction required to meet a PEL and the expected efficiencies of applicable control systems are known, the technological feasibility of a PEL can be assessed by comparing these two numbers. A determination of feasibility requires that the expected reduction efficiency of dust control systems be higher than the reduction efficiency required to meet a PEL. The accuracy of the two efficiency numbers will therefore have a direct impact on the validity of the outcome of the feasibility analysis.

In cases where the required and expected dust reduction efficiencies are very close, a change in either efficiency value could shift the direction of the determination, i.e., from feasibility to infeasibility or vice versa. A margin of error should therefore be included in these analyses to account for any uncertainties that may be involved in applying these efficiency data. JRB has arbitrarily chosen a 5 percent margin of error for the purpose of this study. Sources of uncertainties include the 95 percentile exposure level selected and the expected dust reduction efficiency assigned to each dust control method. Exposure data as contained in the MIDAS files represent a true characterization of the sites and job codes sampled. However, the samples collected in conjunction with the MSHA inspection program were not collected according to an overall statistical design as to the number of samples and numbers of sites required. Statistical analyses of the variance and error estimates of the data for the industry as a whole cannot therefore be made. As for the expected dust reduction efficiency of a control method, a value, generally a typical value or the lowest one among the efficiencies reported by various investigators, is used for the feasibility assessment. This procedure can be expected to yield conservative results, but there is no way to measure the variance of such values. The use of a 5 percent margin of error is an attempt to account for these uncertainties.

Although the margin of error cannot be statistically determined in this assessment, the confidence with which individual judgments are made can be measured qualitatively, based on the number of samples and sites in an industry-operation cell. Obviously, a 95 percentile exposure level derived from 100 samples collected from one-half of the active sites in an industry is a much more accurate estimate than an exposure level based on one sample from one site. To provide a qualitative index of the confidence of a particular determination, industry-operation cells with fewer than five samples, cells in which all of the samples were collected from one site, or cells with samples collected from fewer than 5 percent of the active sites in an industry-operation category are clearly identified in this report.

Use of the 5 percent margin of error means that a PEL is considered feasible if the expected reduction efficiency achievable with a single or combined control method is at least 5 percent higher than the reduction efficiency required to meet the PEL. A PEL is considered infeasible if the expected dust

reduction efficiency is at least 5 percent lower than the required efficiency. Since the efficiency numbers are calculated in whole numbers for this project, cases in which the expected reduction efficiency is within +4 percent of the required dust reduction efficiency are considered borderline in terms of feasibility.

As explained in Chapter 4, the selection of an expected dust reduction efficiency for a control method is based on criteria that will yield conservative results. If typical efficiency values have been reported, they are used. If these are not available, the lowest efficiency value reported for a control method in a well-documented study is used. Only if data from these two sources are not available are efficiencies reported in other sources, such as manufacturers' data, used. Also, efficiency data on controls in noncoal dust applications are used whenever possible. Use of this data selection strategy ensures that PEL's shown to be feasible for a particular operation in a given industry are in fact feasible in this situation.

On the other hand, if a PEL is determined to be infeasible or borderline, the factors involved are further evaluated. The specific factors contributing to the judgment of infeasibility or borderline feasibility are described (e.g., number of data points, probability distribution of these data, number of mines sampled, any special circumstances), so that MSHA can assess the relative degree of infeasibility involved in a particular case. Additionally, the maximum exposure level in each operation for which a PEL would have been judged feasible is determined and given in a summary table at the end of this chapter.

A number of operation categories are composed of several process steps, each of which may have different control options. In such cases, JRB has grouped the exposure data collected for the individual steps into a single profile. For example, exposure data from crushing, grinding, and sizing operations have been combined into one profile, although five control schemes are applicable at the different process steps. The 95 percentile exposure concentration determined from the exposure profile therefore represents the distribution of data taken from all steps combined rather than the data from any specific step. To perform the feasibility analysis, all of the process steps in the operation category have been treated as having the same 95 percentile exposure concentration. The initial assessment of feasibility for the operation category is then made by requiring that the PEL be met by each of the process steps within the operation category. If the PEL is determined to be infeasible or borderline for such an operation, exposure data pertaining to specific MSHA occupational categories are examined to determine whether one particular occupation or process step is responsible for contributing most of the high exposure within the operation category.

5.3 SURFACE DRILLING

5.3.1 Dust Sources and Control Methods

Drilling devices in surface operations remove rock by two basic mechanisms: thermal spalling and mechanical breakage. In both types of drilling, the major dust source results from material disintegration. When the hole is bailed, this material is ejected from the hole as part of the

cuttings. Additionally, the cuttings deposited around the drill hole are sources of ambient dust. The MSHA job codes for this operation are rotary drilling, diamond drilling, jet piercing, and percussive drilling.

Light- and medium-weight drills are best suited for drilling holes that are 2-4 inches in diameter and up to 100 feet deep. Bailing velocities for these drills typically range from 2,000 to 3,000 ft/min. Heavyweight crawler-mounted drills and self-propelled, self-contained drill rigs can drill holes from 4 to 7 inches in diameter to depths of 100 feet or more. These drill rigs are operated with bailing velocities of over 4,000 ft/min. Dust exposure at drilling operations depends on drill size and bailing velocity. Larger drills with higher bailing velocities will generate more dust.

All drill rig types, from light handheld drills to self-propelled, self-contained drill rigs, may be used in any of the industry groups considered in this study. Larger drilling rigs usually have enclosed cabs. Light and medium-sized rigs are not typically equipped with these systems (National Academy of Sciences 1980).

Figure 5-2 shows the dust control options available for surface drilling operations, along with the expected dust reduction efficiency of each method. Dust formation can be controlled by reducing drilling speed or substituting water jet drilling for mechanical drilling equipment. Reduced drill speed is not used in most mining operations due to production requirements and the need for specialized equipment that can withstand the stresses of low speed drilling. Although this specialized equipment is available, no data were found on its effectiveness in reducing dust emissions, and it is therefore not considered in the feasibility analysis. Since water jet drilling is considered a potential technology, it is not included in the feasibility assessment calculations.

Wet drilling, which involves the use of water as the flushing media, is an effective alternative to dry drilling in reducing the amount of dust produced. As mentioned in Chapter 3, a 98 percent dust reduction efficiency has been reported with the use of wet drilling systems (Rodgers 1974). However, wet drilling techniques cannot be used for materials that will cake easily or are water sensitive, such as those found in the other non-metals industry group. Although wet drilling techniques are used in some surface drilling operations, they are not considered as a baseline control because of variability in industry utilization. For instance, wet drilling was not used at the granite quarries and sand and gravel operations selected for JRB site visits (Site Visit Reports Nos. 4 and 8). Based on the report by Rodgers (1974), wet drilling is assigned a dust reduction efficiency of 98 percent.

SEV designed as an integrated dust collection system can be very effective in reducing dust emissions at dry drilling operations because

- The dust source can be completely isolated with a small enclosure.
- The drill can be equipped with suction devices at the front of the feed to capture dust immediately after it is emitted from the hole.

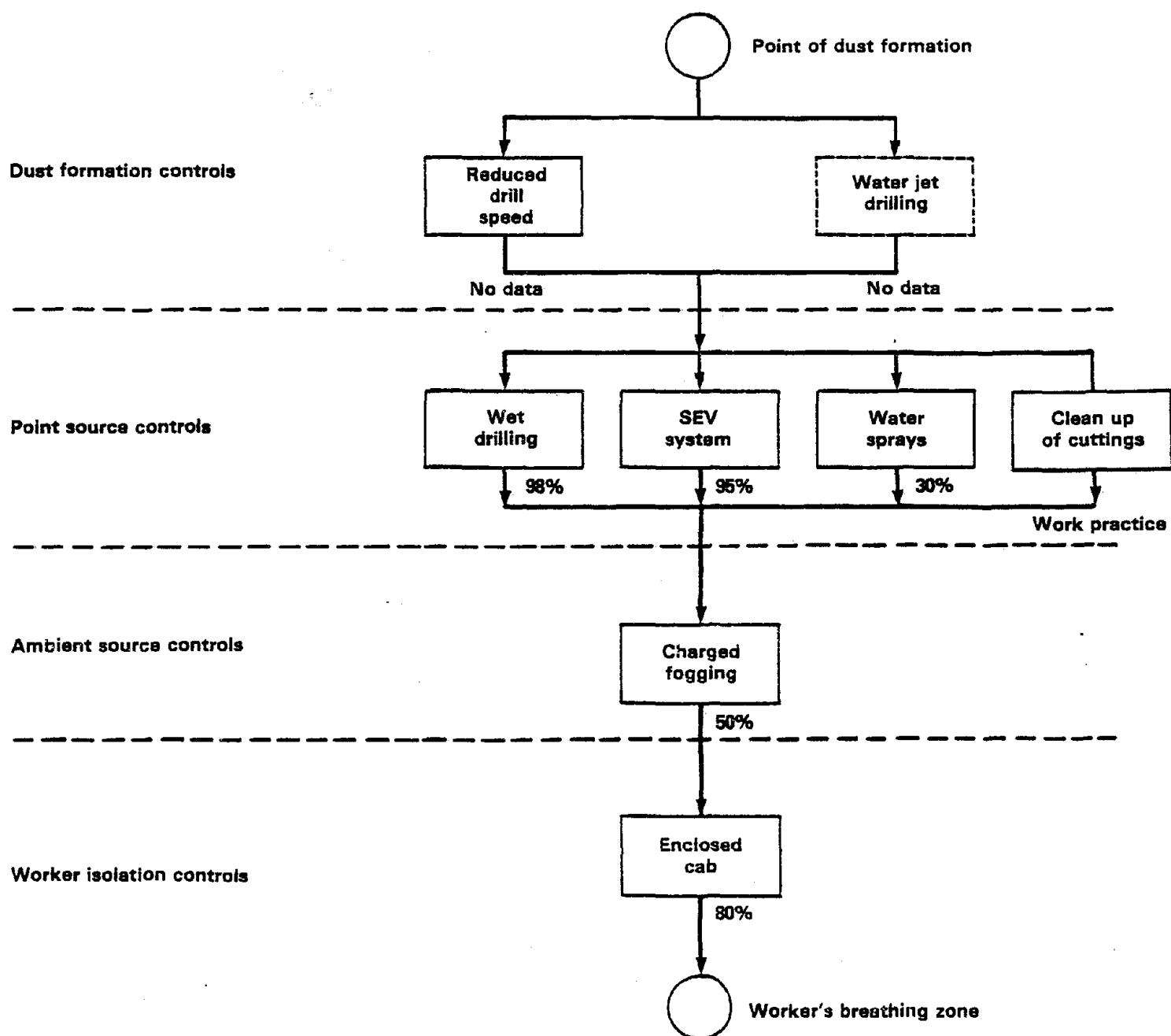


Figure 5-2. Flow diagram of dust control options and applicable reduction efficiencies for surface drilling.

The airflow capacities of such drill SEV systems range from 600 ft³/min to 3,600 ft³/min, depending on the size of the drill and the depth of the hole drilled. Efficiencies of 95 percent or more have been reported for dry drilling operations with SEV systems (Pit and Quarry Magazine 1976; Rock Products 1977b). Therefore, a dust reduction efficiency of 95 percent is assigned for a drill SEV. However, SEV can only be used under dry drilling conditions. JRB could find no evidence to suggest that SEV is more effective than wet drilling.

Point source control can be achieved with water sprays located around the drill steel collar. A dust removal efficiency of 30 percent has been assigned for this control option, as discussed in Chapter 4.

Charged fogging can be used to control dust from ambient sources at surface drilling operations. As described in Chapter 4, the assigned dust reduction efficiency is 50 percent for charged fogging.

Cleanup of cuttings is a method of ambient dust control. However, since drill holes are typically blasted in the same shift in which they are drilled, this control option, which is only useful when cuttings are left in active working areas for extended periods of time before blasting, would not be applicable for most operations and is therefore not considered further in the feasibility assessment.

Worker exposure to dust can be reduced by isolating workers in control cabs on drilling machines. As discussed in Chapter 4, a 95 percent reduction efficiency is attainable using a well-designed stationary operator's booth, and a 65 percent efficiency can be achieved with a mobile cab. Because of the restricted movement and slow speed of most drilling equipment, drilling machines can be regarded primarily as stationary rather than mobile equipment. JRB has therefore assigned a dust reduction efficiency of 80 percent to well-enclosed cabs on drill rigs, which is the average of the two efficiencies listed above. Since heavyweight, crawler-mounted drill rigs and self-propelled, self-contained drill rigs are generally designed with operator cabs, this control option is only applicable to light- and medium-weight truck-mounted drills and crawler-mounted drills that are not already equipped with control cabs (Given 1973). The maximum dust reduction efficiency of a control cab can only be achieved if the operator stays inside the cab for the duration of the drilling operation. If the operator must be located in the proximity of the drill steel and hole, an operator control cab cannot be used; wetting methods or charged fogging are the available dust control options in these situations.

Dust control is most needed at work sites where small drills are used or where workers are located in the vicinity of large drilling operations. For small drills, SEV with a 95 percent expected dust reduction efficiency provides the best result.

5.3.2 Feasibility Assessment of Silica PEL's

The 95 percentile silica exposure data are listed in Table 5-3. Exposure data were not available for the lead and zinc and asbestos industries. For each industry group, the reduction efficiencies required to reduce exposures

Table 5-3. 95 Percentile silica exposure data and percent reductions required to meet the silica PEL's in surface drilling operations.

Industry group	95 Percentile exposure ₃ level (mg/m ³)	Percent reduction required to meet the Q ₃ 0.05 mg/m ³ PEL	Percent reduction required to meet the Q ₃ 0.075 mg/m ³ PEL	Percent of data points equal to or less than the Q ₃ 0.05 mg/m ³ PEL
Copper	0.27	81	72	67
Gold and silver	0.5	90	85	52
Iron	0.10	50	25	84
Lead and zinc	--	--	--	--
Molybdenum	0.06	17	None	93
Uranium	0.14	64	46	80
Other metals	0.8	94	91	57
Limestone	0.09	45	17	87
Other stone	0.39	87	81	58
Clay and shale	0.15	67	50	66
Asbestos	--	--	--	--
Talc	0.07	29	None	89
Oil shale	0.04	None	None	99
Other nonmetals	0.09	45	17	83
Sand and gravel	0.10	50	25	83

Source: JRB calculations based on MSHA data.

A double dash indicates that no exposure data were available.

to the 0.05 and 0.075 mg/m³ PEL's and the percentage of data points lower than the 0.05 mg/m³ PEL are also given. From this table, it can be seen that the gold and silver and other metals categories have the highest 95 percent cumulative silica exposure levels among the industry groups. These groups require implementation of the most effective controls to meet the 0.05 mg/m³ PEL. Exposure levels in the oil shale industry group are already below the 0.05 mg/m³ PEL.

With an expected dust reduction efficiency of 30 percent, achievable using water sprays, the 0.05 mg/m³ silica PEL is feasible for the molybdenum and talc industry groups. (Use of wet drilling can reduce dust levels by 98 percent.) The 0.05 mg/m³ silica PEL is feasible for all industry groups except the other metals industry if wet drilling is used instead of dry drilling. For the other metals industry, the 0.05 mg/m³ is marginally feasible if wet drilling is used.

From site visit information, it was determined that only dry drilling is used at most granite quarries (Site Visit Report No. 4). Therefore, the 0.05 mg/m³ silica PEL would be feasible if SEV were used during the drilling operation. At one dimension stone quarry in Georgia, silica dust exposure for the drill workers ranged from 0.02 to 0.27 mg/m³ (MSHA exposure data). If SEV with a 95 percent reduction efficiency were used with the drills in this case, the high dust exposure would be reduced to 0.014 mg/m³.

5.3.3 Feasibility Assessment of Asbestos PEL's

MSHA data on mineral fiber exposures for surface drilling operations are available for six industries: limestone, talc, iron, other stone, asbestos, and other nonmetals. The 95 percentile exposure level and the percent reductions required to meet the PEL's in these industries are shown in Table 5-4. The exposure level in the iron industry group is currently below the 0.1 fibers/cc PEL. The 95 percentile fiber exposure in the limestone industry is at the 0.1 fibers/cc PEL, and this industry therefore also meets the higher fiber PEL's.

Since a dust reduction efficiency of 95 percent is expected from the use of SEV on small drills, the asbestos PEL of 0.1 fibers/cc is marginally feasible in the other stone, talc, and other nonmetals industries and is feasible for the asbestos group. The two higher PEL's are also feasible in the talc, other stone, and asbestos industries since no more than a 75 percent reduction efficiency is required to achieve them. For this feasibility analysis, only one sample was available for the iron industry and three samples each for the other stone and asbestos industries.

5.4 UNDERGROUND DRILLING

5.4.1 Dust Sources and Control Methods

The greatest amount of dust produced in underground drilling operations is caused by the impact or abrasion of rock by drill bits. Underground drilling, including collaring, is usually done wet, with cuttings removed by water flushing. Dust can be formed and dispersed when insufficient water is

Table 5-4. 95 Percentile mineral fiber exposure data and percent reductions required to meet the asbestos PEL's in surface drilling operations.

Industry group	95 Percentile fiber exposure (fibers/cc)	Percent reduction required to meet the 1.0 fibers/cc PEL	Percent reduction required to meet the 0.5 fibers/cc PEL	Percent reduction required to meet the 0.1 fibers/cc PEL
Iron	0.01	None	None	None
Limestone	0.1	None	None	None
Talc	1.7	41	71	94
Other stone	1.6	37	69	94
Asbestos	1.0	None	50	90
Other nonmetals	2.0	50	75	95

Source: JRB calculations based on MSHA data.

used during the drilling operation. Air leaks into the flushing water stream of pneumatic drill systems can cause bubbles that reduce dust suppression efficiency.

For most underground blasting and roof bolting operations, small drill holes, generally less than 3 inches in diameter, are drilled. These small-diameter holes are usually drilled with percussion drills, which may be either handheld or jumbo mounted. The job codes for this operation category are rock bolting, percussive drilling, rotary drilling, diamond drilling, and jet piercing.

Figure 5-3 illustrates the dust control options and various combinations that can be used to control dust in underground drilling operations. The control system options are similar to those applicable to surface drilling operations.

Reducing the drill speed and drilling fewer but larger holes are dust formation controls. A recent development in mining techniques involves drilling large holes (6-8 inches in diameter) for blasting purposes. Use of this technique requires major changes in blasting patterns and procedures. Since no data were available on the effectiveness of this method, JRB has not

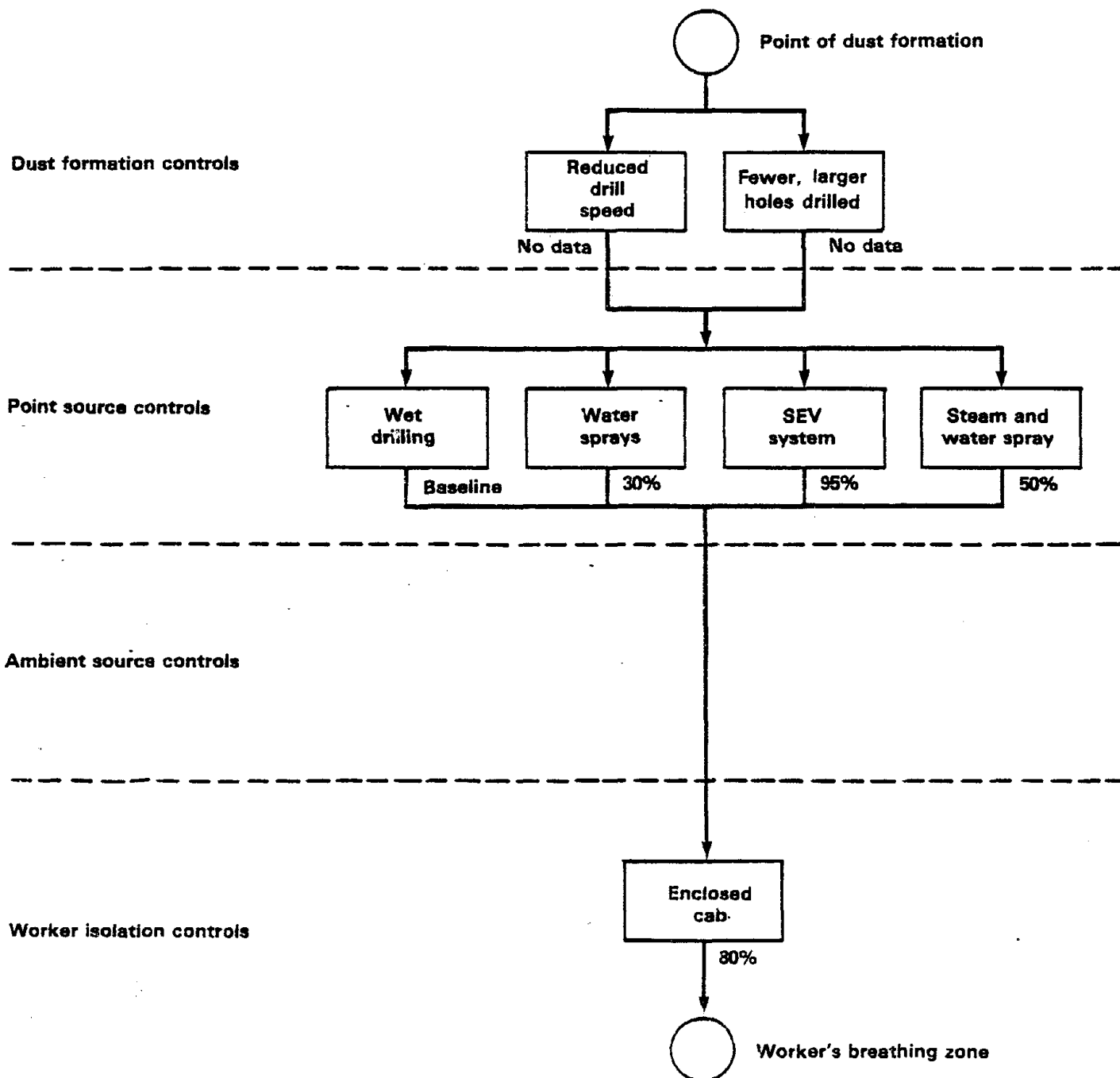


Figure 5-3. Flow diagram of dust control options and applicable reduction efficiencies for underground drilling.

assigned a dust reduction efficiency to drilling fewer holes. Rotary drill speed can be reduced to decrease dust levels. Currently, pneumatic or hydraulic percussion drills are generally used in underground operations. Reducing drill speed is not considered in the feasibility assessment since no data were available to assess this control.

Water sprays can be used as a point source control on drilling machines; as discussed in Chapter 4, a 30 percent dust reduction efficiency can be achieved with this method. A 95 percent dust reduction can be achieved with SEV designed for drill rigs, as discussed in the section on surface drilling (Section 5.3); however, this efficiency is applicable only if the drilling is done dry. Water used in wet drilling may clog up the ductwork associated with a SEV system. Although all drilling machines can be equipped with SEV, it is difficult to use SEV on the small drills commonly used for roof bolting or face drilling. The use of steam to suppress dust will achieve a 50 percent dust reduction efficiency when used in combination with water sprays, as mentioned in Chapter 4.

Completely enclosed cabs are effective for controlling the operator's dust exposure, although workers located in the drilling area will not be protected by this control. As discussed in Section 5.3, Surface Drilling, an 80 percent dust reduction efficiency can be achieved with an air-filtered enclosed cab. However, because of the confined conditions underground, only heavy-duty drills designed for large-scale construction projects, such as tunnel excavation and room-and-pillar mining, are equipped with enclosed cabs. Since the use of enclosed cabs applies only to a small segment of the mining industry, this control will not be considered in the feasibility assessment.

5.4.2 Feasibility Assessment of Silica PEL's

Table 5-5 lists the 95 percentile silica exposure data for underground drilling operations. There were no data for the asbestos, talc, and sand and gravel industries. The percentage of samples lower than the 0.05 mg/m^3 silica PEL and the reduction efficiencies required to reduce exposures to this PEL are also given. Levels in the other metals industry group are already below the 0.05 mg/m^3 PEL. The clay and shale industry has the highest 95 percentile silica dust level. The 95 percent exposure concentration for iron and the other nonmetals groups are near 0.075 mg/m^3 and would therefore require only a limited amount of additional dust control to achieve the 0.05 mg/m^3 PEL.

As discussed in the previous section, a dust reduction efficiency of 95 percent can be attained with the use of SEV, but this dust control method is only practical for dry drilling operations. Therefore, in industries where wet drilling is the method typically used, SEV cannot be considered as an applicable control method. In the other nonmetals industry group where wet drilling is not commonly used, SEV on dry drilling equipment can be used to control dust exposure. With this method, the 0.05 mg/m^3 PEL is feasible in the other nonmetals industry since the dust reduction efficiency required to achieve this PEL is only 38 percent. In the iron industry group, the use of a steam and water spray combination, with an expected dust reduction of 50 percent, would provide sufficient dust reduction to lower the dust concentrations to levels below the 0.05 mg/m^3 PEL. Using the same method, the gold and silver and oil shale industry groups could only meet the 0.075 mg/m^3 PEL. For

Table 5-5. 95 Percentile silica exposure data and percent reductions required to meet the silica PEL's in underground drilling operations.

Industry group	95 Percentile exposure ₃ level (mg/m ³)	Percent reduction required to meet the 0.05 mg/m ³ PEL	Percent reduction required to meet the 0.075 mg/m ³ PEL	Percent of data points equal to or less than 0.05 mg/m ³ PEL
Copper	0.25	80	70	67
Gold and silver	0.11	55	32	79
Iron	0.09	45	17	84
Lead and zinc	0.18	73	58	77
Molybdenum	0.22	78	66	64
Uranium	0.15	67	50	71
Other metals	0.03	None	None	99
Limestone	0.17	71	56	73
Other stone	0.20	75	62	66
Clay and shale	0.32	85	77	48
Asbestos	--	--	--	--
Talc	--	--	--	--
Oil shale	0.13	62	42	81
Other nonmetals	0.08	38	6	89
Sand and gravel	--	--	--	--

Source: JRB calculations based on MSHA data.

A double dash indicates that no exposure data were available.

the uranium industry, the 0.05 mg/m^3 PEL is infeasible and the 0.075 mg/m^3 would be marginally feasible if steam and water spray were used. However, no single control or combination of controls is available to reduce the levels to or below the 0.05 mg/m^3 PEL for these industries.

Both silica PEL's are judged to be infeasible for underground drilling operations in the copper, lead and zinc, molybdenum, limestone, other stone, and clay and shale industry groups, where the use of steam and water spray is the most effective dust control system available.

Since the highest expected dust reduction efficiency available for most industry sectors is 50 percent (with the use of steam and water spray) and allowing for a 5 percent margin of error, the maximum exposure level that can be reduced to the 0.05 mg/m^3 PEL is 0.09 mg/m^3 . For the copper industry, 11 exposure samples that were higher than this level were all from one site; in all, 8 sites were sampled between 1977 and 1981 for a total of 56 samples. In the lead and zinc industry, 3 of the 14 sites sampled had 5 samples that were above the 0.09 mg/m^3 level, out of a total of 38 samples in this group. For the molybdenum industry, results of 35 samples taken from underground drilling on two sites were available. Both sites had 7 samples above the exposure level of 0.09 mg/m^3 . In the uranium industry, 6 of the 26 sites sampled had 8 samples that were above the 0.09 mg/m^3 exposure level. A total of 76 samples were included for underground drilling operations in this industry.

In the limestone industry, results of 116 samples from 50 sites were available for the feasibility analysis. Of these, 10 sites had 18 samples that were above the 0.09 mg/m^3 exposure level that can be reduced to the 0.05 mg/m^3 PEL with the steam and water spray method. For the other stone industry, two of the six sampled sites had three samples with concentrations above the 0.09 mg/m^3 exposure level. There were 17 samples available for underground drilling operations in this industry. In the clay and shale industry, results of 56 samples from 7 sites were available for analysis. Samples from all 7 sites had concentrations higher than the 0.09 mg/m^3 exposure level, but more than half of the 21 samples that were in this higher range were from one site.

5.4.3 Feasibility Assessment of Asbestos PEL's

Mineral fiber exposure data are available for the limestone; talc; gold and silver; other stone; asbestos; and other nonmetals industries. The 95 percentile exposure fiber counts and the reductions required to meet any of the three PEL's for these industries are shown in Table 5-6. For the other stone industry, the 95 percentile concentration already meets the lowest PEL. The 95 percentile concentrations for the limestone and talc industry sectors are above the highest PEL. With the highest expected dust reduction efficiency of 50 percent achievable with steam and water spray, only the highest PEL, 1.0 fibers/cc, is feasible for these two industries. Achieving the lower PEL's is not feasible, except that the 0.5 fibers/cc PEL is marginally feasible in the talc industry. In the asbestos and gold and silver industries, the 95 percentile exposure level already meets the 0.5 and 1.0 fibers/cc PEL's. The 50 percent reduction achievable should make the 0.1 fibers/cc PEL marginally feasible in the asbestos industry group but that PEL is still

Table 5-6. 95 Percentile mineral fiber exposure data and percent reductions required to meet the asbestos PEL's in underground drilling operations.

Industry group	95 Percentile fiber exposure (fibers/cc)	Percent reduction required to meet the 1.0 fibers/cc PEL	Percent reduction required to meet the 0.5 fibers/cc PEL	Percent reduction required to meet the 0.1 fibers/cc PEL
Limestone	1.2	17	59	92
Talc	1.1	9	50	90
Gold and silver	0.4	None	None	75
Other stone	0.1	None	None	None
Asbestos	0.2	None	None	50
Other nonmetals	0.6	None	17	74

Source: JRB calculations based on MSHA data.

infeasible in the gold and silver industry. For the other nonmetals industry, where the 95 percentile exposure level already meets the 1.0 fibers/cc PEL, the expected dust reduction achievable through the use of steam and water spray will make the 0.5 fibers/cc feasible; however, the 0.1 fibers/cc PEL is infeasible for this industry.

The feasibility analysis for the asbestos PEL's in underground drilling operations is based on limited exposure data. Only one sample was available in each of the gold and silver, limestone, other stone, and asbestos industry groups. There were four samples in the talc industry and eight samples in the other nonmetals industry for underground drilling operations.

5.5 BLASTING

5.5.1 Dust Sources and Control Methods

Blasting is done to fracture hard, consolidated material so that it can be removed more easily by excavating equipment. Blasting is difficult to sample for dust exposure because the operation is of short duration and any sampling equipment placed near the blast may be damaged.

In surface operations, blasting is rarely done more than once a day (Jutze et al. 1976). For safety reasons and to minimize disruption of other mining activities, blasting is usually conducted between work shifts. The area to be blasted must be cleared of equipment and workers while the holes are being charged and wired for detonation, so drilling and blasting are generally as isolated from other active mining operations as possible.

In underground blasting operations, the frequency and time of shots will depend on the mining method used. For example, block caving requires that finger raise hangups be shot periodically to allow the ore to run. Since the ore from the raises is slushed during the shift, the raises must be shot when workers are present. In mines using sublevel stoping, the full width and height of the stope is shot for stope development; because of the large amount of explosives used, the shot is detonated when workers are not present underground.

Applicable dust control methods for blasting operations are shown in Figure 5-4. Dust formation during blasting can be reduced by using the proper amount of explosives, which will also reduce the amount of smoke and fumes, fragmentation, and the spread of fragmented rocks (DuPont 1969). Because of the wide variety of blasting techniques and types of explosives used in mining operations and the difficulty in determining where and to what extent improvements in blasting techniques might reduce dust levels, JRB has not assigned a reduction efficiency to this option.

Wet stemming can be used as a point source control during detonation. Gerhardsson and coworkers (1977) reported that when water-filled plastic bags or water cartridges were used to stem blast holes, dust concentrations were reduced by 30-50 percent. The dust reduction efficiency of this method will vary with the type of hole drilled and the explosive used. Therefore, the lowest efficiency reported (30 percent) is assigned for wet stemming.

5.5.2 Feasibility Assessment of Silica PEL's

Table 5-7 lists the 95 percentile exposure data for surface and underground blasting operations in the industries sampled. No data were available for five industry groups: uranium, talc, oil shale, asbestos, and sand and gravel. Industry groups with exposures above the 0.05 mg/m³ PEL are copper, iron, molybdenum, limestone, and clay and shale. The gold and silver, lead and zinc, other metals, other stone, and other nonmetals industry groups had exposure levels at or below the 0.05 mg/m³ PEL.

The exposure profiles for blasting operations (from which Table 5-7 was generated) contain data from both surface and underground blasting operations. However, there were very little exposure data for surface blasting operations. In the industries where exposure data for surface blasting were available, the highest silica concentration was 0.09 mg/m³ in the copper industry, 0.06 mg/m³ in the iron industry, 0.02 mg/m³ in the limestone industry, and 0.07 mg/m³ in the other stone industry. Based on these data, a reduction efficiency of no more than 44 percent is required to meet the 0.05 mg/m³ silica PEL for surface blasting operations.

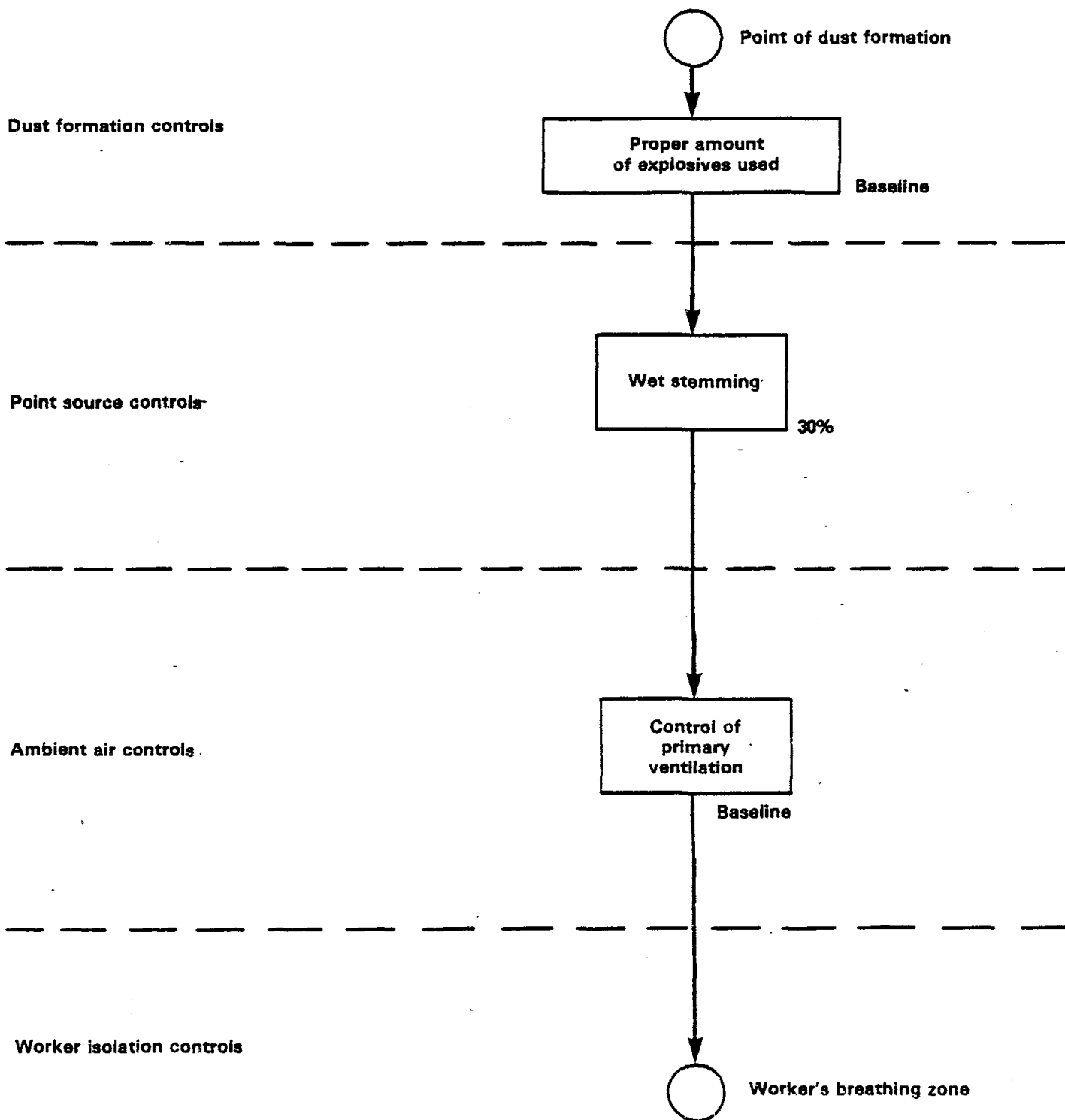


Figure 5-4. Flow diagram of dust control options and applicable reduction efficiencies for blasting.

Table 5-7. 95 Percentile silica exposure data and percent reductions required to meet the silica PEL's in blasting operations.

Industry group	95 Percentile exposure ₃ level (mg/m ³)	Percent reduction required to meet the 0.05 mg/m ³ PEL	Percent reduction required to meet the 0.075 mg/m ³ PEL	Percent of data points equal to or less than 0.05 mg/m ³ PEL
Copper	1.2	96	94	57
Gold and silver	0.05	None	None	100
Iron	0.08	37	6	81
Lead and zinc	0.01	None	None	100
Molybdenum	0.195	74	62	52
Uranium	--	--	--	--
Other metals	0.03	None	None	100
Limestone	0.165	70	55	74
Other stone	0.04	None	None	99
Clay and shale	0.07	29	None	85
Asbestos	--	--	--	--
Talc	--	--	--	--
Oil shale	--	--	--	--
Other nonmetals	0.01	None	None	100
Sand and gravel	--	--	--	--

Source: JRB calculations based on MSHA data.

A double dash indicates that no exposure data were available.

MSHA mine inspectors collected personal respirable dust samples for workers involved in setting up blasting operations. The activities involved in preparing a blast site include drilling blast holes, transporting the explosives to the site, loading holes with explosives, wiring in the round, and detonating the charge. The dust exposures of personnel involved in this operation result primarily from other dust sources unrelated to the blast itself. Therefore, dust controls applied at the blasting site to control dust during blasting will not significantly reduce the exposures of these personnel; they will only reduce the amount of dust released into the mine environment. Because the exact extent to which various dust sources contribute to a blaster's exposure cannot be estimated, the feasibility of attaining the PEL's cannot be analyzed directly from the dust control techniques used to control dust during the blast. However, if drilling operations are the most significant source of a blaster's dust exposure, the maximum exposure reduction that is achievable for the blasting operation cannot exceed the maximum attainable by using controls applicable in the drilling operation (discussed in Section 5.3, Surface Drilling, and Section 5.4, Underground Drilling). The exposure data included in the blasting operation category were collected primarily in underground locations, where the highest exposures were found. For underground drilling operations, a maximum exposure reduction of 50 percent is achievable as discussed in Section 5.4. Assuming that the underground drilling operation is a major dust source for an underground blaster, the 0.05 mg/m³ PEL is feasible only in the iron and clay and shale industries, based on an exposure reduction of 50 percent. For other industries, including copper, molybdenum, and limestone, where the 95 percentile concentration was higher than 0.05 mg/m³, both the 0.05 and 0.075 mg/m³ PEL's are infeasible.

5.5.3 Feasibility Assessment of Asbestos PEL's

Mineral fiber exposure data were not available for blasting operations. The feasibility of achieving the asbestos PEL's in this operation category is therefore not assessed.

5.6 CUTTING AND BORING

5.6.1 Dust Sources and Control Methods

As an alternative to the conventional mining method of drilling, blasting, and ore removing, special machines can be used to cut, bore, shear, or gouge the ore or material from the face being worked. Operations that use these machines are included in the cutting and boring operation category. Four types of machines are used: continuous mining machines for headings in room-and-pillar sections (continuous miners), continuous mining machines for headings in longwall sections (longwall shearers, longwall plows, or longwalls), auger and roadheader machines, and cutting machines. These machines were originally developed for coal mining, and their use in other applications is limited to soft-seam noncoal ores, such as uranium, talc, trona, and potash of the other nonmetals industry, and clay and shale. However, recent developments in roadheaders have expanded their application to copper, lead, and zinc mines (manufacturer's data, DOSCO Corporation, received December 1981).

No MSHA job codes are specifically related to cutting and boring operations using the four types of machine used in metal and nonmetal mines. However, one job category, rock sawing, or cutting rocks at the quarry face, is included in this operation category. Rock sawing is performed only in the dimension stone sector of the limestone and other stone industry groups; it is done wet with wire saws, and generally a slurry of hard sand or silica carbide in water is used. Since a wet process is used, very few options are available for reducing dust exposure in rock sawing operations. Additional water spray is not expected to result in any appreciable reduction for these operations. A different quarrying method, such as jet piercing or a splitting technique, may generate less dust, but no data on dust emissions generated by these techniques were available.

In cutting and boring operations other than rock sawing, dust is formed when the machine's cutting head makes contact with the material to be excavated. This dust is dispersed in the high air currents that are typical of face ventilation. Falling of the mined ore to the floor also creates airborne dust. Then, transfer and conveying of ore release more dust into the air. Studies involving continuous miners (Courtney et al. 1978; Black et al. 1978) and roadheaders (Burnett et al. 1981) have shown that the cutting step accounts for 60-70 percent of the total dust exposure, and shearing and loading account for the remainder. Based on these studies, 70 percent of the dust in cutting and boring operations will be assumed to be derived from the cutting actions and is the only part of an operator's exposure that can be controlled at the face.

The dust control options and various combinations that can be used for cutting and boring operations other than rock sawing are illustrated in Figure 5-5. Dust control methods chosen will depend on the type of machine used in the cutting and boring operation. Applicable control methods are discussed with each machine type.

Continuous Miners--

Controlling dust dispersed at the cutting face by a continuous miner can be achieved by applicable methods from several lines of controls. Dust formation can be reduced by controlling cut depth and drum speed; increasing the typical 1-inch cutting depth to 2 inches and slowing the drum rotating speed from 51 to 18 rpm decreases the dust level at the operator's station of a continuous mining machine by 77 percent (Black et al. 1978).

Water sprays can be used at the face during continuous mining operations, but since this technology is part of the baseline level of control, sprays are not considered an option in this application. Applying foam at the face can reduce respirable dust by 50 percent (Chapter 4); substituting foam for water will achieve an additional 20 percent dust reduction efficiency, since the baseline control of water sprays has been estimated at 30 percent.

Machine-mounted SEV can be used in continuous mining operations. Dust cloud capture efficiencies of 80 percent and higher can be achieved when machine-mounted SEV is used in room-and-pillar development, where the dust

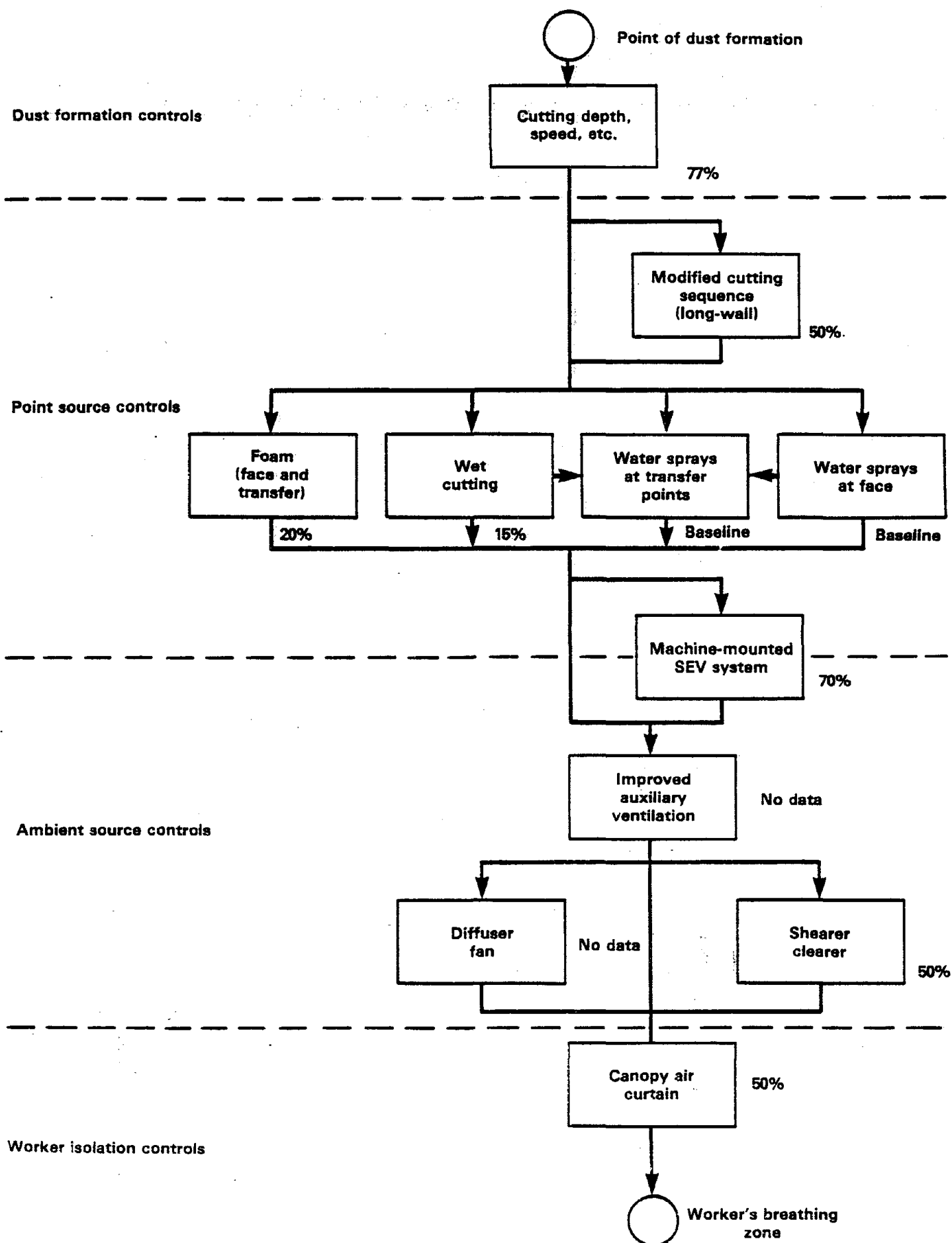


Figure 5-5. Flow diagram of dust control options and applicable reduction efficiencies for cutting and boring operations.

cloud is contained close to the face (Bureau of Mines 1977a). The dust collection efficiency of the SEV system is reported to range from 87 to 100 percent (Bureau of Mines 1977a). Therefore, the overall respirable dust reduction efficiency based on the lowest collection efficiency of 87 percent and a dust cloud capture efficiency of 80 percent is 70 percent (87 percent multiplied by 80 percent).

Auxiliary ventilation can also be used in continuous mining operations. The line brattice method is the most commonly used face ventilation method in continuous mining, and is considered a baseline control. Continuous mining machines may be equipped with blowing auxiliary fans (diffuser fans) that blow fresh air over the mining machines toward the face and exhaust into the return airway. As discussed in Chapter 4, this method is not assigned any reduction efficiency because of lack of performance data. At the operator's station on the machine, a 50 percent dust reduction can be attained with the use of a canopy air curtain, as discussed in Chapter 4.

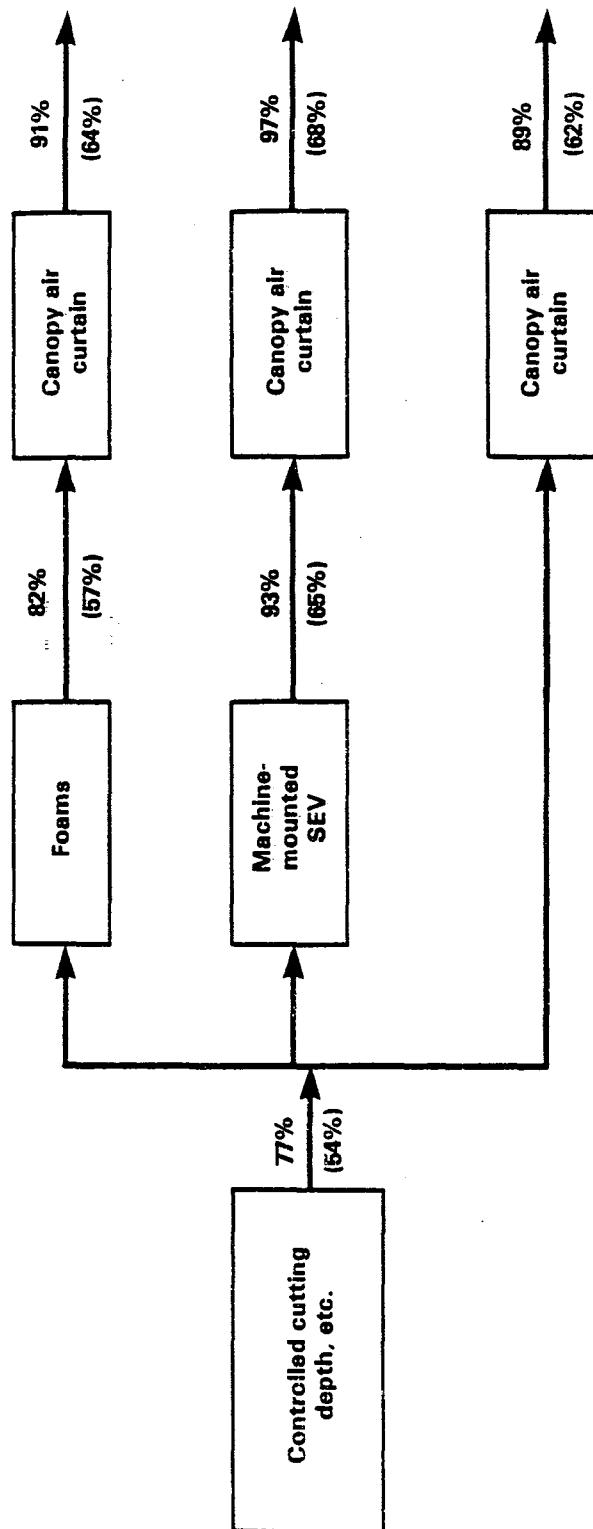
Several combinations of applicable control methods can be formulated for continuous mining operations. Examples are shown in Figure 5-6, with their expected combined dust reduction efficiencies. Since the cutting part of the process is assumed to contribute only 70 percent of the operator's overall exposure, the reduction efficiencies attributable to this part of the process are shown in parentheses in the figure, and range from 62 to 68 percent.

Dust control at ore transfer points in room-and-pillar continuous mining operations can be achieved with water sprays. This wetting method is used at the present time, was observed during a site visit conducted for this project (Site Visit Report No. 6), and is therefore considered as a baseline control.

Longwall Miners--

As in the case of continuous miners, dust in longwall mining operations can be reduced at various lines of control. Dust formation can be reduced by modifying the cutting sequence on a longwall shearer to a unidirectional sequence so that the operator can stay upwind from the head shear for most of the time; however, no data have been found on the dust reduction efficiency of this work practice. Therefore, no dust reduction efficiency is assigned for this method.

A recently developed technology, called a shearer clearer, combines auxiliary ventilation and water sprays to improve dust removal at longwall mining operations. The method uses a system of barriers and optimally directed water sprays to divide airflow around the machine into a clean and a contaminated split. Laboratory tests have indicated a dust reduction efficiency of 97 percent for the shearer clearer technique (Kissell et al. 1981). Derating this efficiency by one-fifth to adjust for field conditions, the same difference in performance efficiency reported for field and laboratory results of studies of the canopy air curtain (Bureau of Mines 1977a), and subtracting for the water spray efficiency (considered baseline) of 30 percent yields an expected efficiency of 50 percent for shearer clearers used in longwall mining operations.



Note: Percentage in parentheses denotes corresponding reduction efficiency for overall exposure of the operator.

Figure 5-6. Applicable combinations of dust control options and applicable reduction efficiencies for continuous miners at the cutting face.

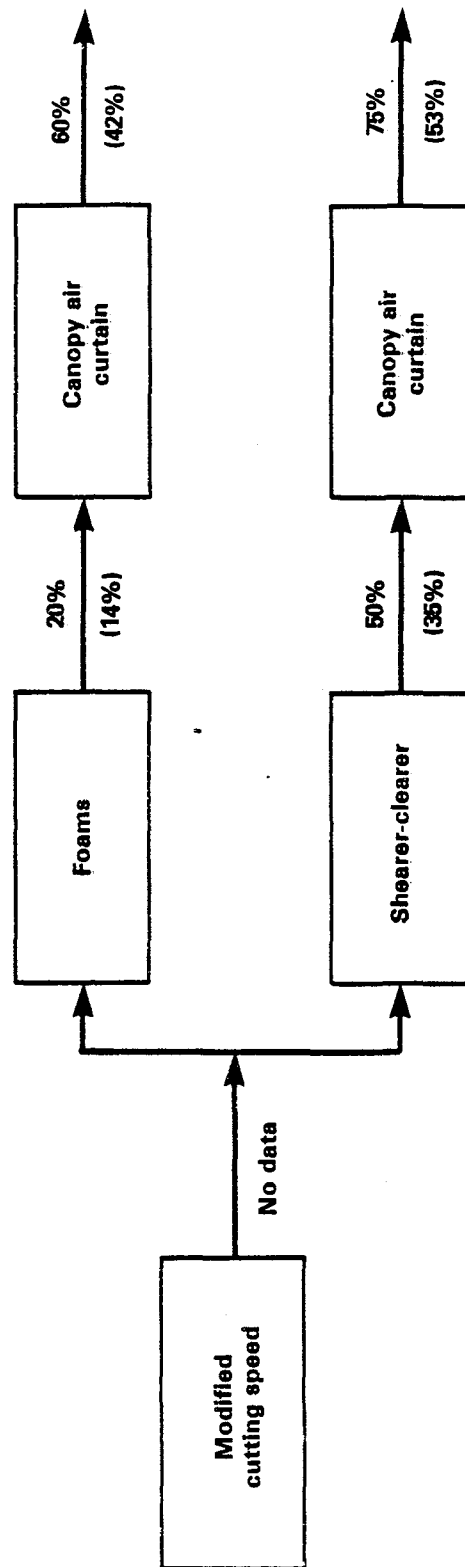
Other methods that can be applied to these operations include foams, canopy air curtains, and dust controls at ore transfer and conveying points. The effectiveness of these controls was discussed in the previous section on continuous miners. As shown in Figure 5-7, combining the applicable dust control methods for longwall continuous miners can be expected to produce a respirable dust reduction of 42 or 53 percent.

Augers and Roadheaders--

The direct formation of dust during an auger or roadheader operation can be reduced by the use of the wet-head technique. This technique, which differs from an externally applied water spray, involves use of a water spray system that feeds water to nozzles located at the base of the auger flight. The spray wets the ore as it is being broken, and most of the respirable dust thus adheres to large fragments rather than becoming airborne. Although wet-head techniques can also be used on continuous miners and longwalls, studies have shown that wet-head sprays are more efficient when used with augers and roadheaders (Strebig in Bureau of Mines 1977a; Burnett et al. 1981). Respirable dust reduction efficiencies of between 46 and 60 percent over those achieved with water sprays alone have been reported when this technique is used on augers (National Academy of Sciences 1980). JRB has therefore assigned a reduction efficiency of 45 percent to the wet-head technique. Since water sprays, which have an expected reduction of 30 percent, are routinely applied to the cutting face in auger operations, the wet-head technique would provide only a 15 percent additional reduction. Auxiliary ventilation can be used to reduce the auger operator's exposure, but this method has not been assigned any reduction efficiency, as discussed in Chapter 4. Machine-mounted SEV systems and canopy air curtains (discussed in the Continuous Miners section) are other methods that can be applied to augers and roadheaders. From these available methods, combining the wet-head and canopy air curtain would provide a 63 percent reduction and combining the wet-head, machine-mounted SEV, and canopy air curtain would reduce dust exposure by 88 percent. Since only 70 percent of the dust at the cutting face is generated by the cutting action (as discussed earlier in this section), the actual reduction in exposure would be 44 and 62 percent, respectively, for these two dust control systems.

Cutting Machines--

The wet bar method is the most commonly used technique for controlling dust at a cutting machine. With this technique, water is sprayed onto the cutting bar and chain, wetting the kerf as it is being cut. A wide range of dust reduction efficiencies, from 0 to 66 percent, have been reported for total dust in coal mines with this technique (Page et al. 1981). Results presented in this report of wet bar method comparison tests conducted in salt mines found an average reduction efficiency of 54 percent, using one-tenth the amount of water required in the coal mine tests. Since water sprays are baseline technology, no additional dust removal efficiency will be assigned to the use of this technique. However, as described in the continuous mining section, the use of foams can be expected to provide an additional 20 percent reduction in respirable dust over that contributed by water sprays alone. Canopy air



Note: Percentage in parentheses denotes corresponding reduction efficiency for overall exposure of the operator.

Figure 5-7. Applicable combinations of dust control options and applicable reduction efficiencies for long-wall continuous miners at the cutting face.

curtains have an expected dust reduction efficiency of 50 percent. Using a combination of foam and a canopy air curtain will provide a reduction of 60 percent. Using a combination of foam, machine-mounted SEV, and a canopy air curtain will provide an expected reduction of 88 percent. When adjusted to account for the only portion of dust that is controllable by these methods, the reduction efficiencies become 42 and 62 percent, respectively.

5.6.2 Feasibility Assessment of Silica PEL's

The only exposure data available in cutting and boring operations were those related to rock sawing operations in the limestone and other stone industries. The 95 percentile concentration₃ and the required percent reductions to meet the 0.05 mg/m³ and 0.075 mg/m³ PEL's are shown in Table 5-8. As

Table 5-8. 95 Percentile silica exposure data and percent reductions required to meet the silica PEL's in cutting and boring (rock sawing) operations.

Industry group	95 Percentile exposure ₃ level (mg/m ³)	Percent reduction required to meet the 0.05 mg/m ³ PEL	Percent reduction required to meet the 0.075 mg/m ³ PEL	Percent of data points equal to or less than 0.05 mg/m ³ PEL
Limestone	0.075	33	None	90
Other stone	0.1	50	25	81

Source: JRB calculations based on MSHA data.

discussed in Section 5.6.1, no control method with known performance data is available to control dust exposures in this operation, and therefore the 0.05 mg/m³ PEL is not feasible in either industry. The 95 percentile concentration in the limestone industry group is currently at the 0.075 mg/m³.

5.6.3 Feasibility Assessment of Asbestos PEL's

No mineral fiber exposure data are available for cutting and boring operations; the feasibility of achieving the asbestos PEL's in this operation category is therefore not assessed.

5.7 SURFACE PRODUCTION

5.7.1 Dust Sources and Control Methods

Overburden removal in almost all surface mining production operations entails removal of all topsoil, subsoil, and other material overlying the deposit to be mined. The MSHA job codes included in this operation category are machine mucking, hand mucking, mining machine operation, slurring, and dredging at surface locations. Three kinds of equipment are used to excavate overburden in typical surface mining operations:

- Draglines
- Shovels
- Small mobile tractors, including bulldozers, scrapers, and front-end loaders.

At most large surface mines, the bulk of the materials transported from the mine to a crusher or a waste dump is conveyed by truck. Truck dumping involves dumping the mined materials from the truck into a crusher. Conveyor haulage is also used at some open pit mines.

Two primary fugitive dust sources are associated with overburden removal:

- Dumping of dragline buckets or shovels full of overburden material into adjacent trenches or spoil banks
- Operation of scrapers and bulldozers during topsoil and subsoil removal and transfer.

In most surface mines, the ore or material being mined is loaded onto trucks or trains for transport from the point where it is removed to a central transfer location or processing area at the mine site. Any of the excavation equipment described for overburden removal can be used to scoop material and load it onto trains or trucks; however, crawler-mounted shovels are most often used for this purpose. Small front-end loaders may be assigned to an active mining area to remove spilled material that could cause damage to truck tires and to move materials that cannot be easily reached by less maneuverable shovels. In the loading operation, the main source of dust is the excavating of loose material by the shovel or front-end loader.

Dust control methods that are applicable to surface production are shown in Figure 5-8, along with the expected dust reduction efficiencies assigned to each method (see Chapter 4). According to MSHA (personal communication, MSHA inspectors, 1983), most surface facilities do not use wetting methods on muck-piles. Of the four surface mines visited by JRB, three (Sites 4, 5, and 8) reported that no wetting methods were used during the loading of ore; therefore, wetting ore and rock with water should reduce airborne dust levels by the assigned value of 30 percent (see Chapter 4). In situations where

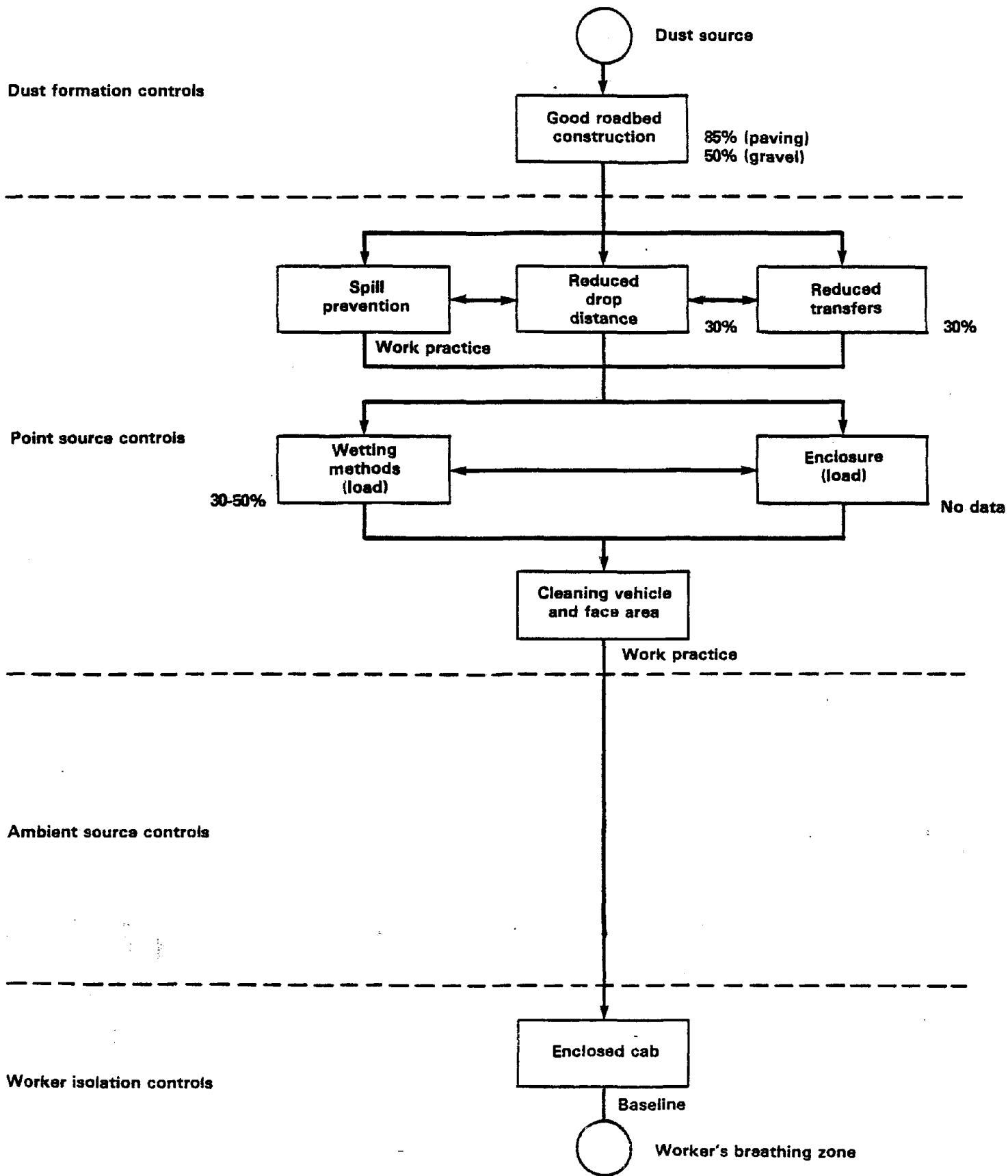


Figure 5-8. Flow diagram of dust control options and applicable reduction efficiencies for surface production.

freezing conditions exist, brine may be added to water to prevent freezing (personal communication, MSHA inspectors, 1983). Foams may also be used to improve the wetting action of water. JRB estimates that foams can reduce dust levels by 50 percent (see Chapter 4), or 20 percent more than using water alone.

At each of the four surface facilities visited, JRB observed that drop distances could be reduced or that the number of transfer points could be limited. Each of these process modifications could be used to reduce dust exposure by an estimated 30 percent (see Chapter 4).

Figure 5-9 shows several dust control systems applicable to this operation category and the dust reduction efficiencies of the applicable combined control methods. This figure shows that applying combinations of two dust control methods can result in dust reductions of between 51 and 65 percent.

5.7.2 Feasibility Assessment of Silica PEL's

Table 5-9 shows the 95 percentile exposure level associated with surface production for eight industry sectors, the percent dust reduction required to meet the PEL's, and the percentage of exposure data points that are currently at or below the 0.05 mg/m^3 PEL. Exposure data were not available for the following industry sectors: gold and silver, lead and zinc, molybdenum, uranium, asbestos, talc, and oil shale. These data show that the other nonmetals industry group requires the highest degree of dust reduction (88 and 81 percent for each PEL) compared with all other industry groups (Table 5-9). Three industry sectors (copper, iron, and other metals) do not require additional dust control to meet the 0.05 mg/m^3 PEL during surface production operations.

A comparison of the expected dust reduction efficiencies of combinations of methods shown in Figure 5-9 with the reductions in dust levels required for each industry sector (Table 5-9) reveals that the 0.05 mg/m^3 PEL is infeasible for surface production operations in three industry sectors (other stone, clay and shale, and other nonmetals), and is marginally feasible for surface production operations in the sand and gravel industry sector. The PEL can be met during surface production in the limestone industry. Based on the same expected dust reduction efficiencies, the 0.075 mg/m^3 is feasible in the other stone and sand and gravel industries but is still infeasible in the clay and shale and other nonmetals industries.

As shown in Figure 5-9, the highest dust reduction achievable in surface production is 65 percent. Based on this, and including a 5 percent margin of error, the maximum silica dust concentration that can be reduced to meet the 0.05 mg/m^3 PEL is 0.13 mg/m^3 . For the other stone industry, where the 0.05 mg/m^3 PEL is judged to be infeasible, only two of the 29 available samples were above the exposure level of 0.13 mg/m^3 . These two samples were collected from two sites while the exposure data for this category were derived from samples collected at a total of 18 sites. For the clay and shale industry, 3 of a total of 12 samples from 9 sites were above the exposure level of 0.13 mg/m^3 . For the other nonmetals industry group, where the 0.05 mg/m^3 PEL is

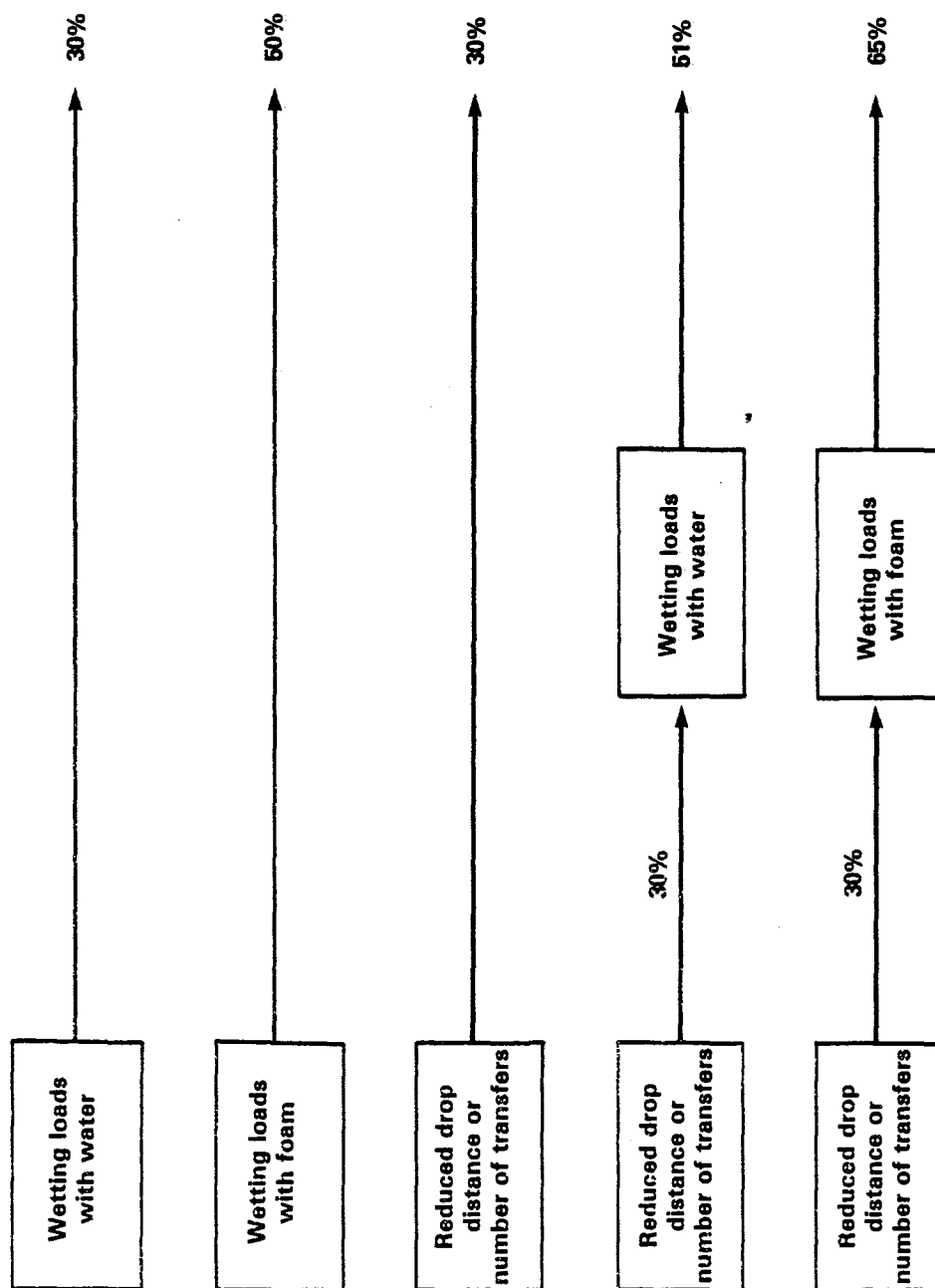


Figure 5-9. Applicable combinations of dust control options and applicable reduction efficiencies for surface production.

Table 5-9. 95 Percentile silica exposure data and percent reductions required to meet the silica PEL's in surface production operations.

Industry group	95 Percentile exposure ₃ level (mg/m ³)	Percent reduction required to meet the 0.05 mg/m ³ PEL	Percent reduction required to meet the 0.075 mg/m ³ PEL	Percent of data points equal to or less than 0.05 mg/m ³ PEL
Copper	0.003	None	None	95
Gold and silver	--	--	--	--
Iron	0.05	None	None	95
Lead and zinc	--	--	--	--
Molybdenum	--	--	--	--
Uranium	--	--	--	--
Other metals	0.005	None	None	95
Limestone	0.06	17	None	93
Other stone	0.17	71	56	74
Clay and shale	0.34	85	78	69
Asbestos	--	--	--	--
Talc	--	--	--	--
Oil shale	--	--	--	--
Other nonmetals	0.4	88	81	54
Sand and gravel	0.15	67	50	82

Source: JRB calculations based on MSHA data.

A double dash indicates that no exposure data were available.

also infeasible, only four samples derived from four sites were available. Two of the sites, a silica flour mill and a phosphate mine, each contributed one sample that was above the 0.13 mg/m³ level.

5.7.3 Feasibility Assessment of Asbestos PEL's

MSHA mineral fiber exposure data on this operation category were available only for the limestone industry. The data for surface production consisted of only one sample, which showed 1.2 fibers/cc. Based on this fiber count level, the percent dust reduction required for this industry to meet the 1.0, 0.5, or 0.1 fibers/cc PEL is 17, 58, or 92 percent, respectively. Using a reduced drop distance and applying foam on muckpiles, estimated to produce a reduction efficiency of 65 percent, the 0.5 fibers/cc PEL could be achieved during limestone surface production operations. The 0.1 fibers/cc PEL is infeasible in the limestone industry using any available control systems.

5.8 SURFACE MOBILE TRANSPORT

5.8.1 Dust Sources and Control Methods

This operation category includes workers who operate trucks or trains to move ore from the production face to the processing site, or waste rock to a disposal site. MSHA job codes relating to operators of electric load, haul and dump (LHD) machines; diesel LHD equipment; gasoline LHD equipment; compressed air LHD machines; track crews; and bulldozer operators at surface locations are included in this category. There may be several dumping and loading points along these routes. During ore and waste rock transport, dust can become entrained or dispersed from the load on the vehicles or from the roads on which the vehicles travel. Haul roads can also become sources of dust due to wind erosion. Dust is generated from truck or train dumping operations as the material falls from the bed and strikes the ground or side of the dump pocket. For mines using conveyor systems to transport ore to the mill, dust can be dispersed at transfer points and from dirty conveyor belts.

There are two major points of dust exposure during this operation: load/dump points and the haulage route itself. Dust emissions from each of these two sources must be controlled independently. As discussed in Section 5.7 (Surface Production), most surface facilities do not use wetting methods or process modifications to reduce dust emissions during loading; therefore, these methods may be used to control dust exposure at load/dump points. Dust generated from the haulageway can be reduced by applying binders or gravel on the haulageway, reducing vehicle speed, or paving haulageways or access roads. All four surface mines visited by JRB (Sites 4, 5, 7, and 8) used water to control dust emissions from the haulageway. According to MSHA (personal communication, MSHA inspectors, 1983), wetting roads with water is a common practice at the larger surface mines. However, only Site 5 reported using binders on main haulageways. JRB observed that the speed of haulage vehicles (particularly unloaded ones) at all four sites could be significantly reduced; at Site 5, vehicles travelled at speeds up to 40 miles per hour.

Dust exposure at load/dump points and along the haulageway can be reduced by the use of enclosed cabs on haulage vehicles. Since haulage vehicles are usually equipped with cabs, this method was considered for this analysis to be a baseline dust control. However, JRB observed on Sites 5 and 8 that cabs were often left open during vehicle operation. A significant reduction in dust exposure may be achieved through proper use and maintenance of haulage vehicle cabs.

Figure 5-10 shows dust control methods that are applicable to surface mobile transport operations, and the expected dust reduction efficiencies assigned for each method (see Chapter 4).

5.8.2 Feasibility Assessment of Silica PEL's

Since dust exposure can be controlled at two distinct points in this operation, the application of a dust control method at one point will not necessarily lower dust exposure at the other point. For example, using binders on the haulageway will not affect dust levels at the load/dump point. JRB could not obtain data describing the relative contribution of dust emissions at either load/dump points or the haulageway to a haulage vehicle operator's 8-hour time-weighted average (TWA) exposure. JRB therefore assumes in this feasibility assessment that 20 percent of the operator's total exposure originates from load/dump stations, and the remaining 80 percent of the total exposure originates from the haulageway. For this analysis, dust control systems are formulated separately for load/dump stations and haulageways. The effectiveness of dust control combinations was determined in the same way as for the other operations described in this chapter. The dust reduction efficiency values for control systems formulated for controlling dust at load/dump stations were then multiplied by 20 percent to measure the effectiveness of these systems in reducing an operator's 8-hour TWA exposure. Efficiency values for systems formulated for controlling dust on haulageways were multiplied by 80 percent.

Efficiency values for dust control systems used at load/dump stations were added to efficiency values for systems used on haulageways to determine the combined dust reduction efficiency of using systems at both exposure points simultaneously. Dust control systems and their dust reduction efficiencies are presented in Figure 5-11. The combined dust reduction efficiencies for the combinations of dust controls depicted range from 6 to 76 percent.

Table 5-10 shows the 95 percentile exposure level associated with surface mobile transportation for each industry sector, the percent dust reduction required to meet the 0.05 and 0.075 mg/m³ PEL's, and the percentage of exposure data points that are currently at or below the 0.05 mg/m³ PEL. These data indicate that all of the industry sectors require some additional dust control to meet the 0.05 mg/m³ PEL. Eight industry sectors must reduce current exposure levels by 50 percent or more. By comparing the expected dust reduction efficiencies of the dust control systems in Figure 5-11 with the required reductions in dust levels for each industry sector (Table 5-10), it can be seen that the 0.05 mg/m³ PEL is infeasible for surface mobile transport

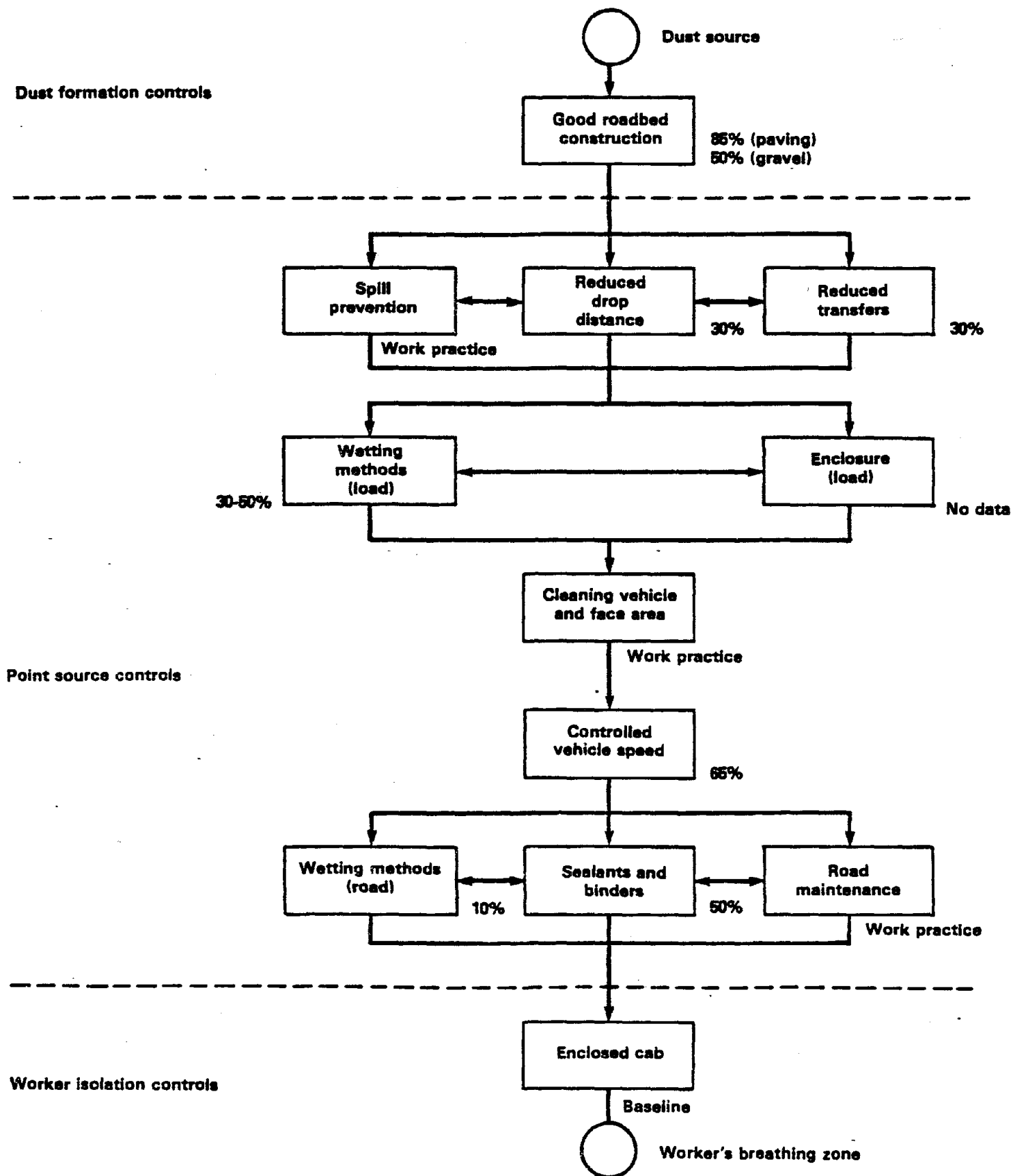


Figure 5-10. Flow diagram of dust control options and applicable reduction efficiencies for surface mobile transport.

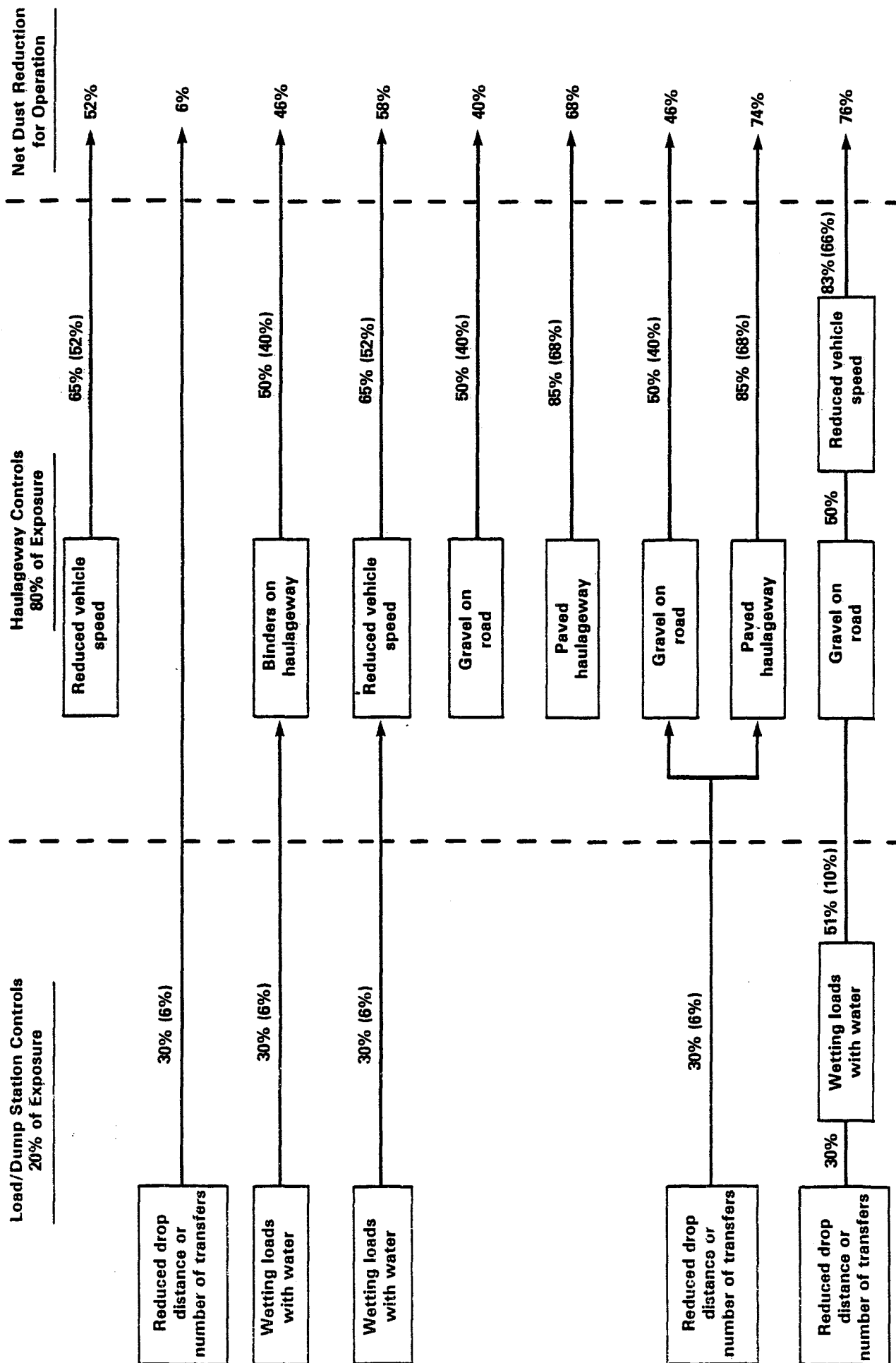


Figure 5-11. Applicable combinations of dust control options and applicable reduction efficiencies for surface mobile transport (net reduction in time-weighted average exposure is shown in parentheses).

Table 5-10. 95 Percentile silica exposure data and percent reductions required to meet the silica PEL's in surface mobile transport operations.

Industry group	95 Percentile exposure ₃ level (mg/m ³)	Percent reduction required to meet the 0.05 mg/m ³ PEL	Percent reduction required to meet the 0.075 mg/m ³ PEL	Percent of data points equal to or less than 0.05 mg/m ³ PEL
Copper	0.36	86	79	71
Gold and silver	0.10	50	25	80
Iron	0.07	29	None	91
Lead and zinc	0.14	64	46	84
Molybdenum	--	--	--	--
Uranium	0.07	29	None	91
Other metals	0.06	17	None	94
Limestone	0.075	33	None	91
Other stone	0.22	77	66	79
Clay and shale	0.20	75	63	73
Asbestos	--	--	--	--
Talc	0.085	41	12	86
Oil shale	0.46	89	84	59
Other nonmetals	0.19	74	61	74
Sand and gravel	0.15	67	50	84

Source: JRB calculations based on MSHA data.

A double dash indicates that no exposure data were available.

operations in the copper and oil shale industry sectors. This PEL is marginally feasible for the clay and shale, other stone, and other nonmetals industry sector. For all other industry sectors, this PEL can be achieved through the use of a variety of dust control combinations.

Based on the expected dust reduction achievable using the methods shown in Figure 5-11 and the percent reduction required to meet the 0.075 mg/m³ PEL shown in Table 5-10, the 0.075 mg/m³ is feasible in all industries except the copper and oil shale industry groups. For the copper industry, the 0.075 mg/m³ is marginally feasible, while for the oil shale industry this PEL is clearly infeasible.

As shown in Figure 5-11, the highest expected reduction efficiency for surface mobile transport operations is 76 percent. At this efficiency and allowing for the 5 percent margin of error, the maximum silica concentration that could be reduced to the 0.05 mg/m³ PEL is 0.17 mg/m³; for the copper industry, 17 samples taken at four sites exceeded this level. There were 161 samples taken at 31 copper mining sites. For the oil shale industry, only 2 of 11 samples taken from one mine were higher than 0.17 mg/m³.

5.8.3 Feasibility Assessment of Asbestos PEL's

MSHA mineral fiber exposure data for surface mobile transport operations were only available for eight industries. The 95 percentile exposure given in the available data is shown in Table 5-11, along with the percent reduction required to meet the asbestos PEL's. For the clay and shale industry, the 95 percentile fiber exposure level already meets the 0.1 fibers/cc PEL. However, there were only three samples from two sites included in this group.

In surface mobile transport operations, the highest reduction efficiency achievable is 76 percent, obtainable through use of a combination of water to wet loads, reduced drop distances, gravel on roads, and reduced vehicle speed, as shown in Figure 5-11. At this expected dust reduction efficiency, the 0.1 fibers/cc PEL is feasible in the limestone industry, where a reduction of 67 percent is required. For two industries, iron and talc, this PEL is marginally feasible since a reduction of 80 percent is required (within 5 percent of the achievable reduction). For the other four industries (asbestos, other nonmetals, other stone, and sand and gravel), which require 84-94 percent reductions, the 0.1 fibers/cc PEL is infeasible. The two higher PEL's are feasible in these industries, since the reduction needed to meet the 0.5 and 1.0 fibers/cc PEL is no higher than 69 percent.

5.9 SURFACE HAULAGEWAY MAINTENANCE

5.9.1 Dust Sources and Control Methods

Tasks that involve the operation of equipment to form and level haulageways, treat haulageways with water or chemicals, create berms, or dump and spread gravel on haulageways and access roads are included in this operation

Table 5-11. 95 Percentile mineral fiber exposure data and percent reductions required to meet the asbestos PEL's in surface mobile transport operations.

Industry group	95 Percentile fiber exposure (fibers/cc)	Percent reduction required to meet the 1.0 fibers/cc PEL	Percent reduction required to meet the 0.5 fibers/cc PEL	Percent reduction required to meet the 0.1 fibers/cc PEL
Iron	0.5	None	None	80
Limestone	0.3	None	None	67
Other stone	0.6	None	17	83
Clay and shale	0.1	None	None	None
Asbestos	1.4	29	64	93
Talc	0.5	None	None	80
Other nonmetals	1.6	38	69	94
Sand and gravel	0.7	None	29	86

Source: JRB calculations based on MSHA data.

category. Exposure to dust during this operation can result from dust being released during these tasks, or from haulage vehicles traveling along haulage-ways.

Dust control methods that can be used to reduce dust emissions during haulageway construction and maintenance are the same as those for controlling dust during surface mobile transport (see Section 5.8). These dust control methods and their assigned dust reduction efficiencies (see Chapter 4) are shown in Figure 5-12. As indicated in the figure, any of the methods used alone can result in a dust exposure reduction of from 50 to 85 percent. Combining the use of binders or gravel on haulageways with a reduction in vehicle speed yields a dust reduction efficiency of 83 percent.

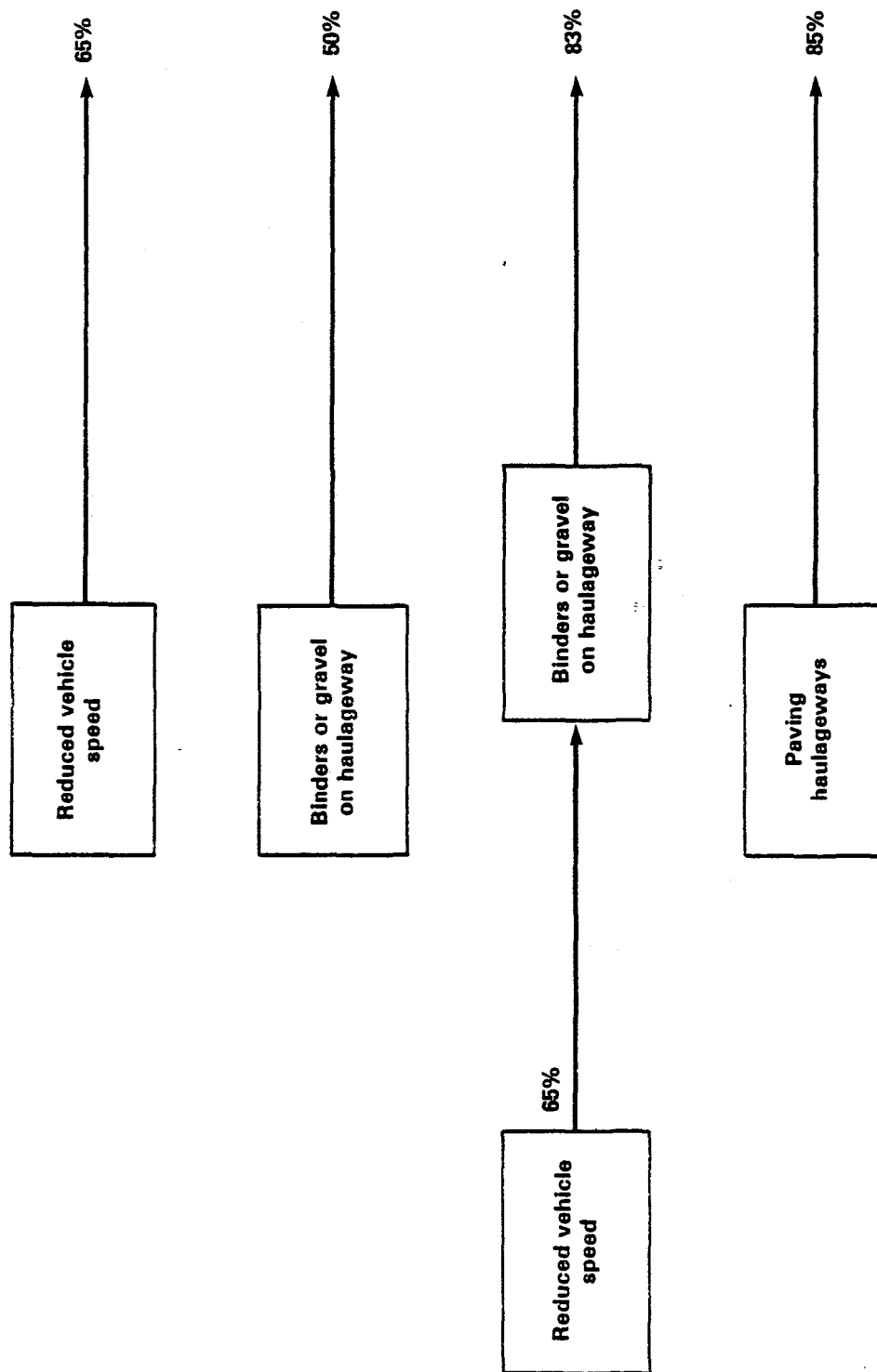


Figure 5-12. Applicable combinations of dust control options and applicable reduction efficiencies for surface haulage maintenance operations.

5.9.2 Feasibility Assessment of Silica PEL's

MSHA silica exposure data for this operation category are available for only four industry sectors: copper, limestone, other stone, and other non-metals. The 95 percentile exposure level, the percentage dust reduction required to meet both PEL's, and the percentage of exposure points at or below the 0.05 mg/m³ PEL are shown in Table 5-12 for this operation category. As shown in the table, no additional dust control is required for the copper and limestone industries to meet both silica PEL's during surface haulageway maintenance operations. The other nonmetals industry group is currently meeting the 0.075 mg/m³ PEL and requires only a 17 percent reduction in dust exposure to meet the 0.05 mg/m³ PEL. The other stone industry group can implement a variety of dust control methods to meet either the 0.075 mg/m³ or 0.05 mg/m³ PEL, which require reductions in dust levels of 38 and 58 percent, respectively.

5.9.3 Feasibility of Asbestos PEL's

No MSHA mineral fiber data were available for this operation category; no feasibility analysis was therefore conducted.

5.10 UNDERGROUND PRODUCTION

5.10.1 Dust Sources and Control Methods

Underground production operations primarily concern the movement of ores from the face to a dump site or haulage vehicle for transport to the next processing site. To move ores, two types of processes are involved, mucking and slushing. Mucking is generally used in a developmental area such as a new face or construction of new haulageways where various types of loading machines are used to load, transport, and dump broken ores into an orepass or finger raise or onto a haulage vehicle. The slushing process is used primarily in established production areas, especially in a narrow cross-section area where the broken ores are scraped into a draw hole and loaded onto waiting haulage vehicles. A hoist, a scraper, and cables are used for slushing operations.

The MSHA job codes included in this operation category are slushing, machine mucking, hand mucking, mining machine operation, and slurring. There are many sources of airborne dust in an underground production area. When a loader bucket or shovel moves through a muck pile near the face and dumps the ores onto a haulage vehicle, dust particles may be dislodged and become airborne. Similarly, when slusher scrapers are pulled through a muckpile, dust can be dispersed into the air along the slusher dash. Vehicle movement in production areas may crush the spilled material along the way and generate airborne dust. Finally, the transfer of ores from a loading bucket to a receiving vehicle or through orepasses or finger raises will disperse significant amounts of dust into the surrounding areas.

Table 5-12. 95 Percentile silica exposure data and percent reductions required to meet the silica PEL's in surface haulage maintenance operations.

Industry group	95 Percentile exposure ₃ level (mg/m ³)	Percent reduction required to meet the 0.05 mg/m ³ PEL	Percent reduction required to meet the 0.075 mg/m ³ PEL	Percent of data points equal to or less than 0.05 mg/m ³ PEL
Copper	0.005	None	None	100
Gold and silver	--	--	--	--
Iron	--	--	--	--
Lead and zinc	--	--	--	--
Molybdenum	--	--	--	--
Uranium	--	--	--	--
Other metals	--	--	--	--
Limestone	0.05	None	None	99
Other stone	0.12	58	38	79
Clay and shale	--	--	--	--
Asbestos	--	--	--	--
Talc	--	--	--	--
Oil shale	--	--	--	--
Other nonmetals	0.06	17	None	93
Sand and gravel	--	--	--	--

Source: JRB calculations based on MSHA data.

A double dash indicates that no exposure data were available.

Mucking--

Applicable methods of dust control for mucking processes are shown in Figure 5-13. The effectiveness of the available first line control methods, including reducing the number of transfers, decreasing drop distances, and controlling load size and spillage at the source, is largely dependent on the rigor with which the work practices are enforced and observed and the design of the equipment used. JRB has therefore assigned no additional dust reduction efficiencies to these methods. Water sprays and foams are applicable at the source as a second line of control. Water sprays can be used to wet down the surfaces of muck piles, the broken ore at the face, the transported load, and the load being dumped to reduce the emission of dust from these sources. In addition to the clogging of nozzles, several factors may interfere with the proper use of water sprays in mucking operations. These include nozzle damage, under- or overuse of water, and freezing of the water line. Therefore, for water sprays to work effectively, the nozzles should be placed as close to the dust source as possible and the sprays should be triggered either manually or automatically when a loader bucket advances into a muck pile, when a drawpoint gate is raised, or when a load is being dumped. Water lines should be designed and installed to minimize the possibility of being damaged by moving vehicles. For instance, water lines can be installed in grooves along the walls that protect them from vehicle traffic. Freezing of the water line can be prevented by methods such as the one used in a Canadian copper mine, where heated air was introduced through the primary ventilation system during the winter months (Press and Johnstone 1976).

In underground production operations, wetting of muckpiles of broken ores is typical. Therefore, water spray is considered as a baseline control (see Site Visit Reports Nos. 2 and 6; personal communication, MSHA inspectors, 1983). Spray nozzles installed near the load arms of gathering-arm loading machines were used in a trona mine visited for this project (see Site Visit Report No. 6). The dust exposure problems at this mine appeared to be well controlled, although no exposure data were available. The experience at the trona mine would appear to indicate that dust reduction can be achieved with water sprays at mucking operations when sprays are properly applied.

As discussed in Chapter 4, adding surfactants to the water or foams will improve the efficiency of dust removal compared to that for water sprays used alone. There were no reports in the literature on the use of surfactants in mucking operations, although one study on the use of foams for dust control in mucking operations was found. Rodgers and coworkers (1978) compared the effectiveness of high expansion foam and water sprays for dust control at orepasses in a copper mine and concluded that the foam was less effective in reducing dust concentrations than water sprays. However, in this study the water sprays and foams were applied at different points of the orepass; the foam was used to fill up the orepass, while water sprays were used at both the dump point of the orepass and at the loading point. Microfoam used in other operations, such as conveyor belt transfers, applied in the same way as the water spray was found to have a minimum dust reduction efficiency of 50 percent (Chapter 4) compared to using no dust control. If foams are sprayed onto muck piles and falling ores at orepasses, this minimum dust reduction efficiency should be achievable. However, water spray is a baseline control and

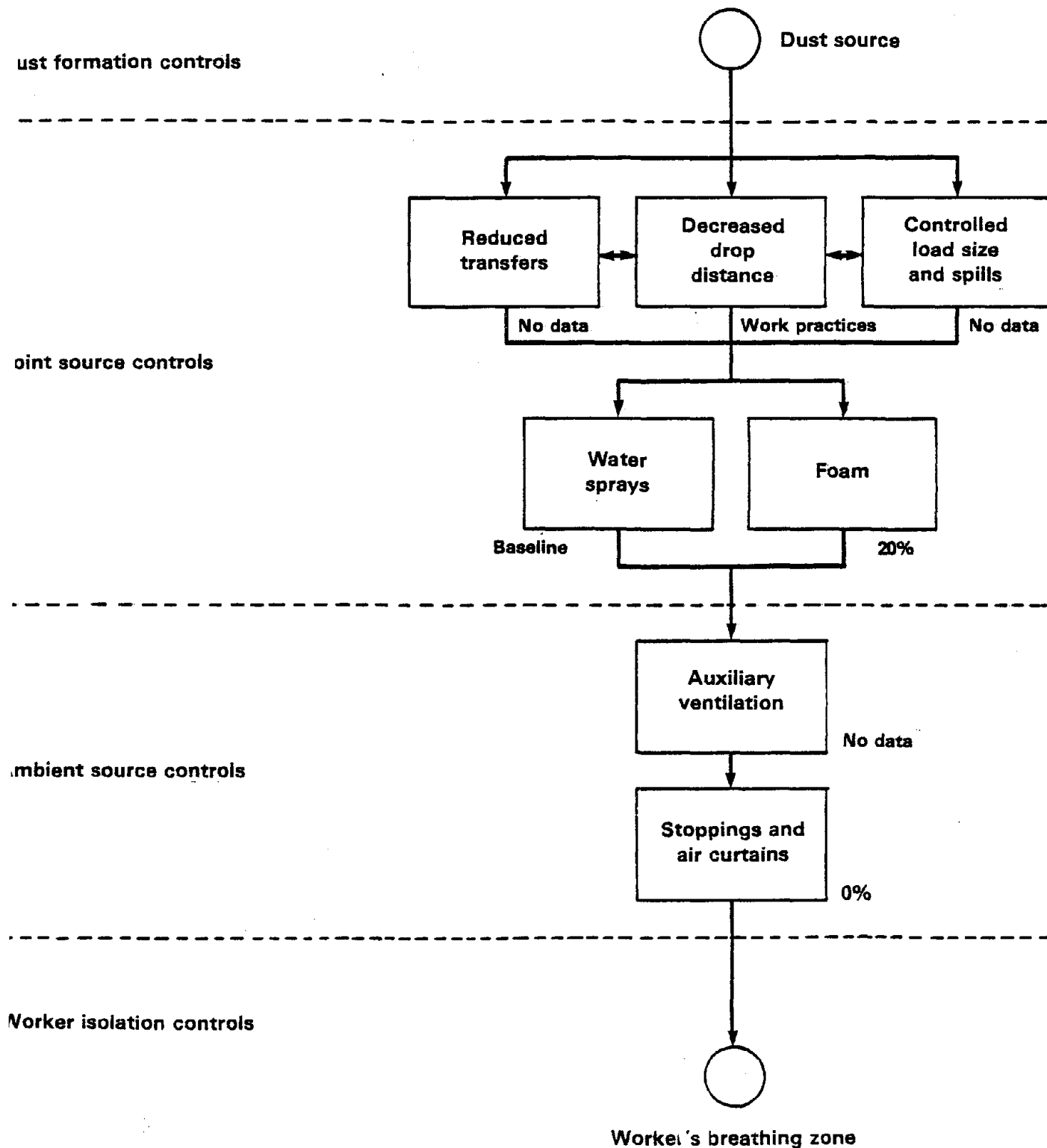


Figure 5-13. Flow diagram of dust control options and applicable reduction efficiencies for underground mucking.

has been assigned an efficiency of 30 percent. The use of foam can be assumed to increase the efficiency of water spray by 20 percent. Similarly, if surfactant is added to the spray, the dust removal efficiency is expected to increase 10 percent over that of the water spray alone, as discussed in Chapter 4.

For ambient source control, auxiliary ventilation can be used at faces, orepasses, or chutes. No reduction efficiency has been assigned to this method, as discussed in Chapter 4. Another ambient source control that is applicable is the use of stoppings. However, since this particular method is an integral component of primary ventilation systems, no reduction efficiency is assigned to it. There are no applicable worker isolation controls for mucking machines.

Dust exposure in mucking operations involves exposure at the loading area, en route to the dump point, and at the dump point. Based on the discussion above, exposures at the loading area near a muckpile and at the dump point can be controlled by adding surfactants to the existing water spray or by substituting water spray with foams. If foam is used, an additional dust reduction of 20 percent is expected. Along the route of travel, dust emitted from the roadway can be controlled by water sprays. If surfactants are added to the water, a 40 percent reduction in dust from the roadway can be achieved, as discussed in Chapter 4. By combining this 40 percent reduction achievable along the travel route, the 20 percent reduction achievable with the use of foams at the loading point, and another 20 percent expected reduction at the dumping points, the average expected dust reduction efficiency for the mucking operation as a whole is 27 percent.

Slushing--

Applicable dust control methods for slushing operations are shown in Figure 5-14. A slushing operation is performed in a fixed location within a well-developed area of the mine, and dust controls can therefore be more easily applied than in a mucking operation. A typical existing control system at a slushing operation, as reported by Rodgers (1974), includes a flat vertical curtain of sprays positioned at a right angle to the wall in front of the draw hole, horizontal sprays over the draw hole toward the falling ores, and primary ventilation down the slusher dash. Dust concentrations measured at this particular operation were not reported, although the current MSHA PEL's for silica had reportedly been met. Slushing operations in a gold mine, copper mine, and molybdenum mine have reportedly achieved silica exposures of less than 0.05 mg/m^3 when spraying systems similar to the one described by Rodgers (1974) were used.

As in mucking operations, foams can be used to control dust in slushing operations. As discussed in Chapter 4, a dust reduction efficiency of 50 percent is expected with the foams; however, since water sprays with an expected efficiency of 30 percent are already in use, a reduction of only 20 percent is assigned to foams used at slushing operations. Based on discussions in Chapter 4, adding surfactants to the water is expected to reduce respirable dust by about 40 percent. If the 30 percent efficiency attributed to the

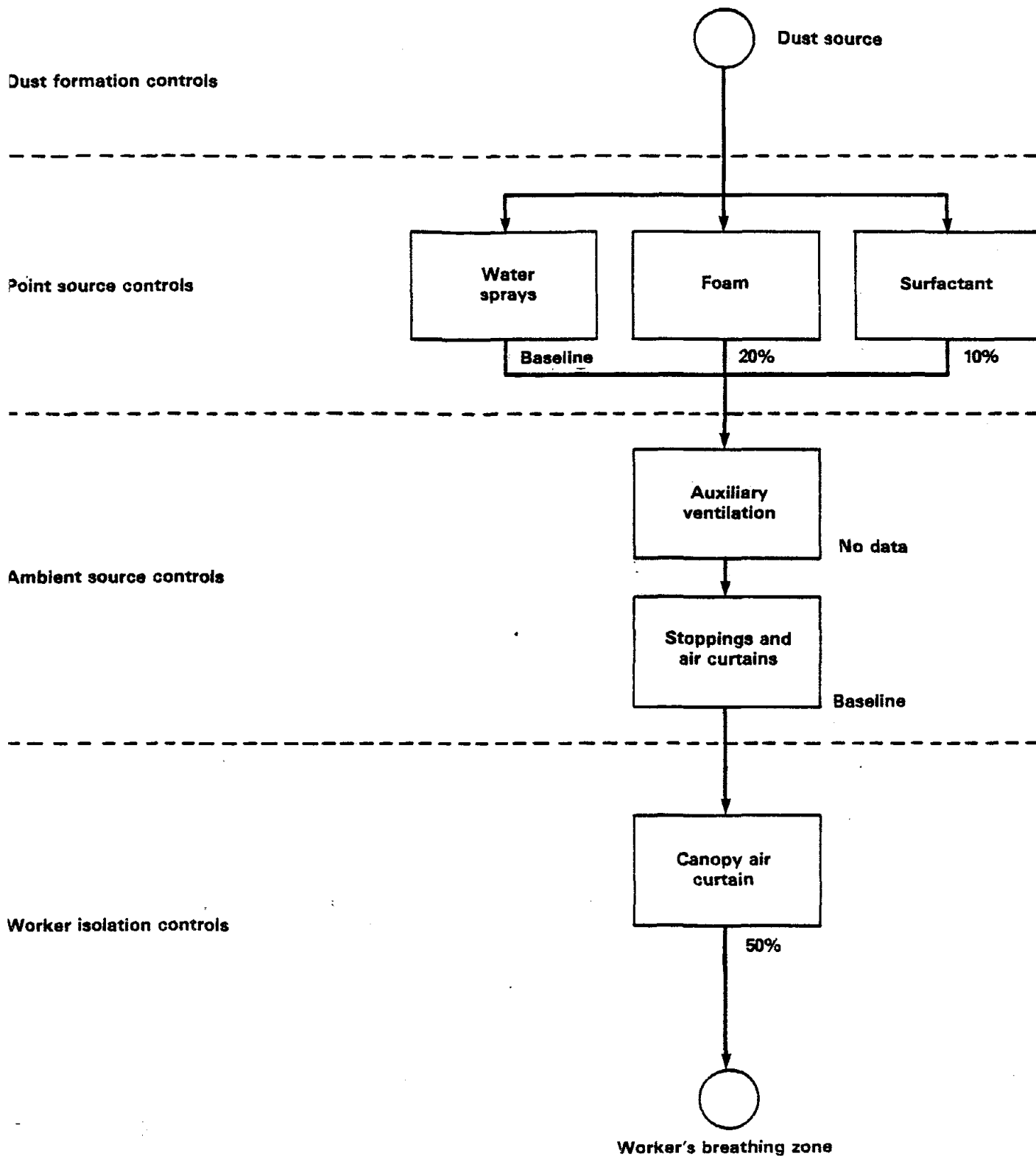


Figure 5-14. Flow diagram of dust control options and applicable reduction efficiencies for slushing.

baseline use of water sprays is subtracted, surfactant can be expected to increase dust reduction efficiency by 10 percent. For the remaining methods shown in Figure 5-14, the expected dust reduction efficiencies assigned are the same as those developed in Chapter 4.

Based on the control methods shown in Figure 5-14, one means of achieving additional dust control at slushing operations is to add surfactants to the existing water spray and to use a canopy air curtain for the slusher operator. Combining these two methods (with efficiencies of 10 and 50 percent) will provide a combined expected efficiency of 55 percent. Another applicable combination of control methods is the use of foam and a canopy air curtain, which can be expected to reduce dust exposure by 60 percent. Using canopy air curtains alone will achieve a 50 percent reduction, as discussed in Chapter 4.

5.10.2 Feasibility Assessment of Silica PEL's

The 95 percentile exposure levels for underground production operations in each industry group are shown in Table 5-13. The 3 percent reduction in silica concentrations required to meet the 0.05 mg/m³ silica PEL and the percentage of data points that are already below this PEL are also included in the table. It can be seen from the table that silica exposures in four industry groups, iron, limestone, other stone, and talc, already meet the 0.05 mg/m³ PEL. However, except for the other stone group, the data available for the other three groups were sparse. For example, in the iron industry, the concentration data are based on two samples taken from two of the seven active establishments. For the limestone industry, there were three data points, which represent samples obtained from 2 of the 104 active sites. Similarly, in the talc industry, only three samples from one mine were available, although eight sites were active. In addition, no data were available for underground production operations in the asbestos, oil shale, and sand and gravel industry sectors.

The feasibility of achieving the lowest PEL in underground production operations has been analyzed for the eight remaining industries: copper, gold and silver, lead and zinc, molybdenum, uranium, other metals, clay and shale, and other nonmetals. Since two processes are involved in this operation category, the feasibility assessment for each industry was made initially by assuming that the initial dust exposure in each process step is the same.

Based on our analysis of dust control methods applicable to underground production processes, silica dust exposure is more difficult to control in mucking than in slushing processes. Since a 27 percent dust reduction is the highest reduction in dust control achievable in mucking operations, the 0.05 mg/m³ PEL is infeasible in underground production operations in all eight industry groups, which would require reductions of from 36 to 90 percent to achieve this PEL. The 0.075 mg/m³ PEL is only feasible in the other metals industry, which needs only a 4 percent reduction to meet this PEL. In addition, this PEL is marginally feasible in the uranium industry, which requires a 25 percent reduction to meet the 0.075 mg/m³ PEL.

Table 5-13. 95 Percentile silica exposure data and percent reductions required to meet the silica PEL's in underground production operations.

Industry group	95 Percentile exposure level (mg/m ³)	Percent reduction required to meet the 0.05 mg/m ³ PEL	Percent reduction required to meet the 0.075 mg/m ³ PEL	Percent of data points equal to or less than 0.05 mg/m ³ PEL
Copper	0.28	82	73	70
Gold and silver	0.17	71	56	68
Iron	0.04	None	None	100
Lead and zinc	0.20	75	63	72
Molybdenum	0.49	90	85	36
Uranium	0.10	50	25	82
Other metals	0.078	36	4	85
Limestone	0.02	None	None	100
Other stone	0.045	None	None	100
Clay and shale	0.40	88	81	66
Asbestos	--	--	--	--
Talc	0.02	None	None	79
Oil shale	--	--	--	--
Other nonmetals	0.11	55	32	80
Sand and gravel	--	--	--	--

Source: JRB calculations based on MSHA data.

A double dash indicates that no exposure data were available.

To determine the relative contributions of the various factors responsible for the judgment of infeasibility, the particular circumstances in each industry sector were analyzed further. Since a dust reduction efficiency of 27 percent is the greatest that can be achieved for the mucking process in underground production operations, the maximum silica dust concentration that could be reduced to the 0.05 mg/m³ PEL is 0.06 mg/m³. In the copper industry, three of the four sites from which dust samples were collected had silica dust concentrations above this level.

For the gold and silver industry, 44 data points representing 8 of the 113 active sites were included in the exposure profile. Fourteen of the 44 samples were taken at mucking operations. Of these 14 samples, only 1, at 0.077 mg/m³, was above the maximum exposure that could be reduced to the low PEL.

For the lead and zinc industry, 10 samples from 5 of the 49 active mines were available. The high concentrations were all associated with slushing operations at these mines; the highest concentration recorded for a mucking operation was only 0.045 mg/m³. For the slushing operations, only the two highest samples, both from the same site, were above the maximum level that can be reduced to the 0.05 mg/m³ PEL through the use of available dust controls.

For the molybdenum industry, there were 44 samples from two of the eight active underground production sites. Of the 44 samples, 43 were from one mine. The one sample from the second mine, which showed a concentration of 0.017 mg/m³, was taken at a mucking operation. Among the 43 samples from the first mine, only 2 were related to the mucking operation; the rest were taken at the slushing operation. The two samples from the mucking operation had concentrations no higher than 0.021 mg/m³. Thus, for underground production operations in the molybdenum industry, the slushing operation becomes the critical factor in achieving the 0.05 mg/m³ PEL. With a required dust reduction efficiency of 90 percent, and the highest reduction efficiency achievable at 60 percent, the 0.05 mg/m³ PEL is obviously infeasible in slushing operations. In the other metals industry group, one of nine samples taken at a slushing operation in an antimony mine caused the 0.05 mg/m³ PEL to be judged infeasible.

In the clay and shale industry, four samples from 2 of the 14 active sites were available. Two samples from the mucking operation at one site were above the maximum concentration of 0.06 mg/m³ that can be reduced to the 0.05 mg/m³ PEL.

In the other nonmetals industry group, two samples taken at a slushing operation in a single barite mine caused the 0.05 mg/m³ to be judged infeasible for this operation. There were 13 samples taken from 4 sites in this industry group.

In summary, the 0.05 mg/m³ PEL is judged to be technologically infeasible for underground production processes in industries where the 95 percentile exposure concentration is above this PEL. These industries are copper, gold and silver, lead and zinc, molybdenum, uranium, other metals, clay and shale,

and other nonmetals. For these industries the 0.075 mg/m³ PEL is feasible only in the other metals industry group, and is marginally feasible only in the uranium industry. In the copper, gold and silver, lead and zinc, molybdenum, clay and shale, and other nonmetals industries, achieving compliance with the 0.075 mg/m³ PEL is not feasible with existing engineering controls.

5.10.3 Feasibility Assessment of Asbestos PEL's

MSHA mineral fiber personal exposure data were available for only four industries in underground production operations: gold and silver, molybdenum, talc, and other nonmetals. The 95 percentile exposure fiber counts for these four industries and the corresponding reduction efficiencies required to meet the asbestos PEL's are shown in Table 5-14. As discussed above for silica PEL's, the mucking process, for which control options can only provide a dust reduction of 27 percent, is more difficult to control than the slushing process. At this expected dust reduction efficiency, the 0.1 fibers/cc PEL is not feasible in any of the four industries, and the 0.5 fibers/cc PEL is only marginally feasible in the gold and silver industry. In the other three industries, the 0.5 fibers/cc PEL is infeasible. The 1.0 fibers/cc PEL is infeasible in the molybdenum and talc industries and marginally feasible in the other nonmetals industry. The 95 percentile fiber exposure levels in the gold and silver industry are currently below the 1.0 fibers/cc PEL. However, except for the talc industry, this analysis of the feasibility of achieving the asbestos PEL's in underground production operations is based on data sets containing no more than three samples.

Table 5-14. 95 Percentile mineral fiber exposure data and percent reductions required to meet the asbestos PEL's in underground production operations.

Industry Group	95 Percentile fiber exposure (fibers/cc)	Percent reduction required to meet the 1.0 fibers/cc PEL	Percent reduction required to meet the 0.5 fibers/cc PEL	Percent reduction required to meet the 0.1 fibers/cc PEL
Gold and silver	0.7	None	29	86
Molybdenum	3.0	67	83	97
Talc	2.0	50	75	95
Other nonmetals	1.3	23	62	92

Source: JRB calculations based on MSHA data.

5.11 UNDERGROUND MOBILE TRANSPORT

5.11.1 Dust Sources and Control Methods

This category comprises operations that occur on haulage levels and the main haulageways between the underground workings and the surface. MSHA codes that are included in this operation category are the same as those for surface mobile transport, except that they are located below ground. These job codes are operators of electric, diesel, gasoline, and compressed air LHD equipment; track crews; and bulldozer operators. Mobile transport begins when ore or waste rock is loaded into transport vehicles and ends when vehicles unload on the surface. There may also be a number of material transfer points along these routes. Vehicles used for underground mobile transport include

- Shuttle cars, which haul material between the advancing face of the mine and a fixed dumping or transfer point
- Trucks, which are used for longer hauls and which are designed with a low profile for underground clearance
- Tractor-trailers, which are rubber-tired vehicles that include end-dump units for unloading
- Locomotives and mine cars, which haul material by rail.

Exposure to dust may occur during haulage operations when dust is formed and released from the roadbed by movement of haulage vehicles, and when dust is released during dumping. Dust release must therefore be controlled from two main sources, the haulageway itself and loading-dumping stations.

Dust control methods that are applicable to both sources of dust are shown in Figure 5-15, along with the expected dust reduction efficiencies assigned to each method (see Chapter 4). Each method is described briefly below.

Water sprays, which are assumed by JRB generally to be 30 percent effective in reducing dust (see Chapter 4), are commonly used in underground locations to control dust exposure (personal communication, MSHA inspectors, 1983). Therefore, water sprays are not considered for this operation and are not assigned a dust reduction efficiency. Surfactants and foams have dust reduction efficiencies of 40 and 50 percent, respectively, when they are used with no other controls. However, since water sprays are assumed to be used in this operation throughout the industry, the additional use of surfactants and foams can be expected to reduce dust emissions by only 10 and 20 percent, respectively. JRB assumes that surfactants and foams, if used, will be applied during loading and dumping, so the additional use of surfactants and foams on loads during haulage will not result in decreased dust emissions.

Dust control methods that can be applied to haulageways to reduce dust emissions include controlling vehicle speed and applying water or binding agents to haulageways. Kothari and Gerstle (1980) reported that decreasing

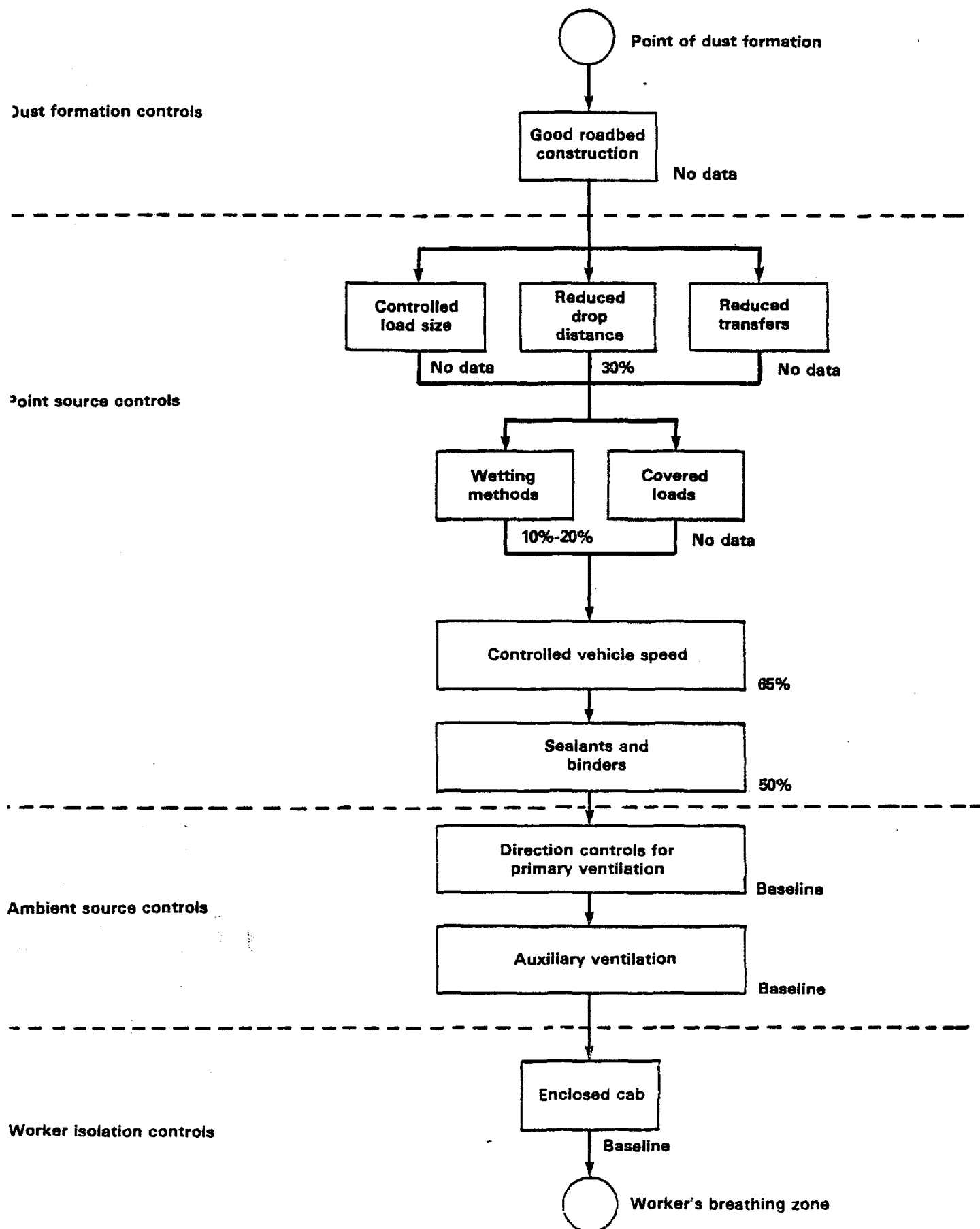


Figure 5-15. Flow diagram of dust control options and applicable reduction efficiencies for underground mobile transport.

haulage vehicle speeds from 15 to 10 miles per hour will reduce dust emissions by an estimated 65 percent; as discussed in Chapter 4, foams and surfactants have been used successfully on underground haulageways (personal communication, MSHA inspectors, 1983). Two sites visited by JRB (Sites 1 and 2) used binders or emulsions on roads, although it is not common in the industry to treat haulageways with chemicals, particularly on upper levels where roads may dry out (personal communication, MSHA inspectors, 1983). JRB assumes that using binders on underground haulageways will reduce dust emissions during mobile transport by 50 percent (see Chapter 4).

Other control methods, including controlling load size and covering loads, have not been assigned any dust reduction efficiency because they are work practice control methods (see Chapter 4). Use of enclosed cabs on haulage vehicles underground, except for locomotives, is not possible except in large underground operations such as in room and pillar mines. Although enclosed cabs are currently used on locomotives, they are not usually equipped with air-filtering systems. Air-filtering systems could be used to reduce the dust exposures of locomotive operators. However, since this control applies only to a portion of the exposed population (the operators) and to a portion of the equipment (locomotives) involved in this process step, the use of enclosed cabs with air-filtering systems is not considered a dust control option for this operation.

5.11.2 Feasibility Assessment of Silica PEL's

As in the case of surface mobile transport, dust exposure can be controlled from two distinct dust sources during underground mobile transport; these dust sources are at the load/dump stations and along the haulageway. For the purposes of this analysis, JRB has assumed that 20 percent of a haulage equipment operator's 8-hour TWA exposure is to dust originating from load/dump stations, and that the remaining 80 percent of the total exposure is to dust originating from the haulageway.

The dust reduction efficiencies of dust control systems were then determined using the same method of calculation as was used in Section 5.8 (Surface Mobile Transport). Combinations of dust control methods and the resulting dust reduction efficiencies are shown in Figure 5-16. Using these combinations of dust controls, dust exposure levels can be reduced by 42-68 percent.

Table 5-15 shows the 95 percentile exposure level for each industry sector associated with underground mobile equipment operations, the percent dust reduction required to meet the PEL's, and the percentage of data points already below the 0.05 mg/m³ PEL. There were no data for the asbestos, talc, and sand and gravel industries. Underground mobile transport operations in the gold and silver, iron, uranium, limestone, oil shale, and other nonmetals industries require a reduction in silica exposure of 34-58 percent to meet the 0.05 mg/m³ PEL. For these industries, the combination of reducing vehicle speed and applying binding agents on haulageways would attain this PEL, since a reduction efficiency of 68 percent is expected from this combination (Figure 5-16). For the copper, lead and zinc, other stone, and clay and shale industry groups, the 0.05 mg/m³ PEL is not feasible with any of the dust control systems shown

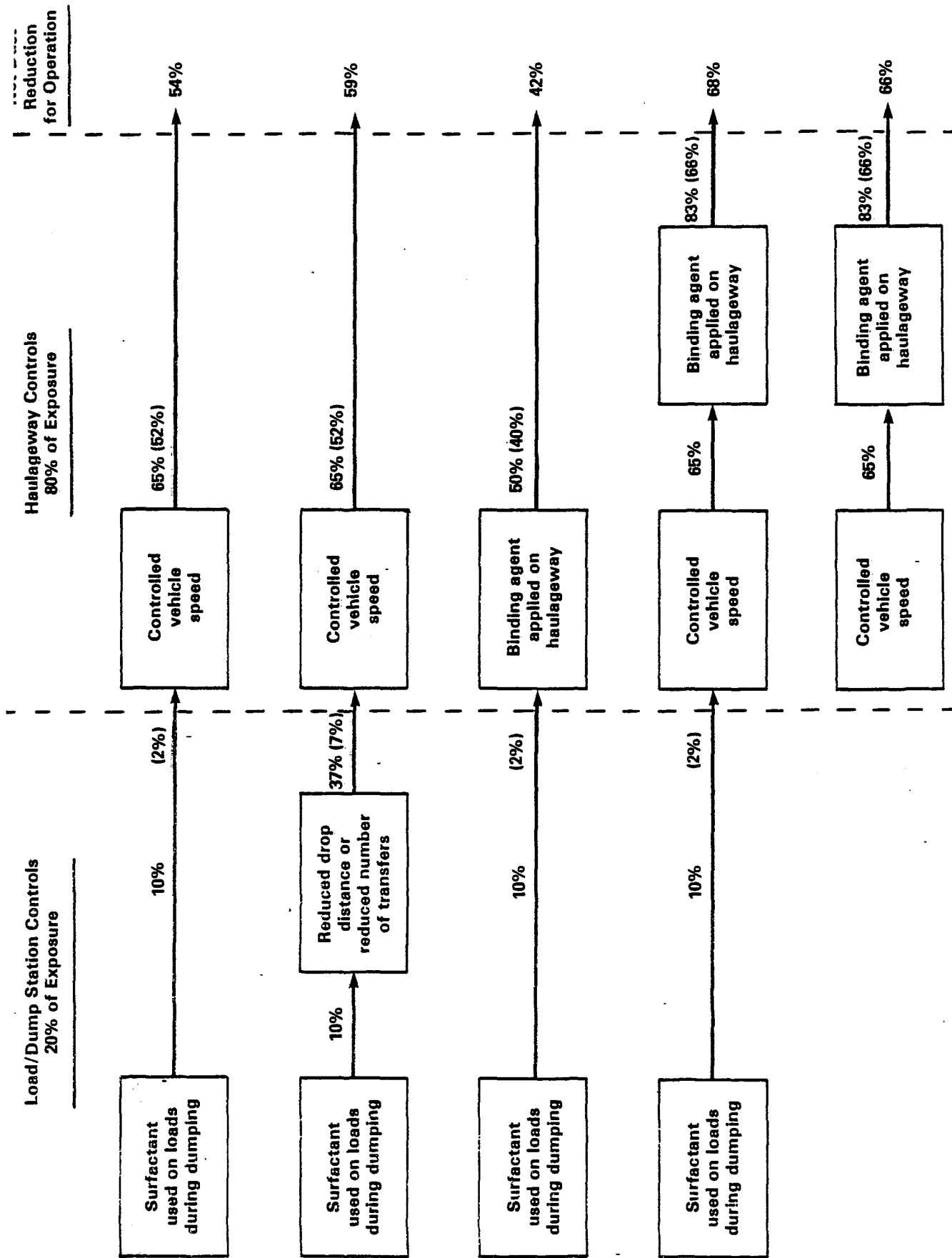


Figure 5-16. Applicable combinations of dust control options and applicable reduction efficiencies for underground mobile equipment (net reduction in time-weighted average exposure is shown in parentheses).

Table 5-15. 95 Percentile silica exposure data and percent reductions required to meet the silica PEL's in underground mobile equipment operations.

Industry group	95 Percentile exposure level (mg/m ³)	Percent reduction required to meet the 0.05 mg/m ³ PEL	Percent reduction required to meet the 0.075 mg/m ³ PEL	Percent of data points equal to or less than 0.05 mg/m ³ PEL
Copper	0.25	80	70	63
Gold and silver	0.11	55	32	76
Iron	0.076	34	1	84
Lead and zinc	0.19	74	61	71
Molybdenum	0.18	72	58	53
Uranium	0.1	50	25	80
Other metals	0.05	None	0	100
Limestone	0.1	50	25	83
Other stone	0.29	83	74	58
Clay and shale	0.22	77	66	61
Asbestos	--	--	--	--
Talc	--	--	--	--
Oil shale	0.12	58	38	85
Other nonmetals	0.12	58	38	83
Sand and gravel	--	--	--	--

Source: JRB calculations based on MSHA data.

A double dash indicates that no exposure data were available.

in Figure 5-16. The 0.05 mg/m^3 PEL is marginally feasible for the molybdenum industry group, which would require a 72 percent reduction in dust levels to meet this PEL. The required percent dust reduction in Table 5-15 also shows that the 0.075 mg/m^3 PEL is infeasible for the other stone industry, marginally feasible for the copper industry, and feasible for all other industry groups.

As shown in Figure 5-16, a maximum expected dust reduction efficiency of 68 percent is achievable in underground mobile transport operations. Based on this efficiency and allowing for a 5 percent margin of error, the highest feasible silica dust concentration that can be reduced to the 0.05 mg/m^3 PEL is 0.14 mg/m^3 . For some of the industry sectors where the 0.05 mg/m^3 PEL was found to be infeasible, a relatively high percentage of the sampled sites had samples with concentrations above this level. In the other stone industry, five of the six sampled sites had seven samples (from the total of 44 for this industry and operation) that were above the 0.14 mg/m^3 level. In the clay and shale industry, the MIDAS file contained 80 samples from 10 sites. Four of the 10 sites had a total of 9 samples with concentrations above the 0.14 mg/m^3 level. In the copper industry, 22 samples from 4 sites of the total of 197 samples from 12 sites that were available for this operation category exceeded the 0.14 mg/m^3 level. For the lead and zinc industries, 4 of the 19 sampled sites had a total of 7 samples (among a total of 101 samples) above this level.

5.11.3 Feasibility Assessment of Asbestos PEL's

MSHA mineral fiber exposure data in underground mobile transport operations were available for five industry sectors: copper, limestone, asbestos, other nonmetals, and talc. The 95 percentile fiber exposure levels for these industry groups and the percent dust reduction required to meet each asbestos PEL are shown in Table 5-16.

Mineral fiber exposures in all five of these industry groups are already below the 1.0 fibers/cc and 0.5 fibers/cc PEL's. To meet the 0.1 fibers/cc PEL, the asbestos, limestone, and talc industry groups must reduce dust exposure by 50, 75, and 80 percent, respectively. Combining the use of surfactants on loads during dumping, reducing vehicle speed, and applying binding agents on haulageways is expected to achieve a reduction efficiency of 68 percent, as shown in Figure 5-16. Using this dust control strategy, the 0.1 fibers/cc PEL is feasible for the asbestos industry group and infeasible for the limestone and talc industry groups. Fiber exposure data in the copper industry and the other nonmetals industry are already below the 0.1 fibers/cc PEL; however, there were only two samples for the other nonmetals industry, eight samples for the copper industry, and four for the limestone industry.

Table 5-16. 95 Percentile mineral fiber exposure data and percent reductions required to meet the asbestos PEL's in underground mobile transport operations.

Industry Group	95 Percentile fiber exposure (fibers/cc)	Percent reduction required to meet the 1.0 fibers/cc PEL	Percent reduction required to meet the 0.5 fibers/cc PEL	Percent reduction required to meet the 0.1 fibers/cc PEL
Copper	0.02	None	None	None
Limestone	0.4	None	None	75
Asbestos	0.2	None	None	50
Other nonmetals	0	None	None	None
Talc	0.5	None	None	80

Source: JRB calculations based on MSHA data.

5.12 UNDERGROUND HAULAGEWAY MAINTENANCE

5.12.1 Dust Sources and Control Methods

Underground haulage maintenance includes tasks such as timbering, grading haulageways, treating rails, and applying gravel or chemical agents to road surfaces. MSHA job codes for timbering and concrete operations are included in this operation category. In these operations, workers are exposed to dust during roadbed construction and while haulage vehicles are traveling on finished roadways.

Dust control methods that apply to underground mobile transport (see Section 5.11) can also be used to control dust during underground haulage maintenance operations. These methods include reducing vehicle speed and applying binders to haulageways. Figure 5-17 shows the two dust control methods that can be used to reduce dust levels further during this operation and the dust reduction efficiencies assigned to each (see Chapter 4). The most effective dust control system includes using binders together with a reduction in vehicle speed; the efficiency of this system is estimated to be 83 percent.

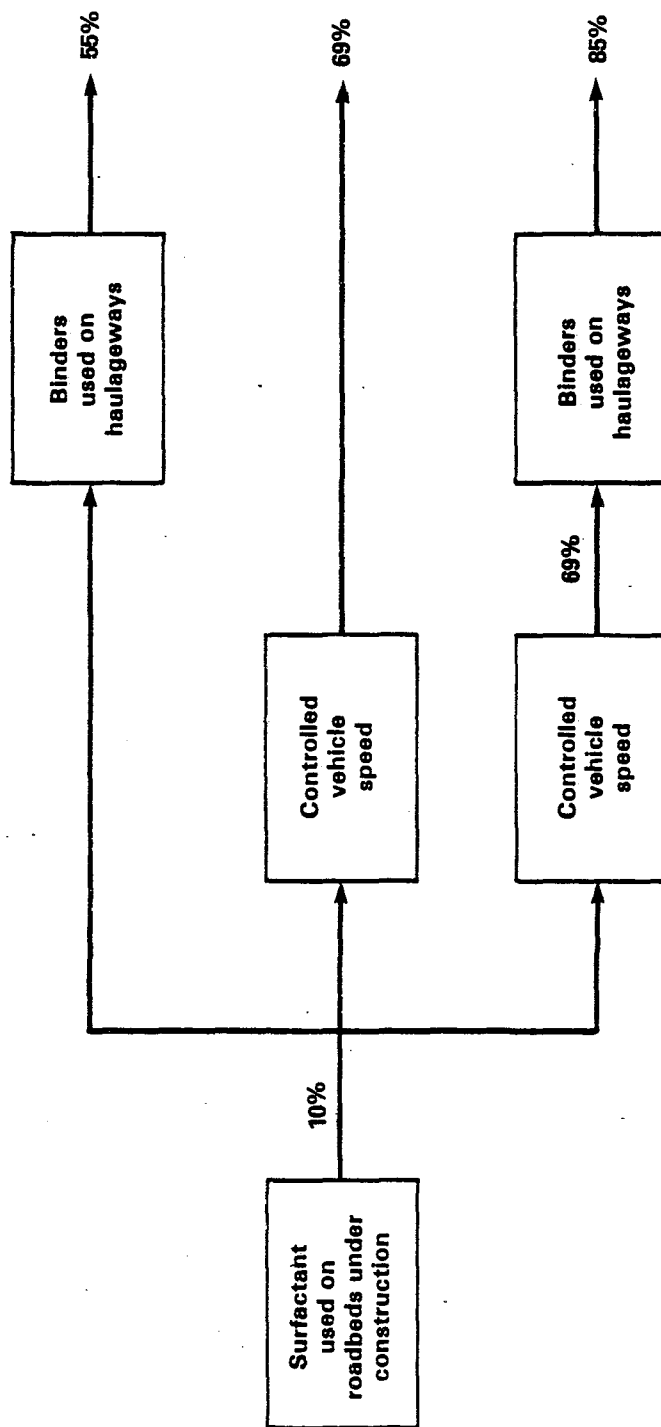


Figure 5-17. Applicable combinations of dust control options and applicable reduction efficiencies for underground haulageway maintenance operations.

5.12.2 Feasibility Assessment of Silica PEL's

Table 5-17 shows the 95 percentile silica exposure level for each industry group, the percent dust reduction required to meet both PEL's, and the percentage of data points at or below the 0.05 mg/m^3 PEL. Data for the iron, other metals, limestone, asbestos, talc, oil shale, and sand and gravel industries were not available for this operation category. The lead and zinc industry group requires the highest degree of dust reduction (69 percent) to meet the 0.05 mg/m^3 PEL. By using binders combined with a reduction in vehicle speed, this PEL can be achieved for underground haulageway maintenance operations in the lead and zinc industry. By using the same combination of controls, the 0.05 mg/m^3 PEL is also feasible for the molybdenum and other stone industries. The gold and silver, uranium, and clay and shale industry groups can meet the 0.05 mg/m^3 PEL by using only one of the dust control methods shown in Figure 5-17. The 0.075 mg/m^3 PEL is also feasible for all industry groups through the use of one or both of the dust control methods shown in Figure 5-17.

5.12.3 Feasibility Assessment of Asbestos PEL's

No MSHA mineral fiber data were available for this operation category.

5.13 STORAGE

5.13.1 Dust Sources and Control Methods

Adequate storage facilities and operations help ensure uninterrupted mine operation, sufficient plant feed, and a controllable shipping schedule. The size and type of storage varies with these requirements and with each mine site. Mines with high production may require large stockpiles to prevent material shortages. For smaller operations, bins and silos may be more suitable.

JRB has classified storage operations in a separate category in this report because dust can be dispersed from these operations to other mining operation locations. However, MSHA sampling data were not collected for storage operations because storage area workers are only intermittently exposed in these areas and are primarily involved in other mining activities for which exposure data were available. The feasibility of achieving a PEL specifically for storage areas can therefore not be determined. However, a summary of the efficiencies of controls that can be used in storage areas is given in this section.

Dust control methods available for storage operations are divided into two groups: those designed for active storage operations and those designed for inactive storage. Active operations involve material conveying and transfer process steps. Inactive storage generally involves only maintenance of stored material. Dust control options and combinations applicable to both active and inactive storage areas are presented in Figure 5-18.

Table 5-17. 95 Percentile silica exposure data and percent reductions required to meet the silica PEL's in underground haulageway maintenance.

Industry group	95 Percentile exposure level (mg/m ³)	Percent reduction required to meet the 0.05 mg/m PEL	Percent reduction required to meet the 0.075 mg/m PEL	Percent of data points equal to or less than 0.05 mg/m PEL
Copper	0.3	None	None	100
Gold and silver	0.08	38	6	90
Iron	--	--	--	--
Lead and zinc	0.16	69	53	70
Molybdenum	0.13	62	42	70
Uranium	0.09	44	None	87
Other metals	--	--	--	--
Limestone	--	--	--	--
Other stone	0.14	64	46	67
Clay and shale	0.11	55	32	83
Asbestos	--	--	--	--
Talc	--	--	--	--
Oil shale	--	--	--	--
Other nonmetals	0.03	None	None	80
Sand and gravel	--	--	--	--

Source: JRB calculations based on MSHA data.

A double dash indicates that no exposure data were available.

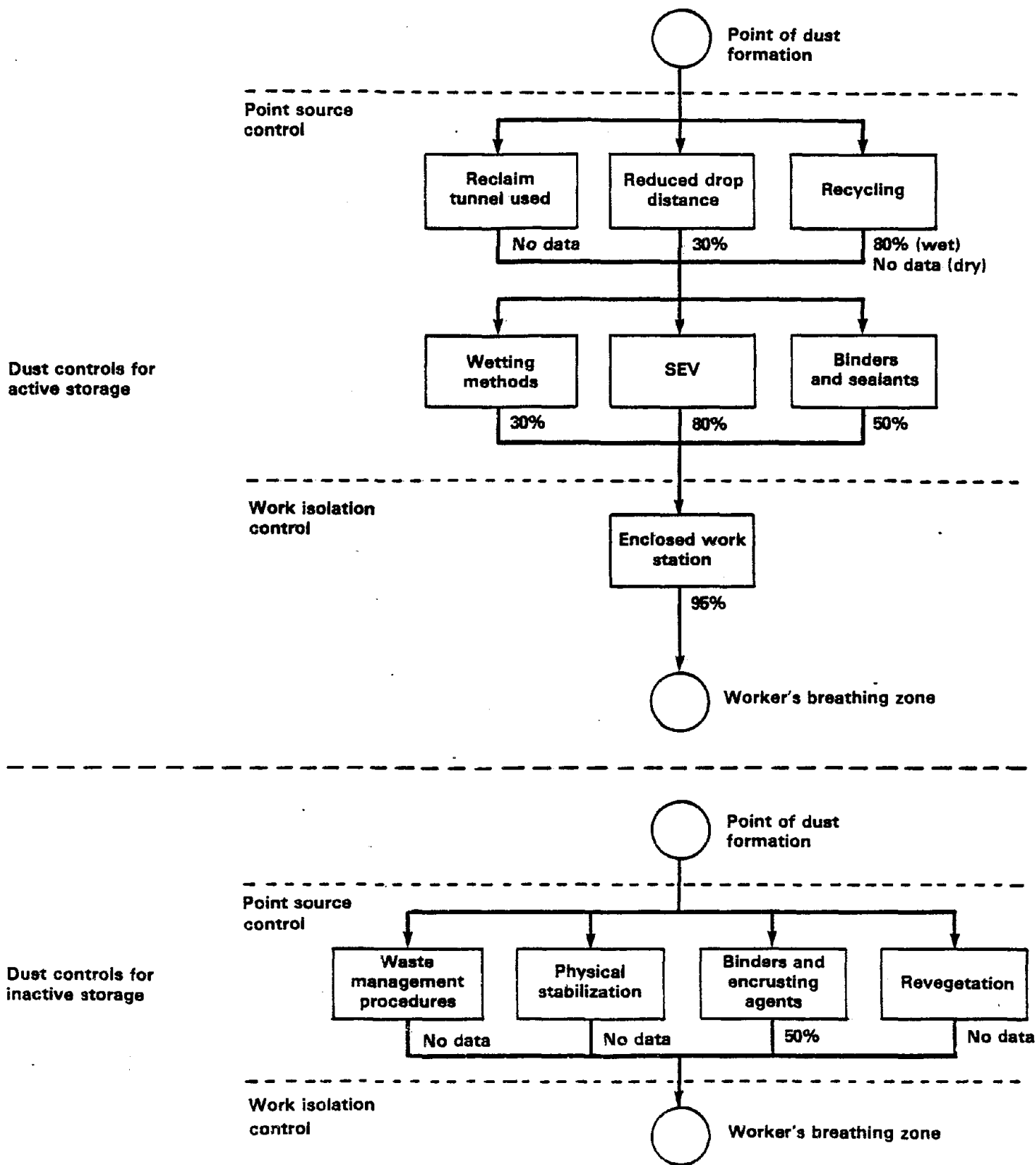


Figure 5-18. Flow diagram of dust control options and applicable reduction efficiencies for storage operations.

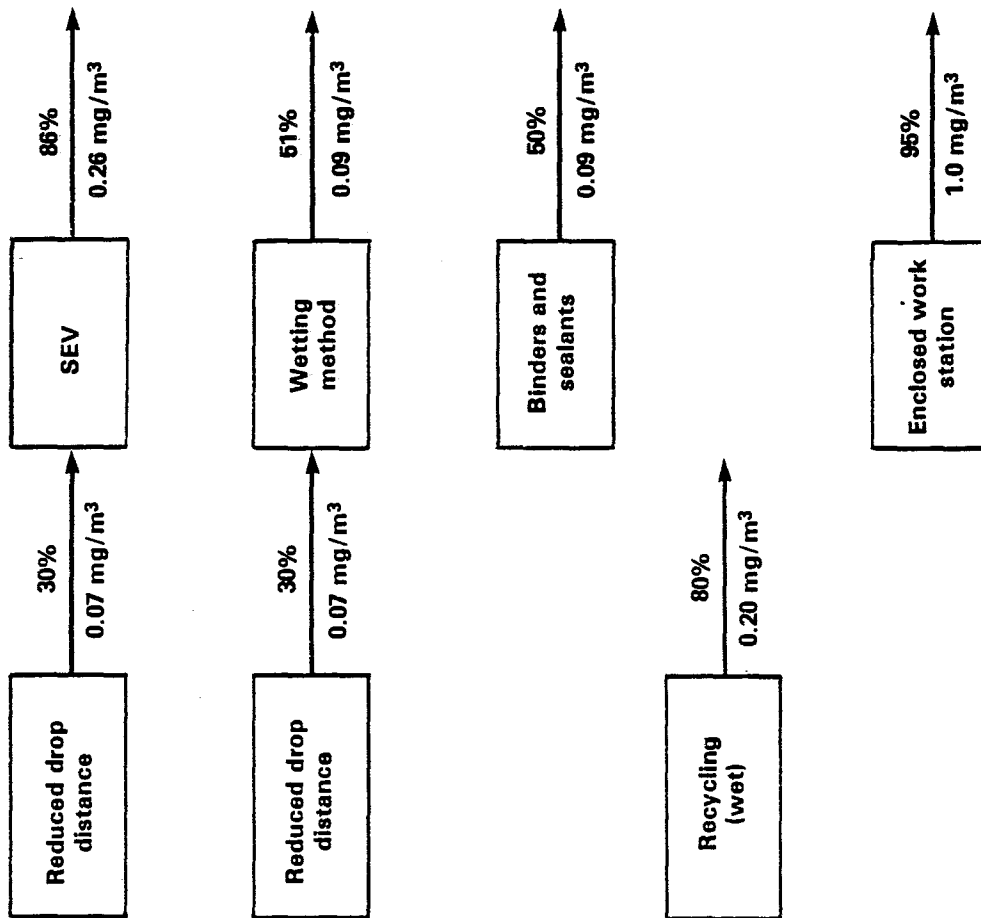
Several process modifications can be used as point source controls to decrease the amount of dust formed in storage operations: reducing drop distance, enclosing dust sources, and recycling dust back into the process stream. The first of these control methods was discussed in Chapter 4; a dust reduction efficiency of 30 percent can be attained if the drop distance is reduced by one half. Stockpiled material can be reclaimed by a tunnel conveyor system; reclaim tunnels eliminate the need for front-end loaders or other mobile equipment to transfer stockpiled material. These tunnels are enclosed and have trapdoors to control ore flow on the conveyor belt. Although such a system can be very effective in controlling dust emissions, no data were available for estimating an expected efficiency.

Dust recycling is a point source control method that can be used dry or wet. With wet recycling, the dust is slurried and sent back into various mill processes. If the recycled material can be completely wetted, an 80 percent dust reduction efficiency is attainable; this efficiency is the highest of those listed in Chapter 4 for wetting methods. With dry recycling, equipment enclosure can be used to control dust emissions. As discussed in Chapter 4, no data were available on the effectiveness of equipment enclosure, and therefore no expected dust reduction efficiency is assigned for dry recycling.

SEV can also be used as a point source control in storage operations. Small storage areas can be equipped with SEV; however, it is not possible to use SEV with large long-term storage piles. As discussed in Chapter 4, a properly designed SEV system has an 80 percent reduction efficiency. Binders and sealants can be used as a point source control to cover the surface of ore and waste material; these are expected to reduce dust emissions by 50 percent. Foams can also be sprayed to cover the surfaces of dusty material, and can achieve a dust reduction efficiency of 50 percent. Wetting methods can be 30 percent effective in controlling dust during the transfer and unloading process steps, as discussed in Chapter 4.

The choice of any combined point source control strategy will depend on the abrasiveness of the material (since abrasive materials can damage reclaiming equipment), the solubility of the material in water, and its hygroscopicity and cementing tendencies. Depending on the dust reduction efficiencies required for individual storage operations, single control options or a combination of controls may be needed. Combinations of methods and their expected dust removal efficiencies (ranging from 30 to 80 percent) are shown in Figure 5-19.

As illustrated in Figure 5-18, binders and encrusting agents and revegetation methods can be used to provide surface coverage for inactive storage piles. Chemical binders and encrusting agents cause the surface particles to adhere to one another, forming a crust that is resistant to rain and insoluble in water. As mentioned above, binders and sealants are expected to reduce dust by 50 percent. Planting vegetation is a control method designed to prevent rain and wind erosion of storage piles; however, several years may be required before an adequate plant covering is established. Because of the variability in the time required to revegetate an area and the differences in results when different plant species are used, no dust reduction efficiency is assigned to revegetation.



Note: Concentrations shown are the levels that can feasibly be reduced to the 0.05 mg/m³ PEL.

Figure 5-19. Applicable combinations of dust control options and applicable reduction efficiencies for active storage operations.

JRB has not assigned a dust reduction efficiency to waste management procedures because of the variability in material bulk density, storage area climate, and packing tendency and other physical factors of the material. Materials of low bulk density are most affected by wind, rain, and snow and would therefore require extensive waste management procedures. Coarse material with only a small amount of fines would not need extensive maintenance.

5.13.2 Feasibility Assessment of Silica PEL's

In storage operations, dust exposure occurs primarily in active storage sites. Since there were no MSHA data related to this operation, no feasibility assessment could be performed. However, based on the expected dust reduction efficiencies of applicable combinations of methods and allowing for a 5 percent margin of error, the highest dust concentrations that can be reduced to the 0.05 mg/m³ PEL range from 0.09-1.0 mg/m³ PEL, depending on the control methods chosen (Figure 5-19).

5.13.3 Feasibility Assessment of Asbestos PEL's

Mineral fiber exposure data were not available for storage operations, and the feasibility of asbestos PEL's cannot therefore be assessed.

5.14 CRUSHING, GRINDING, AND SIZING

5.14.1 Dust Sources and Control Methods

In terms of dust emissions and controls, crushing, grinding, and sizing operations can be divided into five major process steps: crushing, grinding, sizing or screening, conveying, and material transfer. The major dust emission sources are the openings in the equipment used in these processes, and specifically the feed, discharge, and transfer points. Additionally, dust releases through gaps in the equipment enclosures, and sources of ambient dust such as dust from nearby operations and reentrainment of dust on equipment, beams, and floors may contribute to the overall dust exposures occurring during these operations. The MSHA job codes included in this operation category are hoisting, crushing, grinding, sizing, storing, transfer, and conveying. Operations related to these job codes are conducted primarily at surface locations. Dust control methods are evaluated below for each of the five process steps involved.

Primary Crushing--

In primary crushing operations, the major dust source is the feed point. Control options available for this point are shown in Figure 5-20. The expected dust reduction efficiencies, as derived in Chapter 4, are shown in the figure. Because of the size of primary crusher feed systems, using SEV (enclosure and exhaust system) is not possible; the 80 percent reduction efficiency is therefore only applicable to smaller equipment such as that commonly used

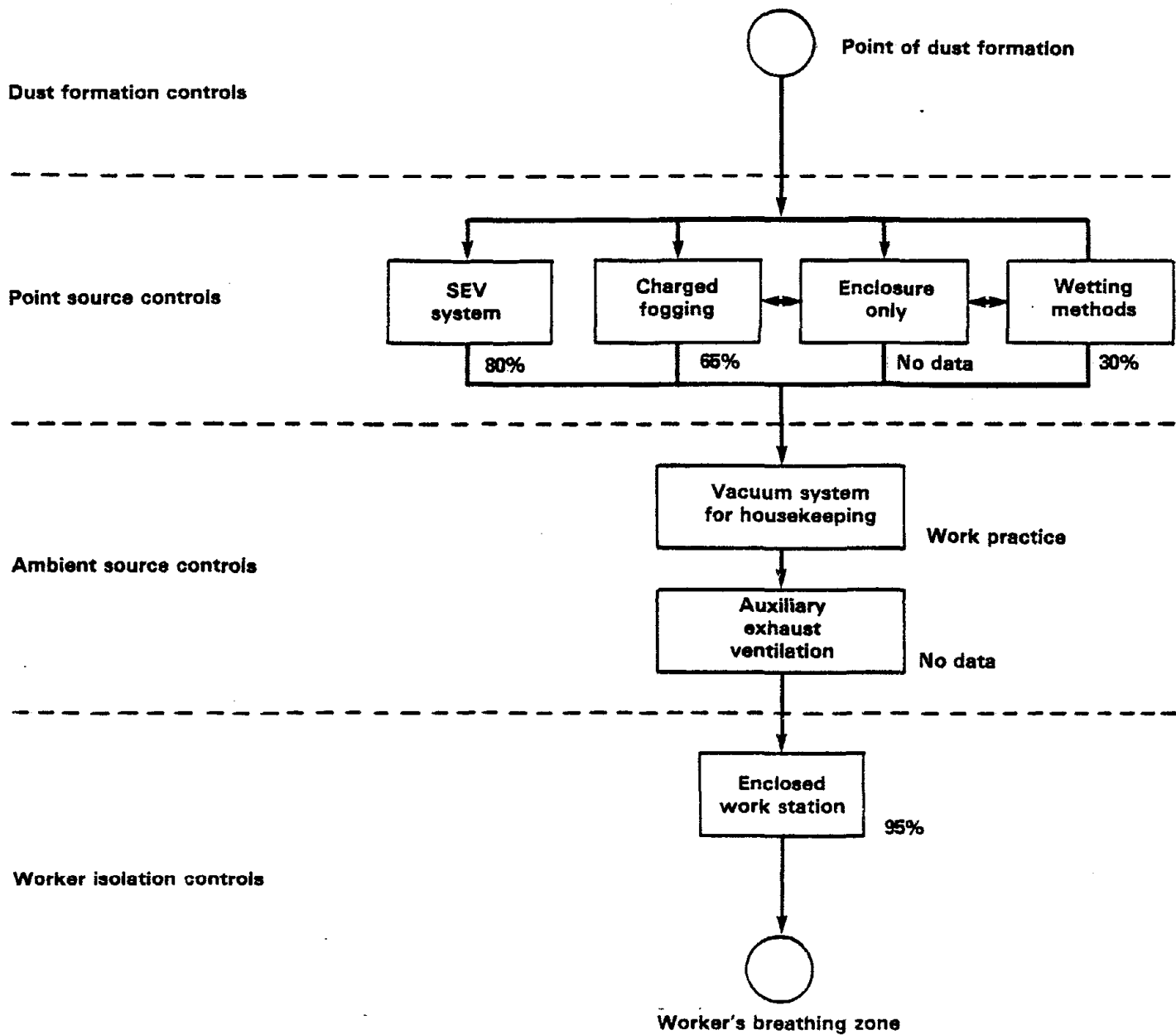


Figure 5-20. Flow diagram of dust control options and applicable reduction efficiencies for primary crushing (feed side).

in some nonmetal industries. Wetting methods can reduce dust by 30 percent, as discussed in Chapter 4, and they are often used for suppressing dust at crusher feed points, as JRB observed during a site visit to a sand and gravel operation (Site Visit Report No. 8). For large primary crushers, the only method that will provide more than a 65 percent reduction efficiency is use of a control booth equipped with a positive-pressure air-filtering system, which yields a removal efficiency of 95 percent (Chapter 4).

Rodgers and coworkers (1978) found air-filtered booths to be the only effective control at the crusher feed in an iron and a copper mine. At the taconite processing plant the authors studied, silica concentrations inside the operator booth were 0.05 mg/m³; outside the booth the concentrations were 1.13 mg/m³. At the copper ore crushing operation, partial enclosure of the feed and use of auxiliary ventilation resulted in silica concentrations of 0.16-2.37 mg/m³, which further indicated the need for positive-pressure air-filtered booths. During a site visit conducted for this project, JRB observed an air-filtered operation booth being used at a crusher station of a molybdenum and copper mine (Site Visit Report No. 7).

Secondary Crushing and Grinding--

The major sources of dust emission in secondary crushing and grinding processes are the feed and discharge points on the equipment, especially those on the secondary crushers. Applicable dust controls for this process step are shown in Figure 5-21. Except for wet processing, which is applicable only in grinding processes, the expected dust reduction efficiencies for other methods have already been discussed in Chapter 4 and are shown in this figure as well. No reports were found on the comparative dust reduction efficiencies of wet and dry grinding processes. However, if water sprays can eliminate up to 80 percent of the respirable dust from an open coal cutting operation (Tomb et al. 1972a), using a closed wet grinding process involving ores in slurry form should be even more effective in reducing dust emissions; therefore, an 80 percent reduction can be considered as the minimum achievable with a wet grinding process.

Two ambient source control methods are applicable in secondary crushing and grinding, primary ventilation and a vacuum housekeeping system, as shown in Figure 5-20. The former is a baseline control and the latter is a work practice; neither is therefore assigned a reduction efficiency.

Wet processing (where ore is mixed with water throughout the process) is not applicable to the secondary crushing process. Using water sprays at the feed point of a secondary crusher can achieve a dust reduction of 30 percent, and using SEV can achieve an 80 percent reduction in dust levels, as discussed in Chapter 4. Since these two methods are difficult to apply at the same time at a secondary crusher because of the possible clogging of ductwork, use of a SEV with an expected efficiency of 80 percent is the best single method. The use of water spray to suppress dust at crushers and SEV for removal of emitted

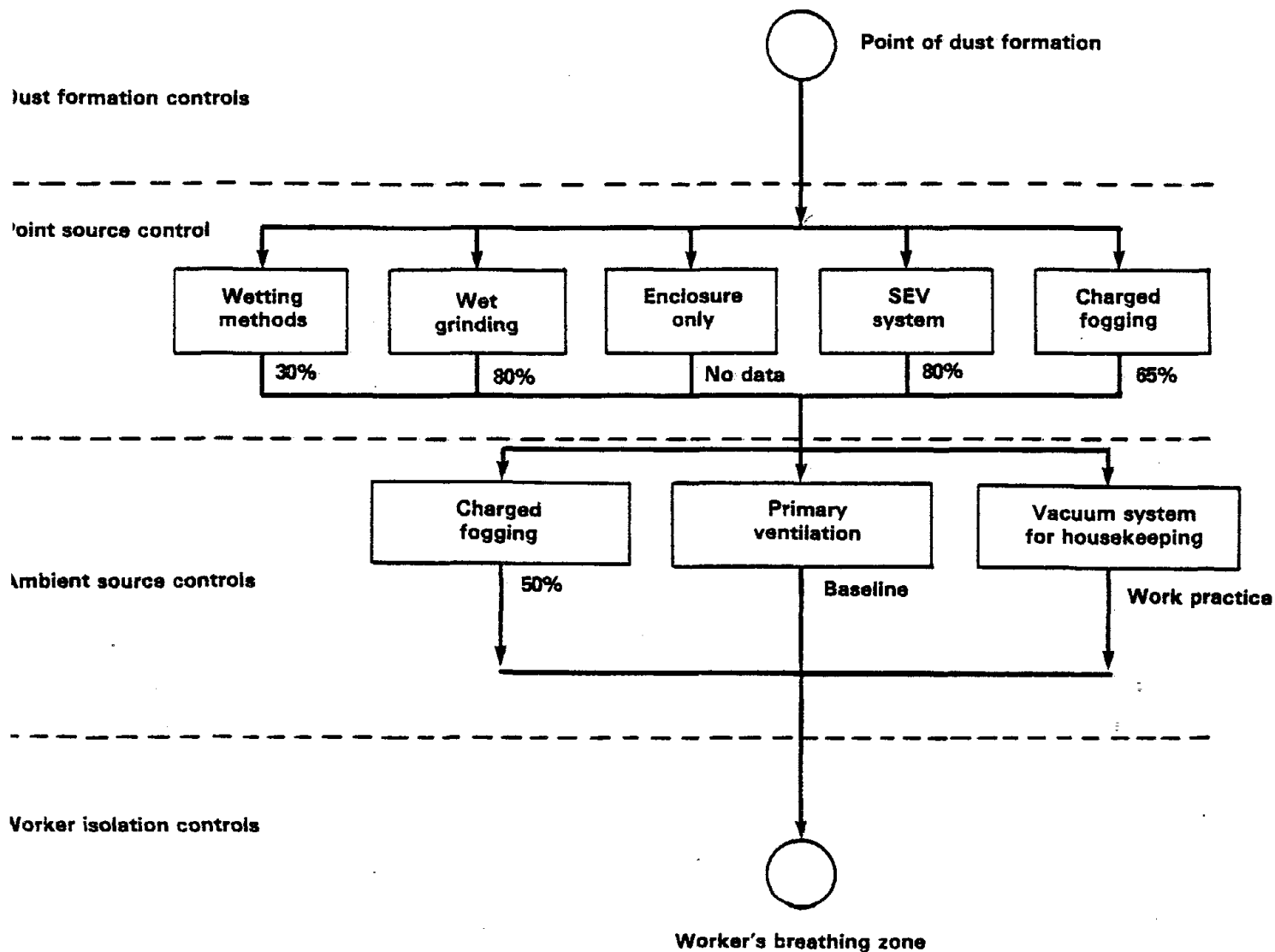


Figure 5-21. Flow diagram of dust control options and applicable reduction efficiencies for secondary crushing and grinding.

dust was observed at different locations during the site visits conducted for this project (Site Visit Reports Nos. 7 and 8). For higher dust removal efficiencies, SEV can be used along with charged fogging as an ambient control, which would have a combined dust reduction of 90 percent.

Sizing--

Dust emission can occur at the feed point or discharge point, and at the location of the vibrating screen or other size classifying-device used in this process step. Applicable dust control methods are shown in Figure 5-22. Wet sizing is assigned a respirable dust reduction efficiency of 80 percent, as in the case of wet grinding (discussed earlier in this section), since both are enclosed wet processing methods. Using SEV alone can be expected to achieve an 80 percent reduction, and combining the use of SEV and charged fogging as an ambient control (50 percent efficiency) would provide a combined reduction in dust levels of 90 percent. In locations where charged fogging cannot be used, enclosed work stations alone have a 95 percent reduction efficiency.

Conveying--

In conveying processes in crushing, grinding, and sizing operations, the primary source of dust is the entrainment of dust particles adhering to ore on the conveyor. Many dust control methods can be used in this process, as shown in Figure 5-23. In the figure, wetting methods are assigned a dust reduction efficiency of 50 percent rather than 30 percent, because applying a wetting method to the conveying process involves washing the underside of the conveyor belt in addition to spraying the ore with water; this dual technique is more effective in suppressing dust than water spray alone. Rodgers et al. (1978) found a reduction of 48 percent in respirable dust when a washing/spraying system was used at a conveyor belt in a taconite processing plant. A BOM study (1977a) reported a 50-60 percent reduction in respirable dust when an under-the-belt spraying system was used in a coal processing plant. When used as ambient source control methods, isolating dusty areas and using wind barriers will prevent dust particles from becoming airborne and contain airborne dust behind barriers. Since no data were available on the effectiveness of these methods, they are not assigned a reduction efficiency in this analysis.

As shown in Figure 5-23, the dust reduction efficiencies of individual methods applicable to the conveying process range from 30 to 80 percent, as discussed above and in Chapter 4. Depending on the required reduction efficiencies, a single method or a combination of several methods may be needed. Some of the combinations and their expected dust reduction efficiencies are shown in Figure 5-24. The examples given in this figure show that combinations of controls can provide dust reduction efficiencies ranging from 65 to 95 percent. The highest overall dust reduction efficiency (93 percent) can be achieved through the combined use of reductions in conveyor speed, SEV, and charged fogging (Figure 5-24).

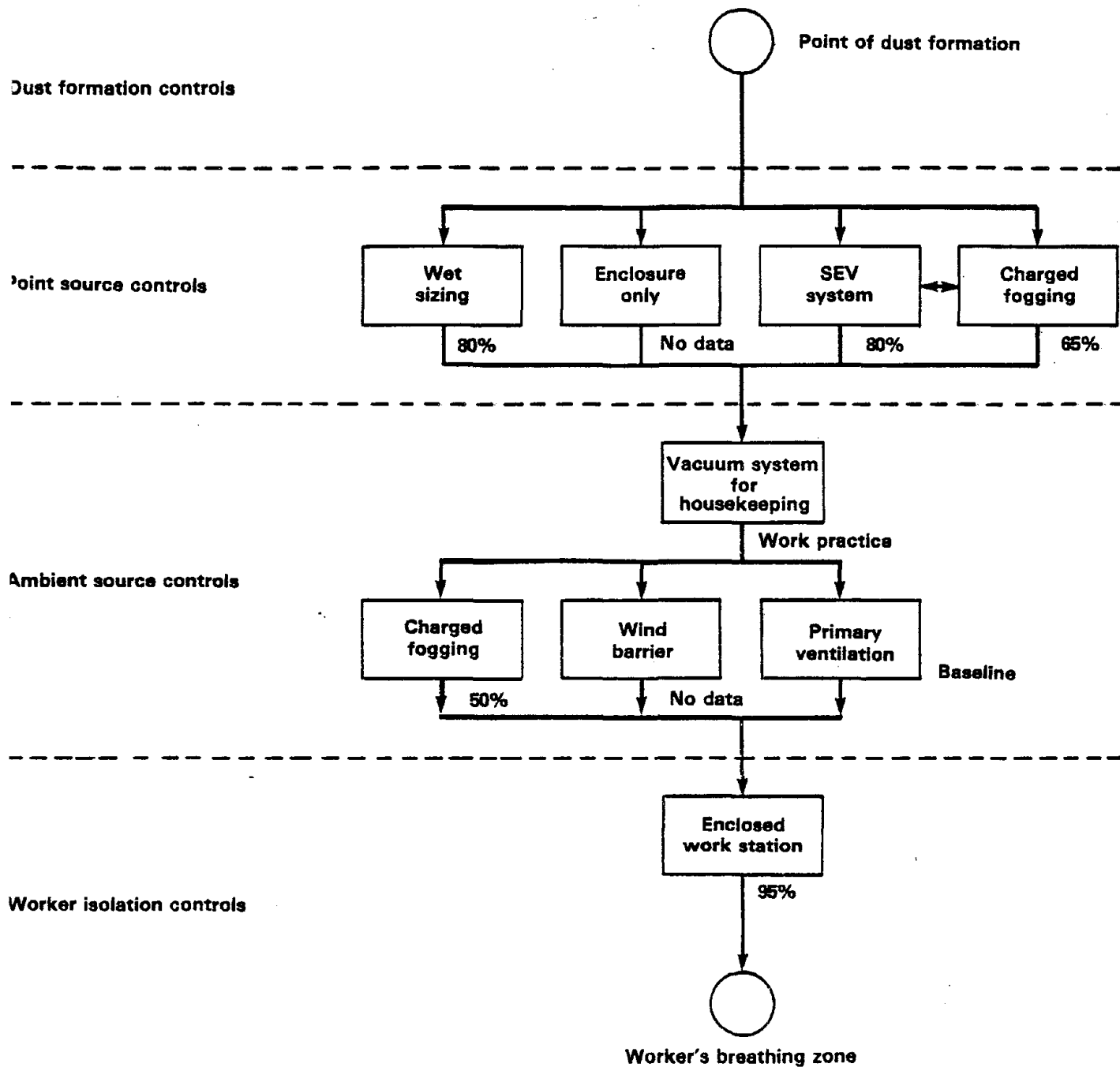


Figure 5-22. Flow diagram of dust control options and applicable reduction efficiencies for sizing.

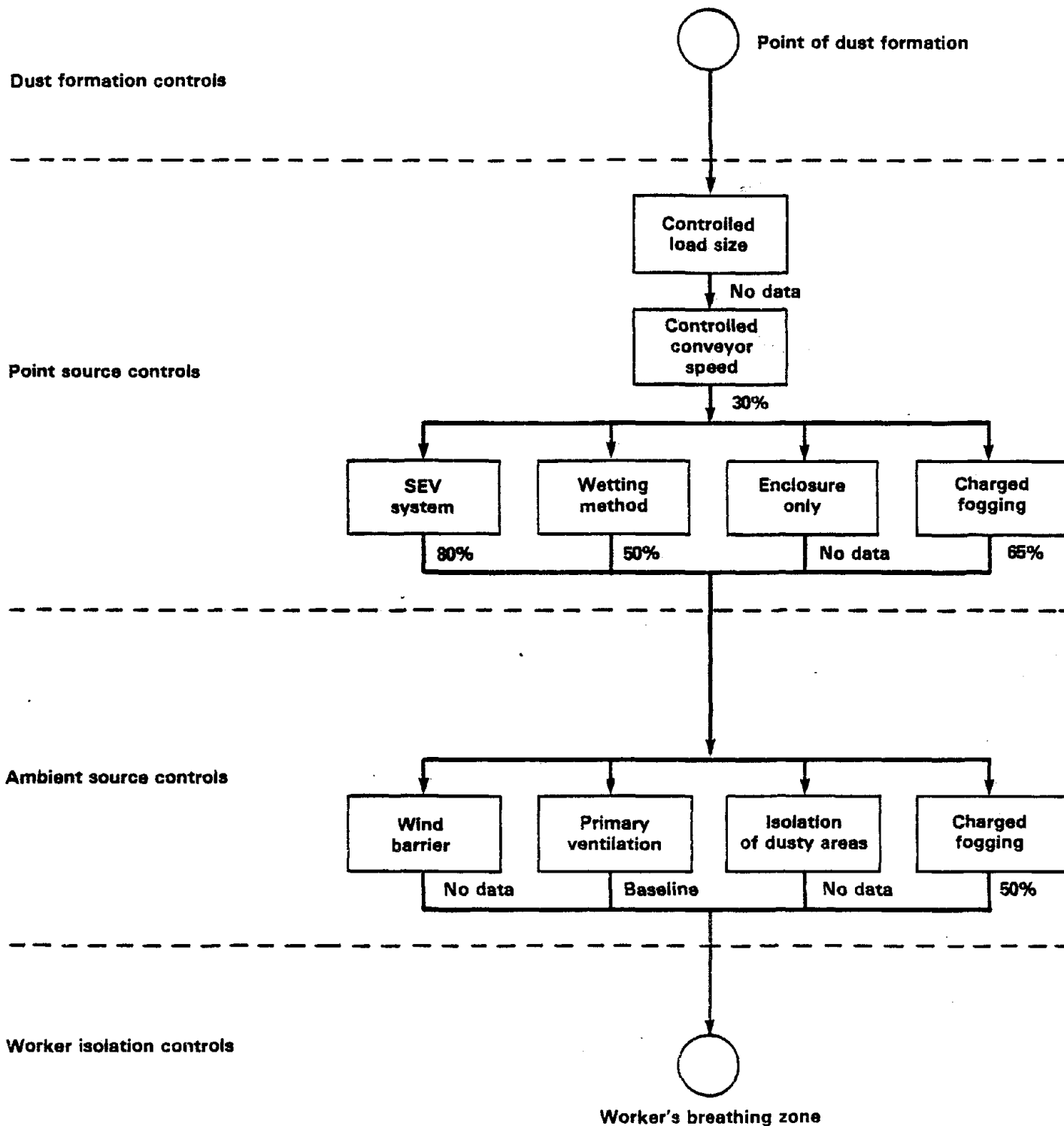


Figure 5-23. Flow diagram of dust control options and applicable reduction efficiencies for conveying processes.

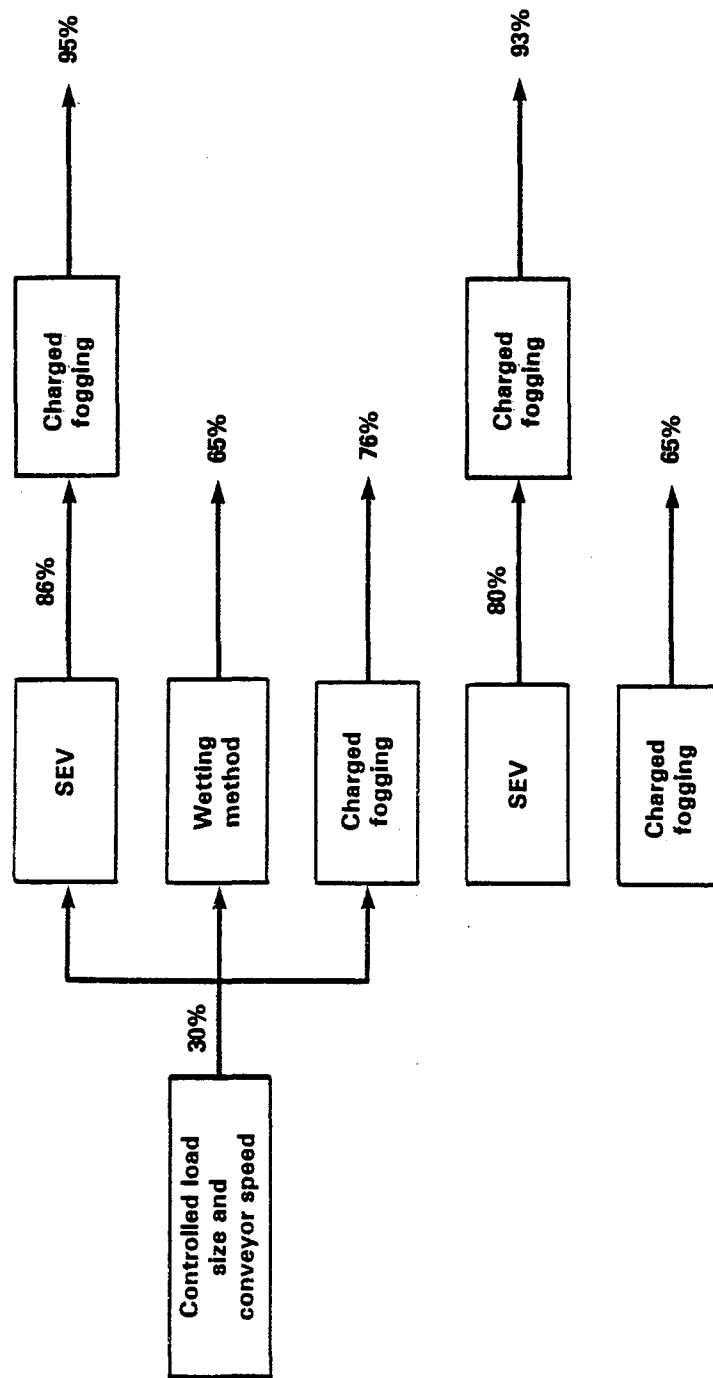


Figure 5-24. Applicable combinations of dust control options and applicable reduction efficiencies for conveying processes.

Material Transfer--

Material transfers occur at the end of a conveyor, where the ores are loaded onto a machine or another conveyor, and at the beginning of a conveyor, where ores are received from the discharge points of various machines. Airborne dusts are caused by the entrainment of dust generated by the falling ore. Individual control methods applicable to material transfer operations are shown in Figure 5-25, along with their expected dust reduction efficiencies, ranging from 30 to 80 percent (derived in Chapter 4). Many combinations of these control methods can be used; examples of such combinations, with their expected reduction efficiencies, are shown in Figure 5-26. These combinations have overall reduction efficiencies ranging from 75 to 93 percent.

5.14.2 Feasibility Assessment of Silica PEL's

According to MSHA data discussed in Chapter 2, the 95 percentile silica exposures in the crushing, grinding, and sizing operation category exceed the 0.075 mg/m³ PEL, and therefore the 0.05 mg/m³ PEL, for all industry groups considered. Table 5-18 shows the 95 percentile silica exposure data, the reduction efficiency required to reduce exposures to the 0.05 and 0.075 mg/m³ PEL's for each industry group, and the percentage of data points equal to or less than the PEL's. The reduction efficiency required shows that the molybdenum industry group would need to implement the most effective controls to achieve the 0.05 mg/m³ PEL, while the limestone and talc groups would need to implement the least stringent controls.

As discussed in Section 5.2.3, an initial determination of feasibility will be made based on the assumption that the 95 percentile exposure level is the same for all five process steps and that the PEL must be met in each of the steps. Based on the analyses of dust control methods for each of the five process steps in crushing, grinding, and sizing operations, the highest dust reduction efficiencies achievable are 95 percent in primary crushing, 90 percent in secondary crushing and grinding, 95 percent in sizing, 93 percent in conveying, and 93 percent in materials transfer. Using the lowest value (90 percent), JRB judges the 0.05 mg/m³ PEL to be infeasible in crushing, grinding, and sizing operations for the molybdenum and other metals industries, marginally feasible in the gold and silver, clay and shale, oil shale, and other nonmetals industries, and feasible for the remaining industries, including copper, iron, lead and zinc, uranium, limestone, other stone, talc, and sand and gravel.

Based on a 90 percent expected reduction efficiency and allowing for a 5 percent margin of error, the highest level that can be reduced to the 0.05 mg/m³ PEL with the control methods discussed above in crushing, grinding, and sizing operations for all industry groups is 0.33 mg/m³. The factors contributing to the feasibility assessments are discussed below for each sector judged marginally feasible or infeasible.

For the oil shale industry, only two data points from one mine were available. JRB does not know how representative these data are of exposures in the industry as a whole. If these two samples are representative, this

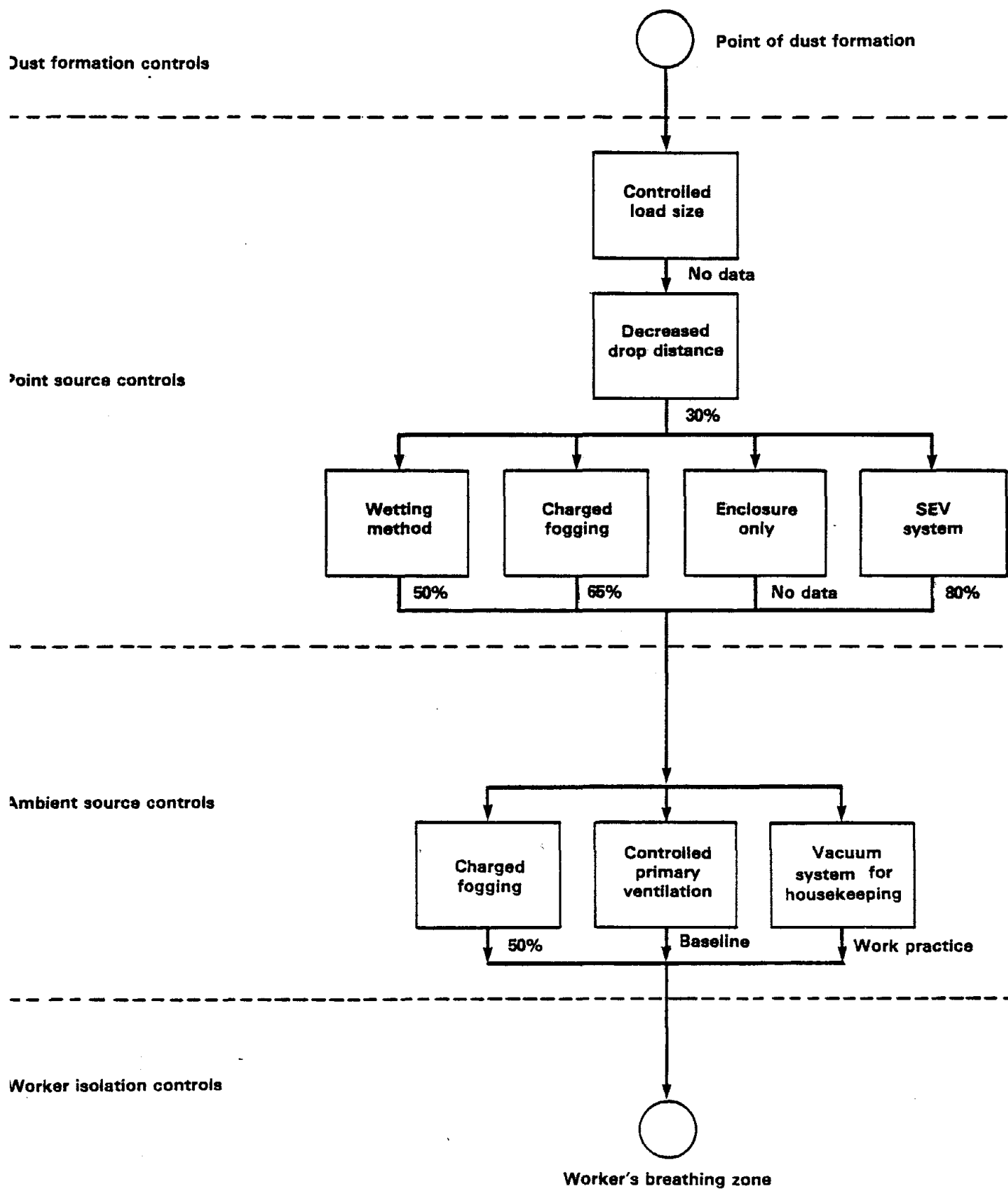


Figure 5-25. Flow diagram of dust control options and applicable reduction efficiencies for a conveyor transfer point.

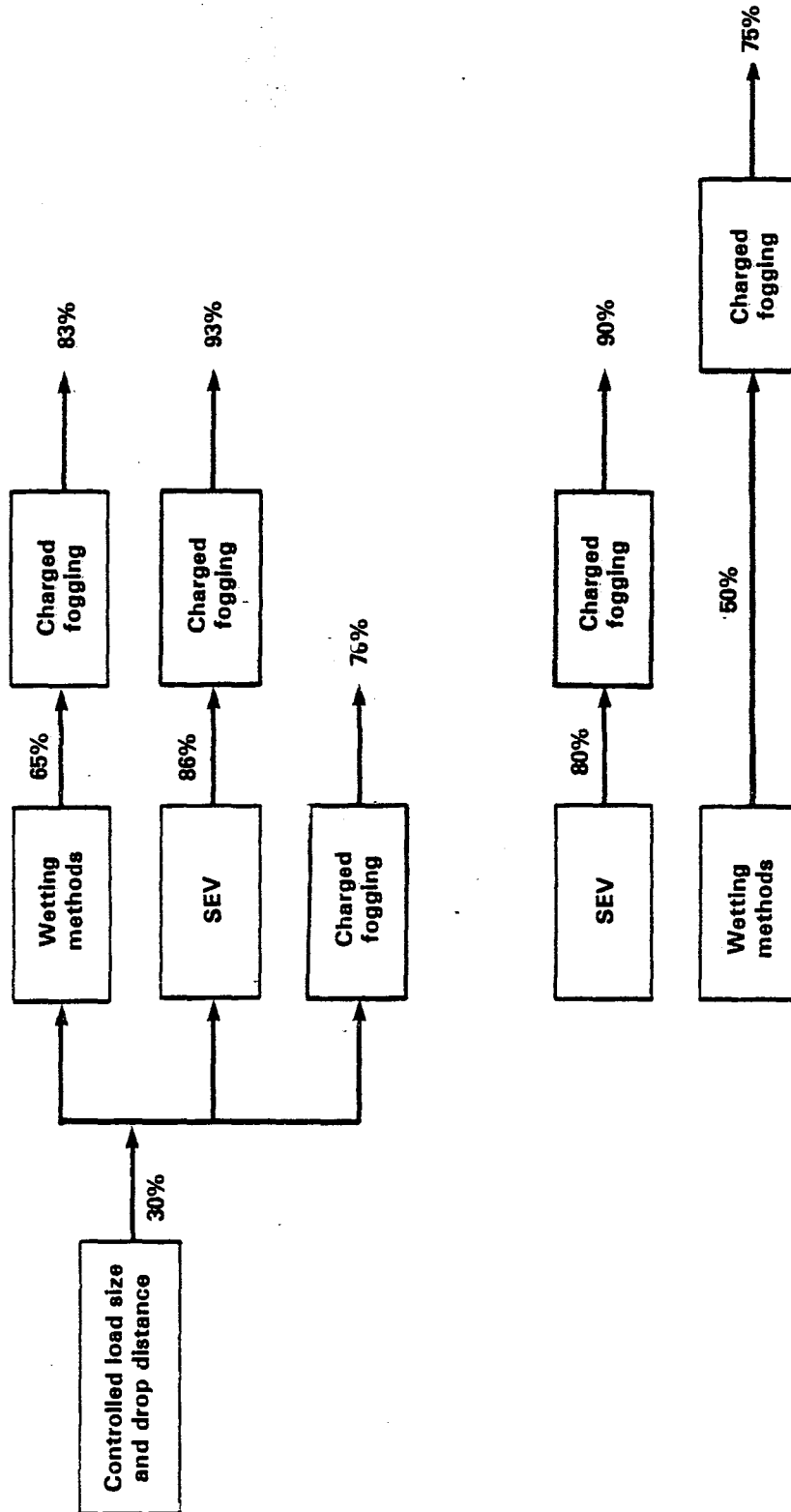


Figure 5-26. Applicable combinations of dust control options and applicable reduction efficiencies for conveyor transfer processes.

Table 5-18. 95 Percentile silica exposure data and percent reductions required to meet the silica PEL's in crushing, grinding, and sizing operations.

Industry group	95 Percentile exposure level (mg/m ³)	Percent reduction required to meet the 0.05 mg/m ³ PEL	Percent reduction required to meet the 0.075 mg/m ³ PEL	Percent of data points equal to or less than 0.05 mg/m ³ PEL
Copper	0.27	81	72	64
Gold and silver	0.38	87	80	48
Iron	0.20	75	63	68
Lead and zinc	0.26	81	71	61
Molybdenum	1.5	97	95	25
Uranium	0.27	81	72	71
Other metal	1.32	96	94	47
Limestone	0.12	58	38	83
Other stone	0.33	85	77	57
Clay and shale	0.38	87	80	51
Asbestos	--	--	--	--
Talc	0.14	64	46	80
Oil shale	0.7	93	89	0
Other nonmetal	0.56	91	87	59
Sand and gravel	0.29	83	74	68

Source: JRB calculations based on MSHA data.

A double dash indicates that no exposure data were available.

industry would not be able to achieve the 0.05 mg/m^3 PEL. However, if further sampling reveals that typical exposures are lower than is suggested by these two data points, the PEL might be achievable in this operation category.

In the other metals industry group, comprised of many diversified metal industries, data were also limited; in addition, seven of the nine data points showing exposures above the 0.05 mg/m^3 PEL were taken in one antimony mine. The 95 percentile concentration is therefore based on samples from this mine only. If additional data show that these high levels are not typical of the exposures in the other metals industry, the 0.05 mg/m^3 PEL might be feasible. Since most of the samples contributing to the judgment of marginal feasibility were taken in an antimony mine, the exposure data documented may not be typical of mines producing other commodities included in this industry group. It is possible that samples from other mines in this group would alter the assessment of feasibility made for crushing, grinding, and sizing operations in this group. Based on the available exposure data for this industry group and the dust reduction achievable, the 0.075 mg/m^3 PEL would be marginally feasible.

For the other nonmetals group, the 0.05 mg/m^3 PEL is considered marginally feasible. Of the 216 samples available from crushing, grinding, and sizing operations for this industry group, 90 percent had levels no higher than 0.33 mg/m^3 , which could be reduced to the 0.05 mg/m^3 PEL using available technology. For this industry group, the 0.075 mg/m^3 PEL is also marginally feasible because an 87 percent reduction in silica exposure is required to meet this PEL, which is within the 5 percent margin of error of the 90 percent reduction achievable.

The 0.05 mg/m^3 PEL has been judged to be marginally feasible for the gold and silver and the clay and shale industries. In both of these industries, only about 6 percent of the samples were above the maximum level that can be reduced to the 0.05 mg/m^3 PEL. The 0.075 mg/m^3 PEL is feasible in both cases.

For the molybdenum group, achieving the 0.05 mg/m^3 PEL is infeasible because the required reduction efficiency is 95 percent and no method can be expected to achieve a dust removal efficiency of 100 percent (5 percent more than 95 percent). However, exposure data for the crushing, grinding, and sizing operations in the molybdenum industry were available only from two of the 13 sites active in 1980. The exposure concentrations at one of the sites ranged from 0.02 to 0.24 mg/m^3 , with a mean of 0.07 mg/m^3 , while the concentrations at the other site ranged from 0.03 to 0.94 mg/m^3 , with a mean of 0.39 mg/m^3 . Obviously, the degree of dust removal required at only one of these sites was the controlling factor in establishing the 95 percentile concentration. Also, only the exposures at the crushing operation were found to be high in the molybdenum group; concentrations at the grinding and sizing process steps were no higher than 0.074 mg/m^3 , which requires only a 32 percent reduction to meet the 0.05 mg/m^3 PEL.

5.14.3 Feasibility Assessment of Asbestos PEL's

The 95 percentile mineral fiber exposure level and the required reduction to meet the asbestos PEL's in crushing, grinding, and sizing operations for each industry are shown in Table 5-19. For five sectors, the copper, lead and zinc, molybdenum, uranium, and oil shale industry groups, there are no data.

As discussed above, the highest dust reduction efficiencies that can be achieved in each of the five process steps involved in crushing, grinding, and sizing range from 90 to 95 percent. Based on the 90 percent expected reduction efficiencies, the 1.0 and 0.5 fibers/cc PEL's can be achieved by all industries for which exposure data are available, since the reduction in fiber exposure required to meet these two PEL's is no higher than 83 percent. The lowest PEL, 0.1 fibers/cc, is feasible only in two industries with exposure data, the gold and silver and the iron industries. The exposure level for the clay and shale industry is already below the 0.1 fibers/cc PEL. This PEL is infeasible in three industries (other stone, asbestos, and sand and gravel) since a reduction in dust levels of at least 95 percent is required. For the remaining four industries, other metals, limestone, talc, and other nonmetals, the 0.1 fibers/cc PEL is marginally feasible.

Exposure data in several industries were extremely limited for this operation category. The other metals and the clay and shale industries both had only one data point, while the gold and silver industry had four samples. Feasibility determinations for these three industries might change if more data were available. For the other industries in this operation category, at least 10 data points were available.

5.15 CONCENTRATING AND FINISHING

5.15.1 Dust Sources and Control Methods

After ore is crushed, ground, and sized, concentrating and finishing operations are performed to yield a product that is ready for shipping. Except for the oil shale industry and dimension stone quarries (in the limestone and other stone industry groups), concentrating and finishing operations for other minerals generally follow a process flow of classifying, separating, drying, heat treating, bagging, storing, and shipping. Classification is a process in which ore particles of various sizes and densities are separated by a hydraulic or mechanical procedure. Separation of economic ore from waste rock is then accomplished by gravity concentration, heavy-medium separation, froth flotation, magnetic separation, high-tension separation, or leaching. The separating and concentrating process is often performed as a wet process, after which the ores need to be dried. The drying process usually involves a centrifuging, vacuum filtering, or thickening procedure to remove excess water from the ore. The ore may require further refining by heat treatment, which may include sintering, roasting, or briquetting procedures. After heat treatment, the ore is ready to be shipped in bags or in bulk.

Table 5-19. 95 Percentile mineral fiber exposure data and percent reductions required to meet the asbestos PEL's in crushing, grinding, and sizing operations.

Industry Group	95 Percentile fiber exposure (fibers/cc)	Percent reduction required to meet the 1.0 fibers/cc PEL	Percent reduction required to meet the 0.5 fibers/cc PEL	Percent reduction required to meet the 0.1 fibers/cc PEL
Copper	--	--	--	--
Gold and silver	0.4	None	None	75
Iron	0.6	None	17	83
Lead and zinc	--	--	--	--
Molybdenum	--	--	--	--
Uranium	--	--	--	--
Other metals	0.8	None	38	88
Limestone	1.5	33	67	93
Other stone	2.0	50	75	95
Clay and shale	0.04	None	None	None
Asbestos	3.0	67	83	97
Talc	1.5	33	67	93
Oil shale	--	--	--	--
Other nonmetals	1.1	9	55	91
Sand and gravel	2.0	50	75	95

Source: JRB calculations based on MSHA data.

A double dash indicates that no exposure data were available.

For oil shales, retorting is used to extract kerogen from the ore; this can be done in special retorting vessels or directly underground. For dimension stone quarrying, finishing operations include sawing, sandblasting, and polishing.

In concentrating and finishing operations, bagging and bulk loading processes can produce significant amounts of dust. Any dust escaping from the bagging machine or filled bags contributes to airborne levels, and dust that adheres to the outside of bags will also be dispersed when it is disturbed during bag handling. During bulk loading processes, dust can be dispersed if filling spouts are not enclosed. Many classifying, separating, and concentrating processes are performed wet, which reduces problems of dust emission. However, dust can become airborne at the feed and discharge points of drying and heat treating equipment and along conveyors that transport materials between the process steps. The MSHA job codes that are included in this operation category are roasting and retorting, drying and filtering, concentrating, chemical operations, bagging, and palletizing.

Many processes are involved in the concentrating and finishing operation category. To facilitate discussion, the processes used in this operation are broadly divided into four groups. For concentrating and separating operations that generally use wet processing methods, dust exposure is normally not a problem; therefore, dust control methods are not considered for this group of processes. The pre-bagging processes of drying and heat treating generate airborne dust primarily at material transfer points, and these processes will be considered as a unit. The processes of bagging and palletizing are treated as a unit because the principal sources of dust are associated with the use of the bagging machine and the palletizing process, and dust controls must be adapted for these special units of equipment. Bulk loading processes are also treated as a distinct unit because a different set of dust controls must be used in these processes.

Pre-bagging Processes--

In pre-bagging processes, which include drying and heat treating, the major source of dust is the conveyor transfer point at which dry material is loaded into or discharged from process equipment. Dust control at transfer points is discussed in Section 5.14, Crushing, Grinding, and Sizing. According to the analyses made in that section, a dust reduction efficiency of 30-93 percent can be expected from various combinations of control methods. For example, a reduction efficiency of 93 percent could be achieved by controlling load size and drop distance, and using SEV and charged fogging.

Bagging and Palletizing--

Applicable dust control methods for bagging and palletizing processes are shown in Figure 5-27. These methods can be applied to any plant that packages its products, but would not be applicable to plants where the products are shipped in bulk or in containers rather than bags. Palletizing and bagging operations are not generally used in the metal industries (copper, gold and

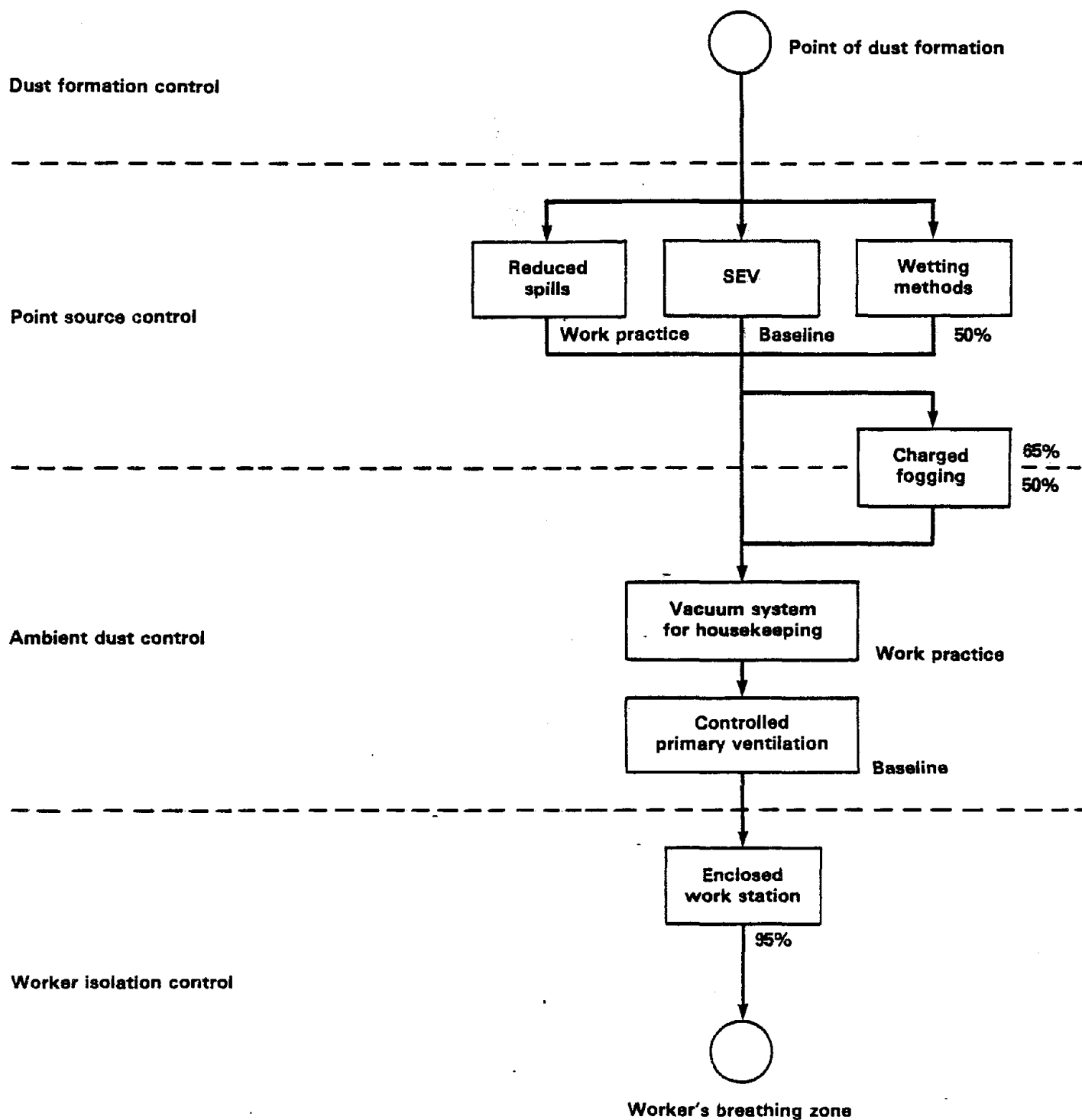


Figure 5-27. Flow diagram of dust control options and applicable reduction efficiencies for bagging and palletizing processes.

silver, lead and zinc, iron, molybdenum, uranium, and other metals), and feasibility is therefore not an issue for these operations in these industries. The first dust control method to consider at bagging processes in the affected industry groups is modifying or improving the design of bagging machines to reduce the amount of spilled dust. Many modifications have been suggested, although no data concerning their effectiveness were found. These modifications may involve

- Delaying the release of bags from the filling nozzle (Volkwein, in ACGIH 1978)
- Using auger-type bagging machines (Schutz et al. 1980a; Weems et al. 1980)
- Using inflatable valve sleeves or tapered sleeves (Schultz 1980a)
- Improving bag quality, e.g., using bags with stronger seams (Volkwein, in ACGIH 1978), plastic-based bags (Li 1975), sturdier bags (Weems and Schutz 1979), and staggered perforations in multi-wall bags (Volkwein, in ACGIH 1978).

These methods reduce dust spills (and airborne dust) in much the same way as work practices do. Since work practices are not assigned additional dust reduction efficiencies for the purpose of feasibility assessment (Chapter 4), bag design modifications and procedures are also not assigned reduction efficiencies.

In addition to these process modifications, SEV with intake hoods at the spouts or exhaust hoods over the bagging machine are most effective in controlling dust in bagging processes. A study by BOM (1977b) on an exhaust hood mounted on a fluidized bagging machine reports a respirable dust reduction efficiency of 83 percent. Volkwein (in ACGIH 1978) reported an efficiency of 89 percent at a bagging operation station in a silica flour mill. A SEV system is normally designed into or retrofitted onto a bagging machine and is therefore considered as a baseline control, although it may not always be as effective as reported in these studies (personal communication, MSHA inspectors, 1983). To be effective, SEV should also be used at the hopper and screw conveyor located beneath the bagging machine. The SEV's indraft velocity is the most important factor in controlling dust. Schutz and coworkers (1980a) recommended that the indraft velocity at the intake vent near a filling spout be at least 400 ft/min, and Weems and Schutz (1979) recommended that the minimum indraft velocity for an exhaust hood over a bagging machine be 250 ft/min, and 400 ft/min for the hood over a hopper.

Wetting methods applicable to bagging operations include injecting a small amount of water into the bags during the filling process and wetting the exterior of the bag, as described by Volkwein et al. (1982a). Based on results of two to four trials, injecting water into the bag was found to reduce respirable dust by 50 percent at the bagging machine, while wetting the exterior of the bag reduced dust by 15 percent at a nearby railcar loading station but did not reduce dust exposure at the bagger position. Because of

material moisture content requirements and freezing problems, injecting water into the bags may not be possible with certain types of products such as cement and talc. Where applicable, internal injection of water will be assigned an expected dust reduction efficiency of 50 percent.

In addition to water injection into the bag, charged fogging, which has an expected dust reduction efficiency of 50 percent as an ambient control (as discussed in Chapter 4), may be used. A combination of these two methods, each of which has a 50 percent reduction efficiency, would provide an overall dust reduction efficiency of 75 percent.

At palletizing stations, filled bags are stacked manually or by a palletizing machine. For the palletizing machine operator, an operator booth equipped with an exhaust system or a totally enclosed booth can be used. If an exhaust system alone is used in the booth or in the equipment room, the expected dust reduction efficiency would be 80 percent, while an enclosed air-filtered booth would have an expected reduction efficiency of 95 percent, as discussed in Chapter 4.

In manual stacking operations, few dust control methods are available because the area concerned is usually large and open. Wetting the exterior of the bags can reduce dust by 15 percent, as reported by Volkwein et al. (1982a). Dust generated by the palletizing process may be further reduced by 50 percent with the use of charged fogging as an ambient control. If bag wetting and charged fogging are combined, an overall dust reduction efficiency of 58 percent can be expected.

For lift truck operators who move the pallets to a storage area or shipping station, the best control method is to seal the entire pallet with a plastic wrapping, thus eliminating this source of dust during handling.

Bulk Loading--

For the bulk loading process, applicable control methods are shown in Figure 5-28, along with their corresponding expected dust reduction efficiencies. The first line of control at the point source includes process modification, SEV, and the use of wetting methods. Modification of the loading process includes the use of drop socks, telescoping bin spouts, and pneumatic conveying systems. Drop socks are heavy-duty fabric tubes that are attached to hopper discharge points and lead into a transport vehicle. They decrease the amount of dust dispersion because the drop distance is decreased. Telescoping spouts will extend and adjust to the filling level in a transport vehicle, thus decreasing drop distances. These spouts can also be fitted with a SEV system (Stearn 1979). Drop socks and telescoping spouts control dust emission primarily by reducing drop distance, and this technique can be expected to have a dust reduction efficiency of 30 percent, assuming it reduces the drop distance by one half, as discussed in Chapter 4. Pneumatic conveying systems use air pressure differentials to transport material in a pipe and can load an enclosed car or truck through hose connections, thus eliminating open points. Vent openings in the car can be equipped with an

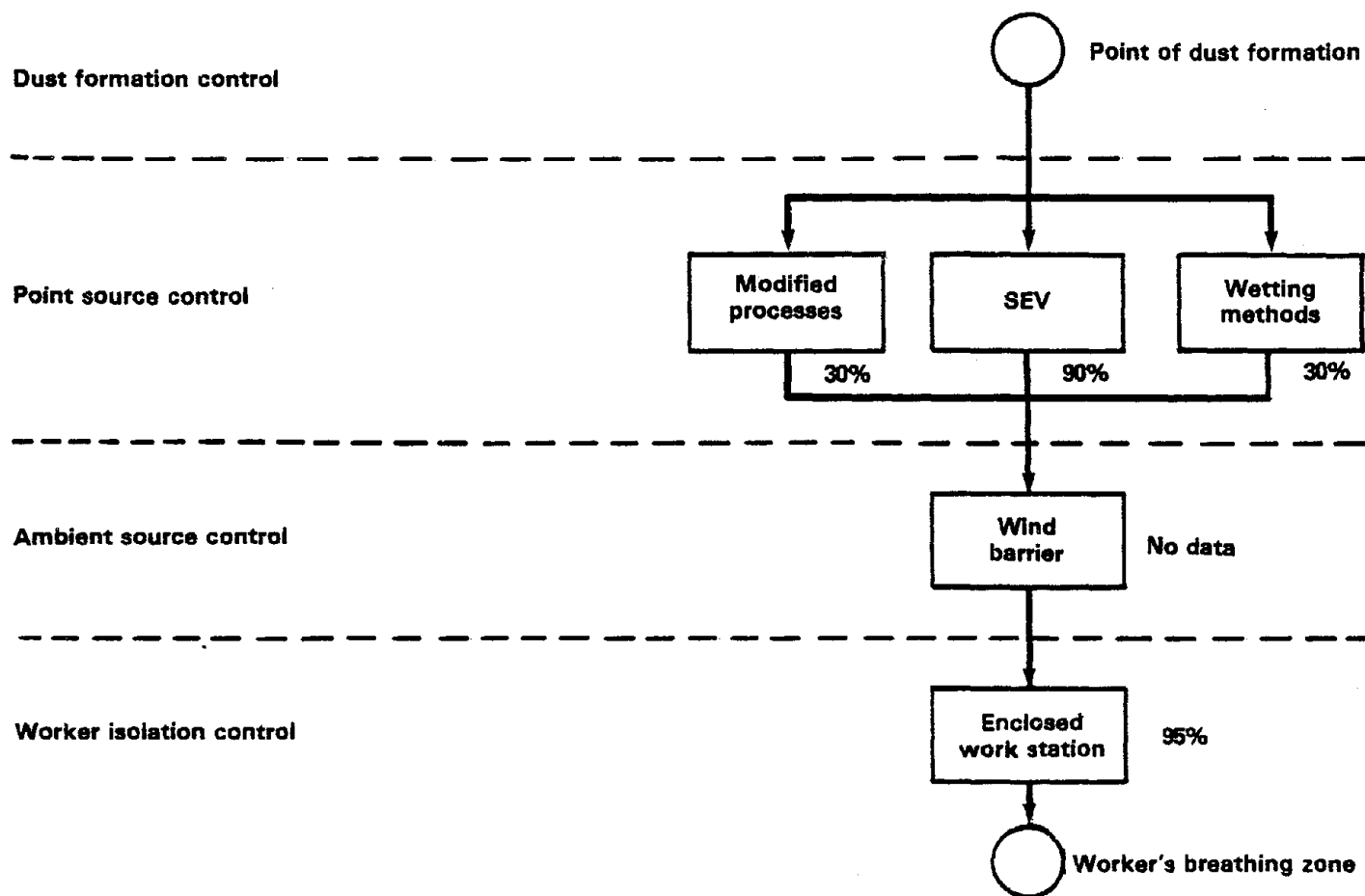


Figure 5-28. Flow diagram of dust control options and applicable reduction efficiencies for bulk loading processes.

insertable filtering system to remove dust from the displaced air. This method works as an equipment enclosure, but no performance data were available.

SEV systems can be effectively used to enclose and remove airborne dust at transfer points from a storage bin or hopper to a truck or railcar. For example, adjustable canopy hoods were used at unloading points in concrete batch plants (Kothari and Gerstle 1980). Harris (1978) recommended covering the loading hatch of a railcar and ducting the displaced air to a SEV system for dust control at a railcar bulk loading process. According to Harris, a SEV system can capture up to 90 percent of the dust if the volume of exhaust air is sufficient, even if vent openings in the railcar cannot all be sealed. Based on this report, JRB has assigned a 90 percent reduction efficiency to SEV systems applied to the bulk loading process.

Water sprays, foams, and surfactants may be used to control dust in bulk loading operations, but are limited to certain specific applications where wetting is not a concern for the shipped product. The dust reduction efficiencies of these wet methods were discussed in Chapter 4.

Wind barriers can be used as an ambient source control to reduce the dispersion of dust caused by winds at bulk loading stations. No dust reduction efficiency has been assigned to this method because of the lack of information, as discussed in Chapter 4.

As the last line of control, a positive-pressure air-filtered control booth can be used to reduce the dust exposure of loading personnel. Such booths have expected dust reduction efficiencies of 95 percent (see Chapter 4).

5.15.2 Feasibility Assessment of Silica PEL's

Table 5-20 shows the 95 percentile exposure concentrations in concentrating and finishing operations for all industries. The percent reduction in silica dust concentration required to meet the 0.05 and 0.075 mg/m³ PEL's are also shown in the table. The 95 percentile exposure concentrations found in three industry groups, copper, molybdenum, and other metals, currently meet the 0.05 mg/m³ PEL. However, there was only one data point for the molybdenum industry, and no data were available for concentrating and finishing operations in the asbestos and oil shale industries.

For the remaining metal industry groups (gold and silver, iron, lead and zinc, and uranium), where bagging processes are normally not used, dust exposure at the various transfer points involved in wet processing, heating, drying, and bulk loading can be controlled to the highest expected dust reduction of 93 percent with a combination of reduced drop distance, SEV, and charged fogging, or to 95 percent with the use of an air-filtered control booth. Because the required dust₃ reduction in these industries ranges from 33 to 72 percent, the 0.05 mg/m³ PEL is feasible for these metal industries. In fact, control options with less efficiency, such as those using a single method, the SEV, would be adequate.

Table 5-20. 95 Percentile silica exposure data and percent reductions required to meet the silica PEL's in concentrating and finishing operations.

Industry group	95 Percentile exposure level (mg/m ³)	Percent reduction required to meet the 0.05 mg/m ³ PEL	Percent reduction required to meet the 0.075 mg/m ³ PEL	Percent of data points equal to or less than 0.05 mg/m ³ PEL
Copper	0.05	None	None	95
Gold and silver	0.18	72	58	74
Iron	0.09	44	17	88
Lead and zinc	0.075	33	None	90
Molybdenum	0.03	None	None	100
Uranium	0.075	33	None	90
Other metals	0.06	None	None	91
Limestone	0.17	71	56	79
Other stone	0.73	93	90	40
Clay and shale	0.37	86	80	52
Asbestos	--	--	--	--
Talc	0.14	64	46	73
Oil shale	--	--	--	--
Other nonmetals	0.91	95	92	51
Sand and gravel	0.40	88	81	49

Source: JRB calculations based on MSHA data.

A double dash indicates that no exposure data were available.

For the nonmetal industry groups, a dust reduction efficiency of 64-95 percent is required to meet the 0.05 mg/m^3 PEL. Of the processes involved in concentrating and finishing operations in these industries, dust emissions from bagging machines often result in the highest exposure among the individual processes involved and are the most difficult to control. The highest efficiency achievable for reducing a bagger's exposure is 50 percent, achievable with the use of charged fogging. The 0.05 mg/m^3 PEL is therefore infeasible for all nonmetal industry groups for which data were available, including limestone, other stone, clay and shale, talc, sand and gravel, and other nonmetals. The 0.075 mg/m^3 PEL is also infeasible except in the talc industry because the required reduction to meet this higher PEL is 56-92 percent. For the talc industry, the 0.075 mg/m^3 is marginally feasible.

The conclusions concerning control of dust exposure in concentrating and finishing operations in the nonmetals industries are based on a conservative estimate of the degree of dust control achievable. Many control methods were not included in this analysis because of the lack of performance data. If control methods such as those mentioned in Section 5.15.2, including bagging machine modifications, improved SEV, and better housekeeping are used, further reductions in dust exposure for the bagging machine operator are expected. If dust exposure during the bagging process can be controlled, exposure at other process steps involved in concentrating and finishing operation can be reduced to meet the PEL's. The highest dust reduction achievable for other processes is between 93 and 95 percent, and the 95 percentile exposure concentrations for this operation would not be as high as those listed in Table 5-20 if data pertaining to the bagging process were excluded from the 95 percentile exposure concentrations.

Based on an expected dust reduction of 50 percent for the bagging operation, the maximum level of silica dust concentration that could be reduced to the 0.05 mg/m^3 PEL is 0.09 mg/m^3 , allowing for a 5 percent margin of error. For the other stone, clay and shale, and sand and gravel industries, about half of the sampled sites had concentrations above this level. In the limestone industry, about 15 percent of the sampled sites had samples with concentrations higher than 0.09 mg/m^3 . For the other nonmetals industry, 19 of the 58 sites had samples with concentrations above this maximum feasible level. These 19 sites included barite, gypsum, feldspar, vermiculite, phosphate rock, and other nonclassified mines. As mentioned previously, about half of the sampled establishments in the sand and gravel industry had exposure concentrations above the 0.09 mg/m^3 level; this level could be reduced to the 0.05 mg/m^3 PEL, using available controls. Silica flour plants are probably the plants with the highest level of silica dust because the material handled in the plant is practically all silica. However, in the MIDAS files, this industry has been included with sand and gravel plants as an industry group, and a more refined analysis of dust exposures and controls is therefore not possible based on the currently available data.

5.15.3 Feasibility Assessment of Asbestos PEL's

Personal exposure data on mineral fibers were only available for eight industries: iron, uranium, other metals, other stone, asbestos, talc, other nonmetals, and sand and gravel. The 95 percentile exposure levels and the reduction required to meet the asbestos PEL's in concentrating and finishing operations in these eight industries are shown in Table 5-21. The 95 percentile fiber counts are already at or below the 0.1, 0.5, and 1.0 fibers/cc PEL's in the iron and other metals industries.

Table 5-21. 95 Percentile mineral fiber exposure data and percent reductions required to meet the asbestos PEL's in concentrating and finishing operations.

Industry group	95 Percentile fiber exposure (fibers/cc)	Percent reduction required to meet the 1.0 fibers/cc PEL	Percent reduction required to meet the 0.5 fibers/cc PEL	Percent reduction required to meet the 0.1 fibers/cc PEL
Iron	0.1	None	None	None
Uranium	0.2	None	None	50
Other metals	0	None	None	None
Other stone	2.0	50	75	95
Asbestos	4.0	75	88	98
Talc	0.8	None	38	88
Other nonmetals	1.6	38	69	94
Sand and gravel	0.2	None	None	50

Source: JRB calculations based on MSHA data.

For the uranium industry, the 95 percentile exposure concentration is already below the 0.5 fibers/cc PEL, and a 50 percent reduction is required to meet the 0.1 fibers/cc PEL. Since applicable control methods are expected to provide a 90-95 percent reduction, the 0.1 fibers/cc PEL is feasible for this process in the uranium industry.

For the other stone industry, where bagging operations may be involved, an expected 50 percent reduction is achievable with available methods, but this will only make the 1.0 fibers/cc PEL marginally feasible. The lower PEL's are infeasible in the other stone industry group. For the same reason, i.e., available controls with a maximum expected dust reduction of 50 percent, all three PEL's are infeasible for the asbestos industry, in which a minimum reduction efficiency of 75 percent is required even to meet the highest PEL.

The 95 percentile exposure level in the talc industry at concentrating and finishing operations is already below the 1.0 fibers/cc PEL. With 50 percent as the achievable reduction, the 0.5 fibers/cc PEL is feasible but the 0.1 fibers/cc PEL is infeasible in this industry.

In the other nonmetals industry where dust reductions required to meet the 1.0, 0.5, and 0.1 fibers/cc PEL's are 38, 69, and 94 percent, respectively, only the 1.0 fibers/cc PEL is feasible because available controls can only achieve a 50 percent reduction. In the sand and gravel industry, the 95 percentile exposure concentration is already below the 0.5 fibers/cc PEL, and a 50 percent reduction is needed to meet the 0.1 fibers/cc PEL. Based on the expected achievable reduction in exposure at bagging operations, the 0.1 fibers/cc PEL is judged to be marginally feasible in the sand and gravel industry.

It should be noted that the feasibility assessments for fiber exposures for concentrating and finishing operations in some industries are based on a small number of samples. These industries include iron (three samples), other nonmetals (one sample), other stone (three samples), and sand and gravel (one sample).

5.15.4 Dimension Stone Quarries and the Oil Shale Industries

For the dimension stone sectors of the limestone and other stone industries, finishing operations are different from those described above because of the large size of the final product. Typically, finishing operations for dimension stone quarries include at least sawing, sandblasting, and polishing. The sawing operation is typically done by diamond rotary saws or wire saws in single or multiple strands, and is usually conducted wet. Sandblasting is used to carve and shape stone surfaces, and is usually conducted in an enclosed booth maintained under negative pressure. Non-silica abrasives are normally used in sandblasting. Polishing may be performed by automatic buffers in a wet mode, or may be done manually, which can involve a wet or dry process. In addition to these processes, small tool finishing with chisels or other tools may also be involved.

Dust can be emitted during any of these processes, especially when they are conducted dry. Since stone sawing is done wet, dust exposure is normally not a problem. When needed, additional dust reduction can be achieved by adding surfactant to the water, as was observed in a granite quarry visited for this project (see Site Visit Report No. 8). Where dust exposure does become a problem at sawing operations, SEV with an intake hood placed near the saw can be used and can be expected to remove 80 percent of the respirable dust. As discussed in Chapter 4, dust control for sandblasting is best achieved through the use of a negative-pressure sandblasting booth. The booth used at a granite quarry visited for this project was equipped with an exhaust filtration system to maintain negative pressure in the booth (Site Visit Report No. 8). The operator remained outside the booth and operated the blasting hose through a port that was tightly surrounded with rubber skirting. Considering such a booth to be a SEV system, a dust reduction efficiency of at least 80 percent can be expected. Similarly, SEV with an intake hood properly placed can be expected to remove at least 80 percent of the respirable dust generated in dry polishing operations.

Dust exposure during chisel finishing or other similar small tool finishing can be controlled with water sprays or SEV. Through the use of SEV, the respirable dust concentration in dimension stone finishing operations can be reduced by at least 80 percent, as discussed in Chapter 4. However, there were no MSHA exposure data specifically related to such operations; the feasibility of achieving one of the PEL's for this sector of the limestone and other stone industries cannot therefore be determined.

In oil shale retorting operations, workers can be exposed to dust from both raw and processed oil shale. Exposure to the processed shale dust may also occur during processed shale disposal (Coomes 1980). Oil shale retorting processes are still in the developmental stage, and most surface experiments or pilot plant operations are conducted on a batch basis. No representative exposure data were available on oil shale retorting operations, and the feasibility of controlling dust to the PEL's cannot therefore be assessed. Since dust exposure in the retorting operation occurs at the loading of the retort and disposal of the spent shale, dust control methods applicable to surface and underground production and storage operations could be used to control dust at these locations.

5.16 DUST CONTROL IN THE COAL MINING INDUSTRY

According to the Federal Coal Mine Health and Safety Act, average respirable dust exposure in active coal mines, as measured with a British Mining Research Establishment (MRE) or equivalent instrument, must be maintained below a 2.0 mg/m^3 PEL or below a number derived by dividing the number 10 by the percent silica content of the dust if the silica content is more than 5 percent. When expressed in absolute silica dust concentrations and corrected for the difference between the MRE and cyclone sampling equipment, this lower standard is equivalent to a level of 0.073 mg/m^3 (National Academy of Sciences 1980).

Control of dust exposure in coal mines depends on the mining system used. Of the approximately 3,500 coal mine sections active in 1981, 69 percent used continuous miners, 23 percent employed conventional methods, 3 percent mined with augers, 2 percent used the longwall mining system, and 3 percent employed other methods (personal communication, W. Southerland, November 1982). A brief review of dust controls in coal mines reveals that ventilation and water sprays are the primary methods of dust control used throughout the coal industry. Depending on the mining machine used, one of these methods may be more effective than the other. In continuous mining and auger mining, ventilation with proper design and arrangement of the air supply and air return can be used effectively. Because of the constantly moving shears in longwall mining systems, water spray is more effective than ventilation. In conventional mining, which may include drilling, blasting, and production operations, ventilation controls and water sprays are equally important.

As discussed in Chapter 1, the technological feasibility of dust control in the coal mining industry has not been assessed in this study. For further information on coal mine dust controls, two recent publications are particularly valuable as references: Measurement and Control of Respirable Dust in Mines (National Academy of Sciences 1980) and Improving Dust Control Technology for U.S. Mines (Breslin and Niewiadomski 1983). In both of these books, existing and developing control technologies are reviewed and extensive bibliographies are provided.

5.17 SUMMARY

The results of the feasibility analysis of the 0.05 and 0.075 mg/m³ silica PEL's are shown in Table 5-22. In this table, an "F" indicates that a PEL is feasible for the industry and operation represented by the cell, an "I" indicates that the PEL is infeasible, and an "MF" indicates that the PEL is marginally feasible. The storage operation category is not included in this table because no exposure data were available for it. An asterisk is placed in those cells where fewer than five data points were available or where all the samples were collected from one site or from fewer than 5 percent of the active sites in an industry sector.

Silica dust exposure data were available for all operation categories in most of the industry groups. Of the 121 cells where exposure data were available, the 0.05 mg/m³ PEL was found to be feasible in 73 cells and the 0.075 mg/m³ PEL was feasible in an additional 13 cells. Among the operation categories, underground production; crushing, grinding, and sizing; and concentrating and finishing operations had the highest number of industry groups in which the PEL's were found to be infeasible. On the other hand, in the surface drilling, surface haulageway maintenance, and underground haulageway maintenance operations, both silica PEL's are feasible, or at least marginally feasible, in all industries for which exposure data were available. Among all of the industry groups, the copper, molybdenum, other stone, clay and shale, oil shale, and other nonmetals industries had more operations than other industry groups for which the PEL's were found to be not feasible. The iron and talc industries had the fewest operation categories with infeasible PEL's.

Table 5-22. Technological feasibility assessments for the 0.05 and 0.075 mg/m³ silica PEL's for the metal and nonmetal mining industries.

Operation category	PEL	Industry Group		
		Copper	Gold and silver	Iron
Surface drilling	0.05 mg/m ³	F	F	F
	0.075	F	F	F
Underground drilling	0.05	I	I	F
	0.075	I	F	F
Blasting	0.05	I *	F *	F
	0.075	I	F	F
Cutting and boring	0.05			
	0.075			
Surface production	0.05	F *		F
	0.075	F		F
Surface mobile transport	0.05	I	F	F
	0.075	MF	F	F
Surface haulageway maintenance	0.05	F *		
	0.075	F		
Underground production	0.05	I	I	F *
	0.075	I	I	F
Underground mobile transport	0.05	I	F	F
	0.075	MF	F	F
Underground haulageway maintenance	0.05	F	F *	
	0.075	F	F	
Crushing, grinding, and sizing	0.05	F	MF	F
	0.075	F	F	F
Concentrating and finishing	0.05	F	F *	F
	0.075	F	F	F

(Continued)

F = Feasible

I = Infeasible

MF = Marginally feasible

*Data set contains fewer than 5 samples or all of the samples were collected from one site or from fewer than 5 percent of the active sites.

Table 5-22. Technological feasibility assessments for the 0.05 and 0.075 mg/m³ silica PEL's for the metal and nonmetal mining industries.

Operation category	PEL	Industry Group		
		Lead and zinc	Molybdenum	Uranium
Surface drilling	0.05 mg/m ³		F *	F
	0.075		F	F
Underground drilling	0.05	I	I	I
	0.075	I	I	MF
Blasting	0.05	F *	I	
	0.075	F	I	
Cutting and boring	0.05			
	0.075			
Surface production	0.05			
	0.075			
Surface mobile transport	0.05	F		F
	0.075	F		F
Surface haulageway maintenance	0.05			
	0.075			
Underground production	0.05	I	I	I
	0.075	I	I	MF
Underground mobile transport	0.05	I	MF *	F
	0.075	F	F	F
Underground haulageway maintenance	0.05	F	F	F
	0.075	F	F	F
Crushing, grinding, and sizing	0.05	F	I	F
	0.075	F	I	F
Concentrating and finishing	0.05	F	F *	F
	0.075	F	F	F

(Continued)

F = Feasible

I = Infeasible

MF = Marginally feasible

*Data set contains fewer than 5 samples or all of the samples were collected from one site or from fewer than 5 percent of the active sites.

Table 5-22. Technological feasibility assessments for the 0.05 and 0.075 mg/m³ silica PEL's for the metal and nonmetal mining industries.

Operation category	PEL	Industry Group		
		Other metals	Limestone	Other stone
Surface drilling	0.05 mg/m ³	MF	F	F
	0.075	F	F	F
Underground drilling	0.05	F *	I	I
	0.075	F	I	I
Blasting	0.05	F *	I	F *
	0.075	F	I	F
Cutting and boring	0.05		I	I
	0.075		F	I
Surface production	0.05	F *	F	I *
	0.075	F	F	F
Surface mobile transport	0.05	F	F	MF
	0.075	F	F	F
Surface haulageway maintenance	0.05		F	F
	0.075		F	F
Underground production	0.05	I	F *	F
	0.075	F	F	F
Underground mobile transport	0.05	F *	F	I
	0.075	F	F	I
Underground haulageway maintenance	0.05			F
	0.075			F
Crushing, grinding, and sizing	0.05	I	F	F
	0.075	MF	F	F
Concentrating and finishing	0.05	F	I	I
	0.075	F	I	I

(Continued)

F = Feasible

I = Infeasible

MF = Marginally feasible

*Data set contains fewer than 5 samples or all of the samples were collected from one site or from fewer than 5 percent of the active sites.

Table 5-22. Technological feasibility assessments for the 0.05 and 0.075 mg/m³ silica PEL's for the metal and nonmetal mining industries.

Operation category	PEL	Industry Group		
		Clay and shale	Asbestos	Talc
Surface drilling	0.05 mg/m ³	F *		F *
	0.075	F		F
Underground drilling	0.05	I		
	0.075	I		
Blasting	0.05	F *		
	0.075	F		
Cutting and boring	0.05			
	0.075			
Surface production	0.05	I *		
	0.075	I		
Surface mobile transport	0.05	MF		F
	0.075	F		F
Surface haulageway maintenance	0.05			
	0.075			
Underground production	0.05	I *		F *
	0.075	I		F
Underground mobile transport	0.05	I		
	0.075	MF		
Underground haulageway maintenance	0.05	F		
	0.075	F		
Crushing, grinding and sizing	0.05	MF		F
	0.075	F		F
Concentrating and finishing	0.05	I		I
	0.075	I		MF

(Continued)

F = Feasible
I = Infeasible
MF = Marginally feasible

*Data set contains fewer than 5 samples or all of the samples were collected from one site or from fewer than 5 percent of the active sites.

Table 5-22. Technological feasibility assessments for the 0.05 and 0.075 mg/m³ silica PEL's for the metal and nonmetal mining industries.

Operation category	PEL	Industry Group		
		Oil shale	Other nonmetals	Sand and gravel
Surface drilling	0.05 mg/m ³	F	F	F *
	0.075	F	F	F
Underground drilling	0.05	I *	F	
	0.075	F	F	
Blasting	0.05		F *	
	0.075		F	
Cutting and boring	0.05			
	0.075			
Surface production	0.05		I *	MF
	0.075		I	F
Surface mobile transport	0.05	I	MF	F
	0.075	I	F	F
Surface haulageway maintenance	0.05		F	
	0.075		F	
Underground production	0.05		I	
	0.075		I	
Underground mobile transport	0.05	F	F *	
	0.075	F	F	
Underground haulageway maintenance	0.05		F	
	0.075		F	
Crushing, grinding, and sizing	0.05	MF *	MF	F
	0.075	MF	MF	F
Concentrating and finishing	0.05		I	I
	0.075		I	I

F = Feasible

I = Infeasible

MF = Marginally feasible

*Data set contains fewer than 5 samples or all of the samples were collected from one site or from fewer than 5 percent of the active sites.

The results of the feasibility analysis of the asbestos PEL's, which were evaluated for the 48 industry-operation cells for which there were asbestos exposure data, are shown in Table 5-23. As in Table 5-22, those industry-operation cells in Table 5-21 with a limited amount of data or with samples from a limited number of sites are marked with an asterisk.

The highest asbestos PEL (1.0 fibers/cc) was judged to be feasible for all but two of these categories. The two exceptions are underground production in the molybdenum and talc industries. The second highest PEL (0.5 fibers/cc) was judged to be feasible or marginally feasible for all but seven industry-operation cells; these are underground production operations in the molybdenum, talc, and other nonmetals industries, underground drilling in the limestone industry, and concentrating and finishing operations in the other stone, asbestos, and other nonmetals industries. The lowest PEL (0.1 fibers/cc) was determined to be feasible for only 15 of the 48 industry-operation categories analyzed.

For each operation category, Table 5-24 summarizes (1) the dust control methods that are expected to yield the highest dust reduction efficiencies, and (2) the maximum levels of current silica dust and mineral fiber exposure that can be reduced to the various PEL's using the most effective dust control methods available.

Table 5-23. Technological feasibility assessments for the 0.1, 0.5, and 1.0 fibers/cc asbestos PEL's for the metal and nonmetal mining industries.

Operation category	PEL	Industry Group		
		Copper	Gold and silver	Iron
Surface drilling	0.1 fibers/cc			F*
	0.5			F
	1.0			F
Underground drilling	0.1		I*	
	0.5		F	
	1.0		F	
Blasting	0.1			
	0.5			
	1.0			
Cutting and boring	0.1			
	0.5			
	1.0			
Surface production	0.1			
	0.5			
	1.0			
Surface mobile transport	0.1			MF
	0.5			F
	1.0			F
Surface haulageway maintenance	0.1			
	0.5			
	1.0			
Underground production	0.1		I*	
	0.5		MF	
	1.0		F	
Underground mobile transport	0.1	F		
	0.5	F		
	1.0	F		
Underground haulageway maintenance	0.1			
	0.5			
	1.0			
Crushing, grinding, and sizing	0.1		F	F
	0.5		F	F
	1.0		F	F
Concentrating and finishing	0.1			F
	0.5			F
	1.0			F

(Continued)

F = Feasible
I = Infeasible
MF = Marginally feasible

*Data set contains fewer than 5 samples or all of the samples were collected from one site or from fewer than 5 percent of the active sites.

Table 5-23. Technological feasibility assessments for the 0.1, 0.5, and 1.0 fibers/cc asbestos PEL's for the metal and nonmetal mining industries.

Operation category	PEL	Industry Group		
		Lead and zinc	Molybdenum	Uranium
	0.1 fibers/cc			
Surface drilling	0.5			
	1.0			
Underground drilling	0.1			
	0.5			
	1.0			
Blasting	0.1			
	0.5			
	1.0			
Cutting and boring	0.1			
	0.5			
	1.0			
Surface production	0.1			
	0.5			
	1.0			
Surface mobile transport	0.1			
	0.5			
	1.0			
Surface haulageway maintenance	0.1			
	0.5			
	1.0			
Underground production	0.1		I *	
	0.5		I	
	1.0		I	
Underground mobile transport	0.1			
	0.5			
	1.0			
Underground haulageway maintenance	0.1			
	0.5			
	1.0			
Crushing, grinding, and sizing	0.1			
	0.5			
	1.0			
Concentrating and finishing	0.1			F
	0.5			F
	1.0			F

(Continued)

F = Feasible

I = Infeasible

MF = Marginally feasible

*Data set contains fewer than 5 samples or all of the samples were collected from one site or from fewer than 5 percent of the active sites.

Table 5-23. Technological feasibility assessments for the 0.1, 0.5, and 1.0 fibers/cc asbestos PEL's for the metal and nonmetal mining industries.

Operation category	PEL	Industry Group		
		Other metals	Limestone	Other stone
Surface drilling	0.1 fibers/cc		F	MF *
	0.5		F	F
	1.0		F	F
Underground drilling	0.1		I *	F *
	0.5		I	F
	1.0		F	F
Blasting	0.1			
	0.5			
	1.0			
Cutting and boring	0.1			
	0.5			
	1.0			
Surface production	0.1		I	
	0.5		F	
	1.0		F	
Surface mobile transport	0.1		F	I
	0.5		F	F
	1.0		F	F
Surface haulageway maintenance	0.1			
	0.5			
	1.0			
Underground production	0.1			
	0.5			
	1.0			
Underground mobile transport	0.1		I	
	0.5		F	
	1.0		F	
Underground haulageway maintenance	0.1			
	0.5			
	1.0			
Crushing, grinding, and sizing	0.1	MF	MF	I
	0.5	F	F	F
	1.0	F	F	F
Concentrating and finishing	0.1	F		I
	0.5	F		I
	1.0	F		MF

(Continued)

F = Feasible
I = Infeasible
MF = Marginally feasible

*Data set contains fewer than 5 samples or all of the samples were collected from one site or from fewer than 5 percent of the active sites.

Table 5-23. Technological feasibility assessments for the 0.1, 0.5, and 1.0 fibers/cc asbestos PEL's for the metal and nonmetal mining industries.

Operation category	PEL	Industry Group		
		Clay and shale	Asbestos	Talc
Surface drilling	0.1 fibers/cc		F *	MF
	0.5		F	F
	1.0		F	F
Underground drilling	0.1		MF *	I *
	0.5		F	MF
	1.0		F	F
Blasting	0.1			
	0.5			
	1.0			
Cutting and boring	0.1			
	0.5			
	1.0			
Surface production	0.1			
	0.5			
	1.0			
Surface mobile transport	0.1	F	I	MF
	0.5	F	F	F
	1.0	F	F	F
Surface haulageway maintenance	0.1			
	0.5			
	1.0			
Underground production	0.1			I
	0.5			I
	1.0			I
Underground mobile transport	0.1		F	I
	0.5		F	F
	1.0		F	F
Underground haulageway maintenance	0.1			
	0.5			
	1.0			
Crushing, grinding, and sizing	0.1	F	I	MF
	0.5	F	F	F
	1.0	F	F	F
Concentrating and finishing	0.1		I	I
	0.5		I	F
	1.0		I	F

(Continued)

F = Feasible
I = Infeasible
MF = Marginally feasible

*Data set contains fewer than 5 samples or all of the samples were collected from one site or from fewer than 5 percent of the active sites.

Table 5-23. Technological feasibility assessments for the 0.1, 0.5, and 1.0 fibers/cc asbestos PEL's for the metal and nonmetal mining industries.

Operation category	PEL	Industry Group		
		Oil shale	Other nonmetals	Sand and gravel
Surface drilling	0.1 fibers/cc		MF	
	0.5		F	
	1.0		F	
Underground drilling	0.1		I	
	0.5		F	
	1.0		F	
Blasting	0.1			
	0.5			
	1.0			
Cutting and boring	0.1			
	0.5			
	1.0			
Surface production	0.1			
	0.5			
	1.0			
Surface mobile transport	0.1		I	I
	0.5		F	F
	1.0		F	F
Surface haulageway maintenance	0.1			
	0.5			
	1.0			
Underground production	0.1		I *	
	0.5		I	
	1.0		MF	
Underground mobile transport	0.1		F	
	0.5		F	
	1.0		F	
Underground haulageway maintenance	0.1			
	0.5			
	1.0			
Crushing, grinding, and sizing	0.1		MF	I
	0.5		F	F
	1.0		F	F
Concentrating and finishing	0.1		I	MF
	0.5		I	F
	1.0		F	F

F = Feasible

I = Infeasible

MF = Marginally feasible

*Data set contains fewer than 5 samples or all of the samples were collected from one site or from fewer than 5 percent of the active sites.

Table 5-24. Maximum levels of mineral fiber counts and silica dust concentration for attaining various PEL's using dust control methods with the highest reduction efficiency (by operation category).

Operation category	Control methods	Percent overall expected reduction efficiency	Maximum mineral fiber counts for asbestos PEL's*		Maximum silica dust concentrations for silica PEL's*	
			0.1 fibers/cc	0.5 fibers/cc	1.0 fibers/cc	0.05 ₃ mg/m
Surface drilling	SEV on drills	95	1.0	5.0	10.0	0.50
	Wet drilling	98	1.4	7.1	14.3	0.71
Underground drilling	Steam and water spray	50	0.2	0.9	1.8	0.09
Blasting	Wet stemming**	30	Not applicable		Not applicable	
Cutting and boring	Controlled cutting depth, machine-mounted SEV, and canopy air curtain	68	0.3	1.4	2.7	0.14
	Shearer-clearer and canopy air curtain	53	0.2	1.0	1.9	0.10
	Wethead, machine-mounted SEV, and canopy air curtain	62	0.2	1.2	2.3	0.12
	Foams, machine-mounted SEV, and canopy air curtain	62	0.2	1.2	2.3	0.12
Surface production	Reduced drop distance and application of foams	65	0.3	1.3	2.5	0.13
Surface mobile transport	Reduced vehicle speed, reduced drop distance, and load wetting	76	0.3	1.7	3.5	0.17

(Continued)

Table 5-24. Maximum levels of mineral fiber counts and silica dust concentration for attaining various PEL's using dust control methods with the highest reduction efficiency (by operation category).

Operation category	Control methods	Percent overall expected reduction efficiency	Maximum mineral fiber counts for asbestos PEL's*		Maximum silica dust concentrations for silica PEL's*		
			0.1 fibers/cc	0.5 fibers/cc	0.05 ₃ mg/m ³	0.075 ₃ mg/m ³	
Surface haulageway maintenance	Reduced vehicle speed and application of binding agents or gravel on haulageways	83	0.5	2.3	4.6	0.23	0.34
Underground production	Foams at muck pile and dump point and water spray on haulage roads for mucking	27	0.1	0.6	1.3	0.06	0.10
	Foams and canopy air curtain for slushing	60	0.2	1.1	2.2	0.11	0.17
Underground mobile transport	Reduced vehicle speed and application of binding agents on haulageways	68	0.3	1.4	2.7	0.14	0.20
Underground haulageway maintenance	Reduced vehicle speed and application of binding agents on haulageways	83	0.5	2.3	4.6	0.23	0.34
Storage	Enclosed control booth	95	1.0	5.0	10.0	0.50	0.75
	Reduced drop distance and SEV	86	0.5	2.6	5.3	0.26	0.39

(Continued)

Table 5-24. Maximum levels of mineral fiber counts and silica dust concentration for attaining various PEL's using dust control methods with the highest reduction efficiency (by operation category).

Operation category	Control methods	Percent overall expected reduction efficiency	Maximum mineral fiber counts for asbestos PEL's*			Maximum silica dust concentrations for silica PEL's*	
			0.1 fibers/cc	0.5 fibers/cc	1.0 fibers/cc	0.05 ₃ mg/m	0.075 ₃ mg/m
Crushing, grinding, and sizing	Enclosed work station for primary crushing	95	1.0	5.0	10.0	0.50	0.75
	SEV and charged fogging for secondary crushing and grinding	90	0.7	3.3	6.7	0.33	0.50
	Enclosed work station for sizing	95	1.0	5.0	10.0	0.5	0.75
	Reduced conveyor speed, SEV, and charged fogging	93	0.8	4.2	8.3	0.42	0.63
Concentrating and finishing	Reduced drop distance, SEV, and charged fogging for material transfer	93	0.8	4.2	8.3	0.42	0.63
	Reduced drop distance, SEV, and charged fogging for pre-bagging material transfer processes	93	0.8	4.2	8.3	0.42	0.63
	Charged fogging	50	0.2	0.9	1.8	0.09	0.14
	Enclosed work station	95	1.0	5.0	10.0	0.5	0.75

*To account for margin of error in the expected reduction efficiency, the maximum exposure levels are calculated with an efficiency that is 5 percent less than the assigned expected efficiency shown in the table.

**This method will reduce the amount of dust released during blasting but may not affect a blaster's dust exposure since this exposure is primarily from work related to blast hole drilling and setting up explosive charges.

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TECHNOLOGICAL FEASIBILITY OF CONTROLLING
ASBESTOS AND SILICA AT MINES AND MILLS

FINAL REPORT

VOLUME 2
APPENDIXES

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APPENDIX A
EXPOSURE PROFILES FOR RESPIRABLE SILICA DUST
IN THE MINING INDUSTRY

APPENDIX A

EXPOSURE PROFILES FOR RESPIRABLE SILICA DUST IN THE MINING INDUSTRY

Exposure profiles for respirable silica dust in 15 mining industry groups that were prepared from the 1977-1981 Mine Safety and Health Administration (MSHA) MIDAS files are presented as probability distribution graphs in this appendix. The dust exposure data have been organized into data sets according to industry group, operation category, and location (surface and underground) as discussed in Volume 1, Chapter 2 of this report. There are 15 industry groups: copper, gold and silver, iron, lead and zinc, molybdenum, uranium, other metals, limestone, other stone, clay and shale, asbestos, talc, oil shale, sand and gravel, and other nonmetals. Operation and location are classified into 14 categories: surface drilling; underground drilling; blasting; cutting and boring; surface production; surface mobile transport; surface haulageway maintenance; underground production; underground mobile transport; underground haulageway maintenance; crushing, grinding, and sizing; concentrating and finishing; nonspecific surface; and nonspecific underground.

For a particular industry and operation category where more than five exposure samples were available, a graph of probability, expressed as a cumulative percentage, versus silica concentration has been prepared. The points in the graph represent individual samples. The horizontal axis, which represents the silica dust₃ concentration in air, is a logarithmic scale with a range of 0.005 to 0.5 mg/m³. The exposure concentration was calculated from the concentration of respirable dust and the percent of silica in the dust as available in the MIDAS files.

The vertical axis of the profile graph indicates the position of a sample within the data set when the data are arranged in order of increasing silica concentration. This axis is in units representing the cumulative percentage of samples in the data set. The scale of the axis corresponds to a normal probability distribution with 50 percent as the median.

If exposure data for a profile were collected from more than 22 establishments, a plus sign has been used to designate the data points. If 22 or fewer establishments were sampled to obtain the data, the samples for different establishments have been plotted using different alphabetic characters. If the data set contained no more than five data points, the data are tabulated rather than plotted.

Each graph includes three vertical lines at 0.05, 0.075, and 0.1 mg/m³. The two vertical markers at 0.05 and 0.075 mg/m³ correspond to the two alternate silica PEL's being evaluated in this study. The other vertical line at 0.1 mg/m³ is included for reference.

A data summary appears beneath the plot in each profile. This data summary includes the following information:

- The number of samples in the data set, including samples outside the limits of the plot
- The number of establishments sampled
- The number of establishments that were listed as active in the 1980 MSHA Address and Employment File
- The cumulative percent of samples that are equal to or below each of the three alternate PEL's. These numbers, which will be called the PEL intercepts, correspond to the cumulative percent represented by the sample point closest to and to the left of each PEL marker.

Silica dust exposure profiles included in this appendix are used as the basis to determine an estimate of worse-case exposure for use in the feasibility assessment. Least squares regression analyses of the data in each profile, except those for nonspecific operations, were performed to determine a best-fit line in order to calculate the 95 percentile silica dust concentration. This analysis was also performed for those industry-operation cells with three to five data points where a graph was not prepared. Equations of the best-fit lines, expressed as

$$Y = A + (B)(\ln X)$$

are obtained as a result of regression analysis. In this equation

X = Silica dust concentration in mg/m^3

Y = The probit unit that corresponds to the cumulative distribution of samples at silica concentration X

A = Value of the probit unit at a silica concentration of zero

B = Slope of the line.

The values of A and B for the equations obtained are listed in Table A-1. Since the exposure profiles are plotted in the units of cumulative percentage instead of probit units, a conversion (Table A-2) is provided for readers who are interested in determining a different percentile exposure concentration from the profiles.

Table A-1. Results of least squares regression analyses of silica dust exposure data.

Figure number	Industry	Operation category	A	B
A-1	Copper	Nonspecific surface	--	--
A-2		Nonspecific underground	--	--
A-3		Blasting	1.551	0.542
A-4		Surface drilling	2.580	0.714
A-5		Underground drilling	2.691	0.750
A-6		Surface haulageway maintenance	--	--
A-7		Underground haulageway maintenance	8.313	1.938
A-8		Surface production	--	--
A-9		Underground production	2.494	0.660
A-10		Surface mobile transport	2.213	0.557
A-11		Underground mobile transport	2.800	0.827
A-12		Crushing, grinding and sizing	2.633	0.759
A-13		Concentrating and finishing	5.055	1.123
A-14	Gold and silver	Surface nonspecific	--	--
A-15		Underground nonspecific	--	--
A-16		Surface drilling	2.123	0.693
A-17		Underground drilling	3.891	1.033
A-18		Underground haulageway maintenance	4.798	1.259
A-19		Underground production	3.385	0.970
A-20		Surface mobile transport	4.171	1.114
A-21		Underground mobile transport	4.260	1.183
A-22		Crushing, grinding, and sizing	2.464	0.836

(Continued)

Table A-1. Results of least squares regression analyses of silica dust exposure data.

Figure number	Industry	Operation category	A	B
A-23	Gold and silver	Concentrating and finishing	3.022	0.792
A-24	Iron	Surface nonspecific	--	--
A-25		Underground nonspecific	--	--
A-26		Blasting	5.478	1.532
A-27		Surface drilling	3.594	0.863
A-28		Underground drilling	4.052	1.024
A-29		Surface production	5.531	1.284
A-30		Surface mobile transport	4.077	0.913
A-31		Underground mobile transport	5.646	1.553
A-32		Crushing, grinding, and sizing	2.960	0.833
A-33		Concentrating and finishing	3.488	0.775
A-34	Lead and zinc	Nonspecific surface	--	--
A-35		Nonspecific underground	--	--
A-36		Underground drilling	2.863	0.709
A-37		Underground haulageway maintenance	3.252	0.879
A-38		Underground production	2.832	0.750
A-39		Surface mobile transport	2.954	0.657
A-40		Underground mobile transport	3.010	0.825
A-41		Crushing, grinding, and sizing	2.759	0.829
A-42		Concentrating and finishing	3.868	0.864
A-43	Molybdenum	Nonspecific surface	--	--
A-44		Nonspecific underground	--	--
A-45		Blasting	3.568	1.178
A-46		Surface drilling	3.687	0.740
A-47		Underground drilling	2.986	0.883

(Continued)

Table A-1. Results of least squares regression analyses of silica dust exposure data.

Figure number	Industry	Operation category	A	B
A-48	Molybdenum	Underground haulageway maintenance	3.774	1.034
A-49		Underground production	2.272	0.878
A-50		Underground mobile transport	3.709	1.216
A-51		Crushing, grinding, and sizing	1.388	0.687
A-52	Uranium	Nonspecific surface	--	--
A-53		Nonspecific underground	--	--
A-54		Surface drilling	3.189	0.778
A-55		Underground drilling	3.522	0.996
A-56		Underground haulageway maintenance	4.125	1.030
A-57		Underground production	4.336	1.145
A-58		Surface mobile transport	3.956	0.875
A-59		Underground mobile transport	4.159	1.105
A-60		Crushing, grinding, and sizing	2.486	0.647
A-61		Concentrating and finishing	3.876	0.862
A-62		Nonspecific surface	--	--
A-63		Nonspecific underground	--	--
A-64	Other metals	Surface drilling	1.130	0.315
A-65		Underground production	5.294	1.427
A-66		Surface mobile transport	3.773	0.743
A-67		Crushing, grinding, and sizing	1.502	0.523
A-68	Limestone	Concentrating and finishing	4.892	1.176
A-69		Nonspecific surface	--	--
A-70		Nonspecific underground	--	--

(Continued)

Table A-1. Results of least squares regression analyses of silica dust exposure data.

Figure number	Industry	Operation category	A	B
A-71	Limestone	Blasting	3.137	0.828
A-72		Cutting and boring	3.784	0.827
A-73		Underground cutting and boring	--	--
A-74		Surface drilling	3.795	0.889
A-75		Underground drilling	3.123	0.842
A-76		Surface haulageway maintenance	5.398	1.231
A-77		Surface production	4.445	0.981
A-78		Surface mobile transport	3.379	0.670
A-79		Underground mobile transport	3.702	0.912
A-80		Crushing, grinding, and sizing	3.291	0.779
A-81	Other stone	Concentrating and finishing	2.874	0.685
A-82		Nonspecific surface	--	--
A-83		Nonspecific underground	--	--
A-84		Blasting	12.106	3.258
A-85		Cutting and boring	4.114	1.080
A-86		Surface drilling	2.296	0.699
A-87		Underground drilling	3.103	0.898
A-88		Surface haulageway	3.812	1.007
A-89		Underground haulageway maintenance	6.859	2.682
A-90		Surface production	3.086	0.811
A-91		Underground production	5.122	1.172
A-92		Surface mobile transport	2.509	0.563
A-93		Underground mobile transport	2.671	0.822
A-94		Crushing, grinding, and sizing	2.505	0.776

(Continued)

Table A-1. Results of least squares regression analyses of silica dust exposure data.

Figure number	Industry	Operation category	A	B
A-95		Concentrating and finishing	1.865	0.706
A-96	Clay and shale	Nonspecific surface	--	--
A-97		Nonspecific underground	--	--
A-98		Blasting	5.713	1.559
A-99		Surface drilling	3.760	1.121
A-100		Underground drilling	2.659	0.902
A-101		Underground haulage way maintenance	4.147	1.125
A-102		Surface production	2.285	0.595
A-103		Underground production	2.083	0.557
A-104		Surface mobile transport	2.806	0.730
A-105		Underground mobile transport	3.046	0.920
A-106		Crushing, grinding, and sizing	2.411	0.796
A-107		Concentrating and finishing	2.429	0.793
A-108	Talc	Nonspecific surface	--	--
A-109		Surface mobile transport	4.129	1.011
A-110		Crushing, grinding, and sizing	3.176	0.781
A-111		Concentrating and finishing	3.696	1.027
A-112	Oil shale	Nonspecific underground	--	--
A-113		Underground drilling	3.262	0.800
A-114		Surface mobile transport	2.147	0.644
A-115		Underground mobile transport	3.175	0.714
A-116	Sand and gravel	Nonspecific surface	--	--
A-117		Surface drilling	3.873	0.975
A-118		Surface production	2.876	0.656

(Continued)

Table A-1. Results of least squares regression analyses of silica dust exposure data.

Figure number	Industry	Operation category	A	B
A-119		Surface mobile transport	2.730	0.581
A-120		Crushing, grinding, and sizing	2.492	0.678
A-121		Concentrating and finishing	2.374	0.802
A-122	Other nonmetals	Nonspecific surface	--	--
A-123		Nonspecific underground	--	--
A-124		Surface drilling	4.423	1.162
A-125		Underground drilling	4.034	0.940
A-126		Underground haulageway maintenance	7.766	1.748
A-127		Surface production	1.034	0.315
A-128		Underground production	3.734	0.963
A-129		Surface mobile transport	2.864	0.740
A-130		Underground mobile transport	3.469	0.844
A-131		Crushing, grinding, and sizing	1.992	0.594
A-132		Concentrating and finishing	1.700	0.561

Table A-2. Equivalent probit unit and cumulative percent for use with equations of least square fit lines for silica dust exposure profiles.

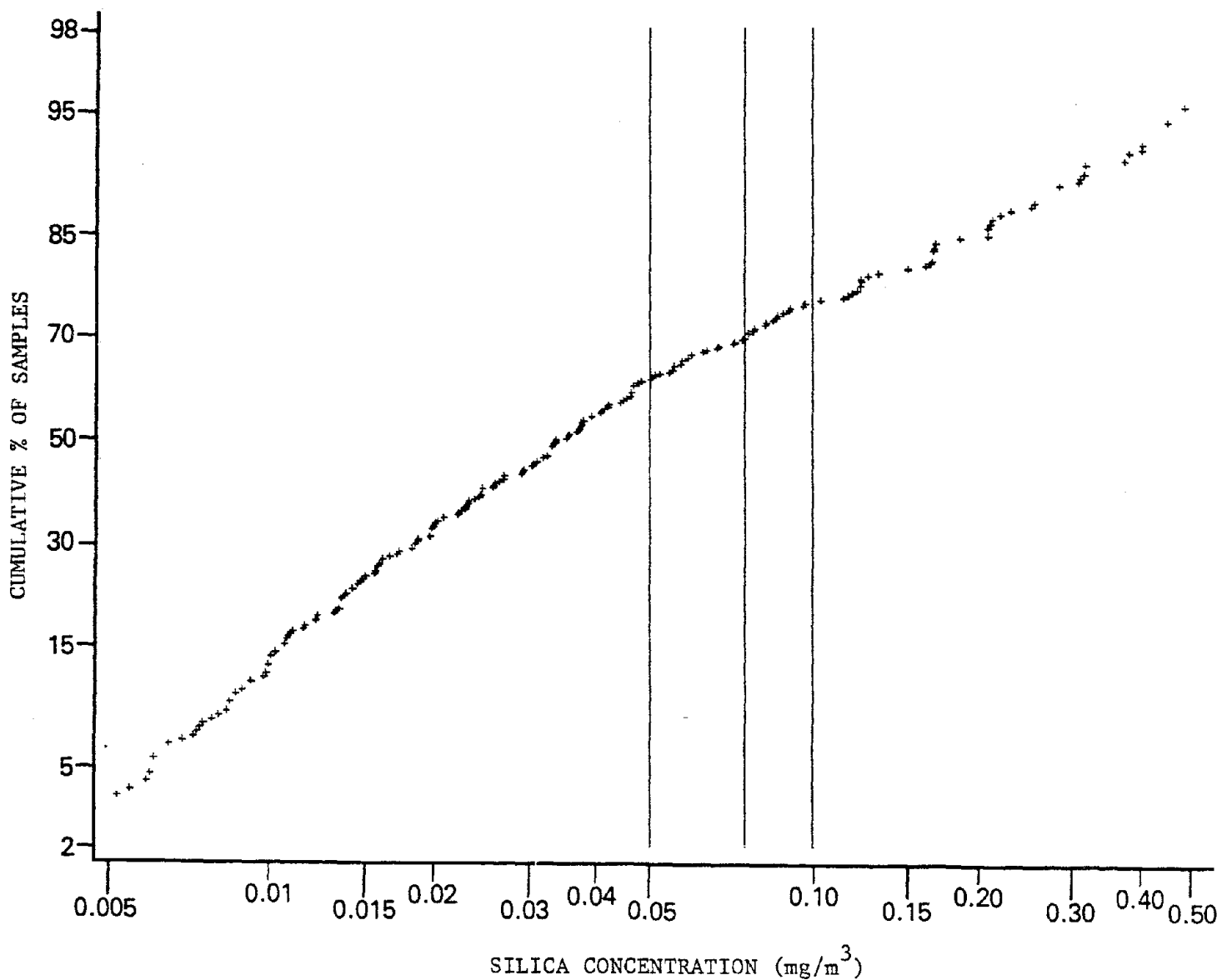
Probit unit	Cumulative percentage	Probit unit	Cumulative percentage
		0	50
-3.0	0.1	0.1	54
-2.5	0.7	0.2	57.9
-2.2	1.4	0.25	60.0
-2.0	2.3		
-1.8	3.6	0.3	61.8
-1.7	4.5	0.4	65.5
-1.645	5.0	0.5	69.1
-1.6	5.5	0.52	70.0
-1.5	6.7	0.6	72.6
		0.7	75.8
-1.4	8.1	0.8	78.8
-1.3	9.7	0.84	80.0
-1.28	10.0	0.9	81.6
-1.2	11.5	1.0	84.1
-1.1	13.6		
-1.0	15.9	1.1	86.4
		1.2	88.5
-0.9	18.4	1.28	90.0
-0.84	20.0	1.3	90.3
		1.4	91.9
-0.8	21.2	1.5	93.3
-0.7	24.2	1.6	94.5
-0.6	27.4	1.645	95.0
-0.52	30.0	1.7	95.5
-0.5	30.9	1.8	96.4
-0.4	34.5	2.0	97.7
-0.3	38.2	2.2	98.6

(Continued)

Table A-2. Equivalent probit unit and cumulative percent for use with equations of least square fit lines for silica dust exposure profiles.

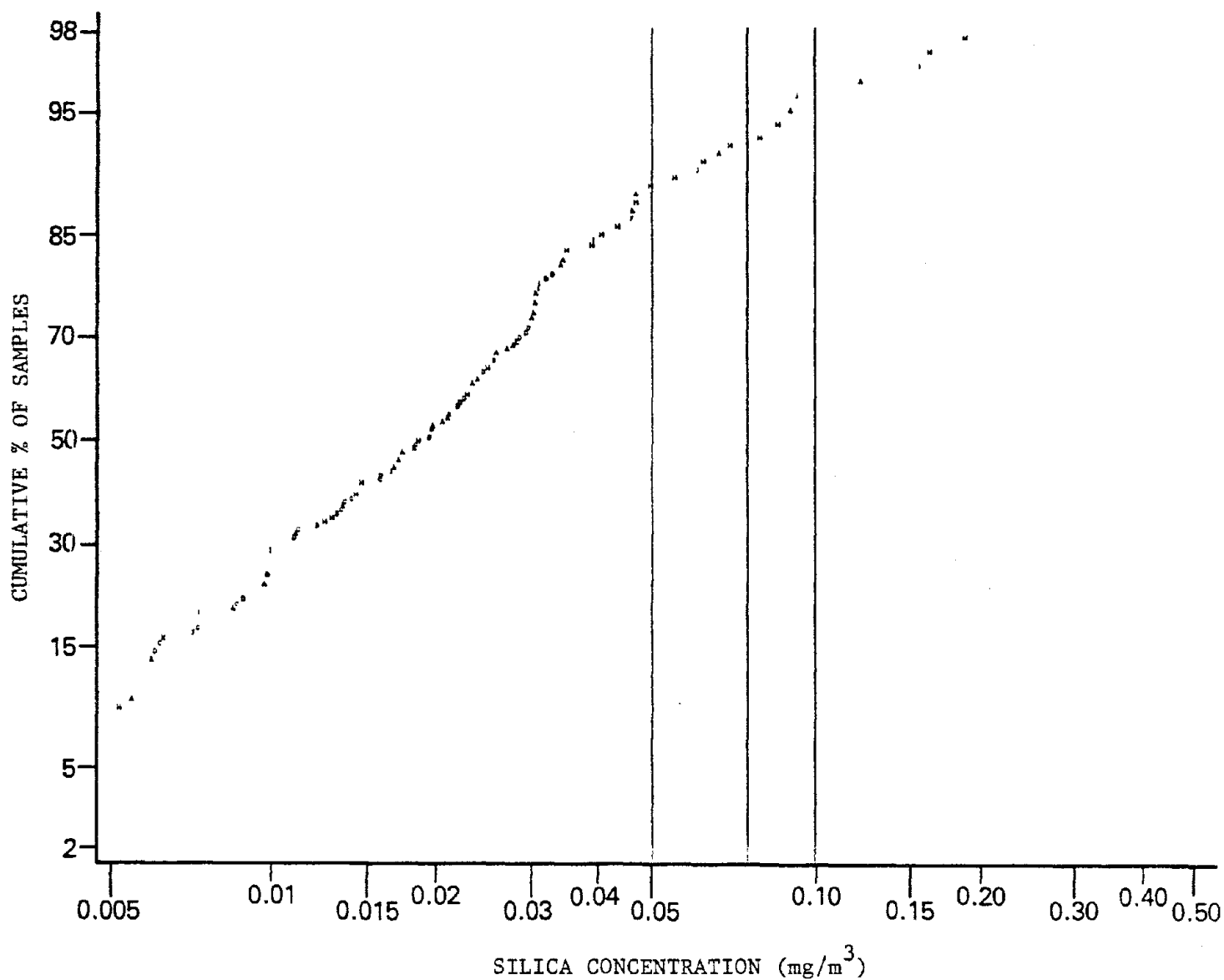
Probit unit	Cumulative percentage	Probit unit	Cumulative percentage
-0.25	40.0	2.4	99.2
-0.2	42.1	2.8	99.7
-0.1	46.0	3.0	99.9

Source: Prepared by JRB based on Tables in National Bureau of Standards - Applied Mathematics Series-23, U.S. Govt. Printing Office, Washington, DC, 1953.



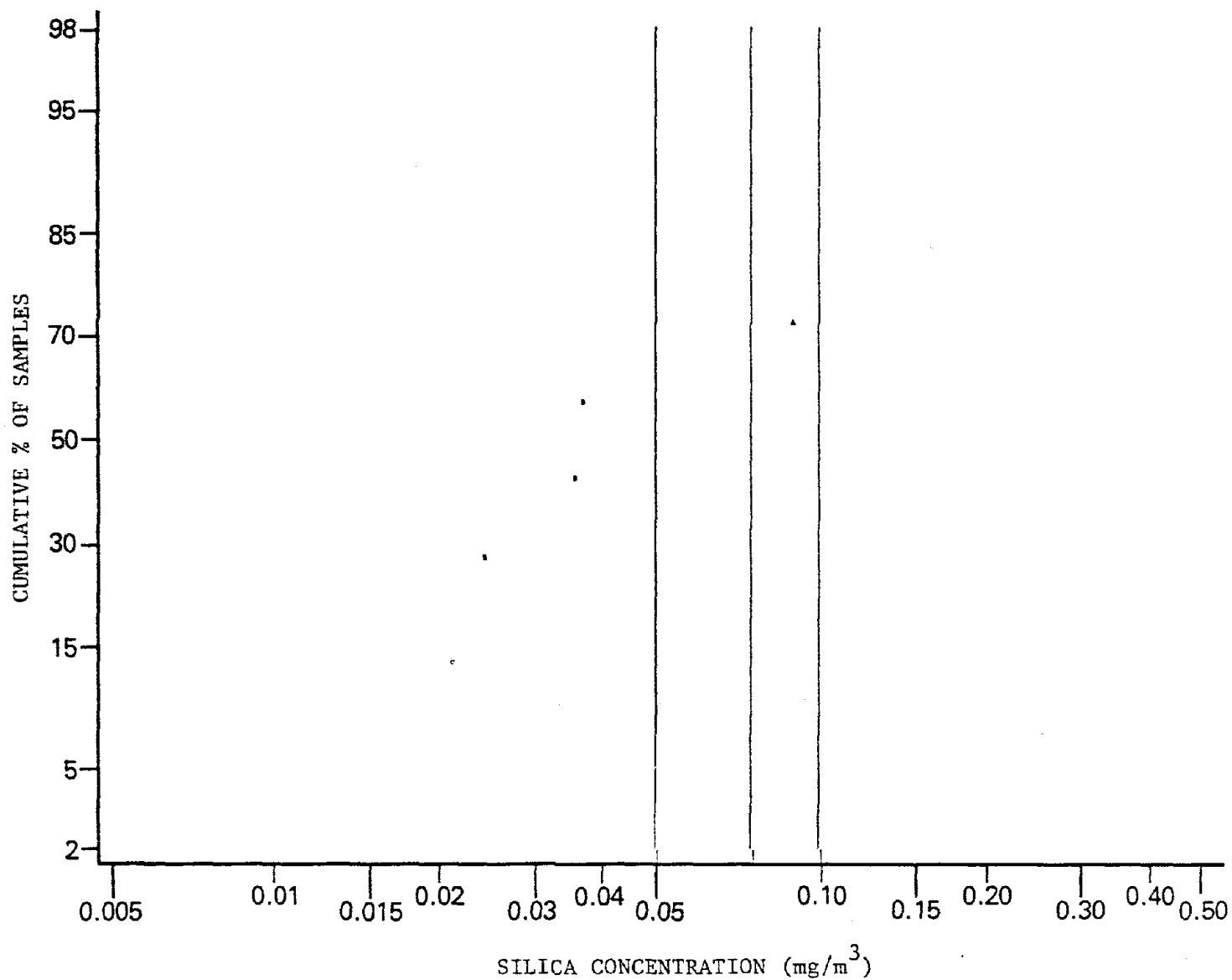
No. of samples: 271
 No. of mine ID's represented: 36
 No. of active sites in 1980: 82
 Percent of samples less than 0.05 mg/m³: 61
 Percent of samples less than 0.075 mg/m³: 69
 Percent of samples less than 0.1 mg/m³: 74

Figure A-1. Respirable quartz concentrations found in nonspecific surface operations in the copper industry group.



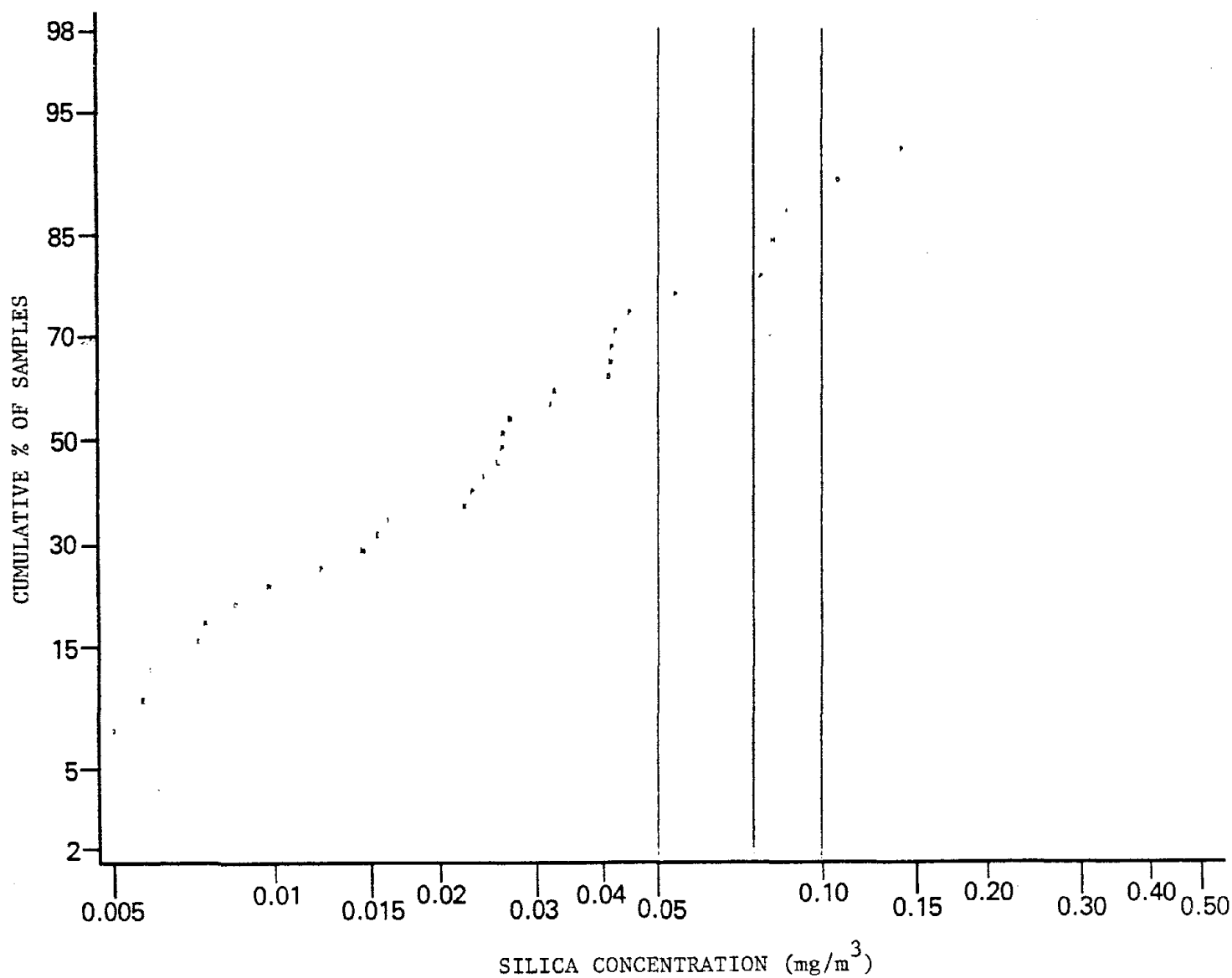
No. of samples: 139
 No. of mine ID's represented: 12
 No. of active sites in 1980: 19
 Percent of samples less than 0.05 mg/m³: 88
 Percent of samples less than 0.075 mg/m³: 92
 Percent of samples less than 0.1 mg/m³: 95

Figure A-2. Respirable quartz concentrations found in nonspecific underground operations in the copper industry group.



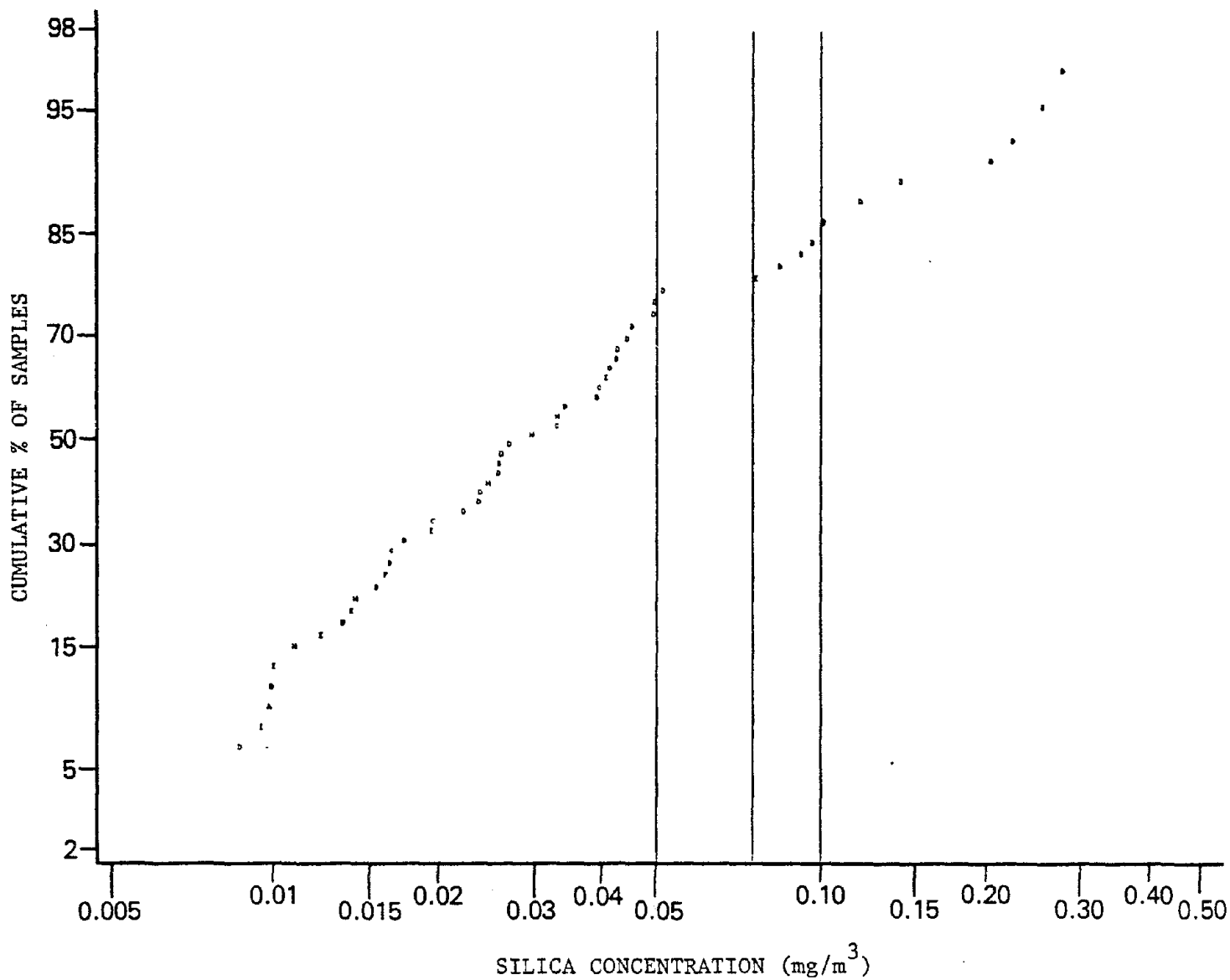
No. of samples: 7
 No. of mine ID's represented: 3
 No. of active sites in 1980: 82
 Percent of samples less than 0.05 mg/m³: 57
 Percent of samples less than 0.075 mg/m³: 57
 Percent of samples less than 0.1 mg/m³: 71

Figure A-3. Respirable quartz concentrations found in blasting operations (surface and underground) in the copper industry group.



No. of samples: 37
 No. of mine ID's represented: 18
 No. of active sites in 1980: 31
 Percent of samples less than 0.05 mg/m³: 73
 Percent of samples less than 0.075 mg/m³: 76
 Percent of samples less than 0.1 mg/m³: 86

Figure A-4. Respirable quartz concentrations found in surface drilling operations in the copper industry group.



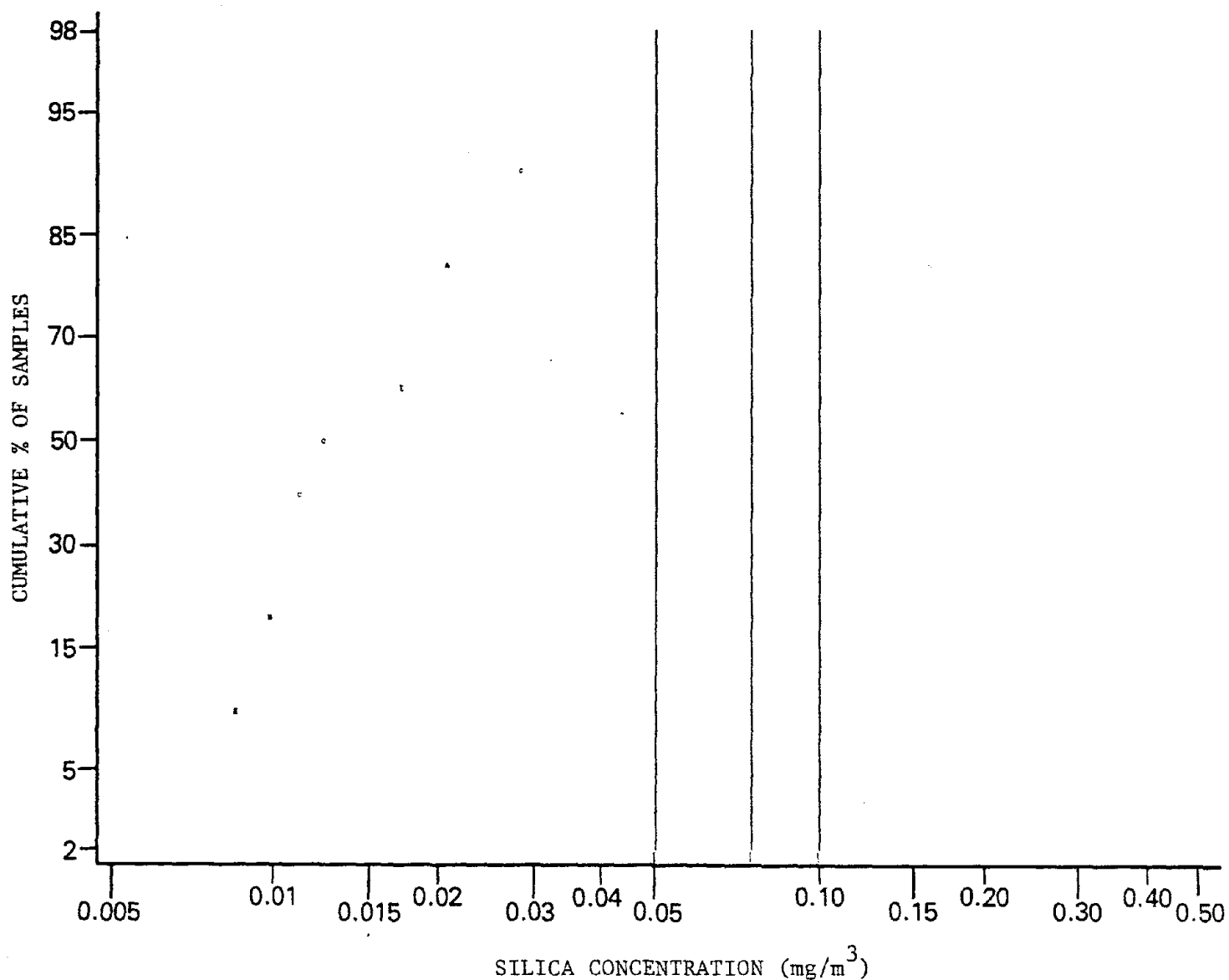
No. of samples: 56
 No. of mine ID's represented: 8
 No. of active sites in 1980: 19
 Percent of samples less than 0.05 mg/m³: 75
 Percent of samples less than 0.075 mg/m³: 77
 Percent of samples less than 0.1 mg/m³: 84

Figure A-5. Respirable quartz concentrations found in underground drilling operations in the copper industry group.

Respirable quartz sample data (mg/m ³ silica)	Establishment (mine ID)
0.0049	791
0.0049	791
0.0051	791
0.0052	791

No. of samples: 4
 No. of mine ID's represented: 1
 No. of active sites in 1980: 31
 Percent of samples less than 0.05 mg/m³: 100
 Percent of samples less than 0.075 mg/m³: 100
 Percent of samples less than 0.1 mg/m³: 100

Figure A-6. Respirable quartz concentrations found
 in surface haulageway maintenance
 operations in the copper industry group.



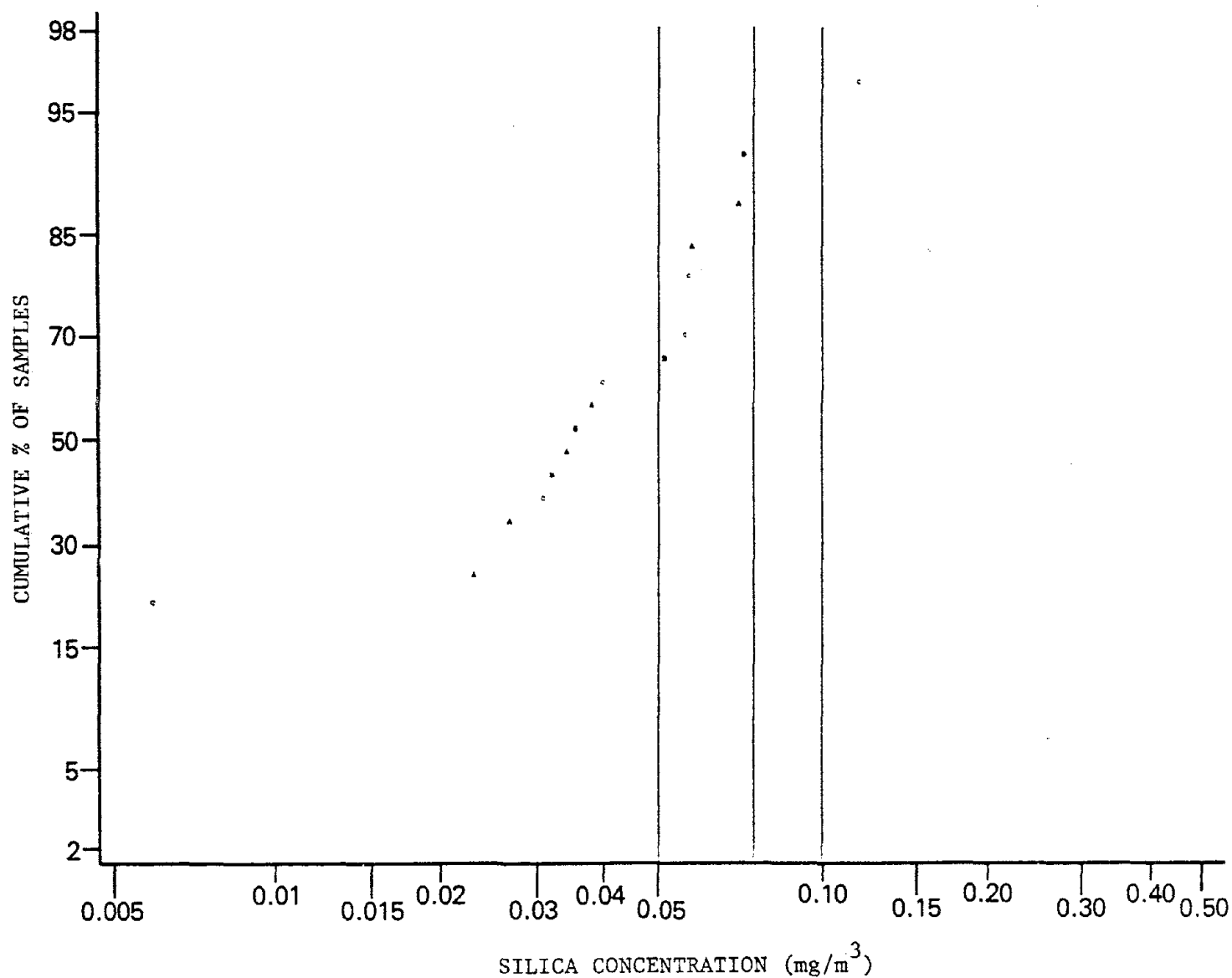
No. of samples: 10
No. of mine ID's represented: 5
No. of active sites in 1980: 19
Percent of samples less than 0.05 mg/m³: 90
Percent of samples less than 0.075 mg/m³: 90
Percent of samples less than 0.1 mg/m³: 100

Figure A-7. Respirable quartz concentrations found in underground haulageway maintenance operations in the copper industry group.

Respirable quartz sample data (mg/m ³ silica)	Establishment (mine ID)
0.0025	791
0.0025	791
0.0025	791
0.0025	791

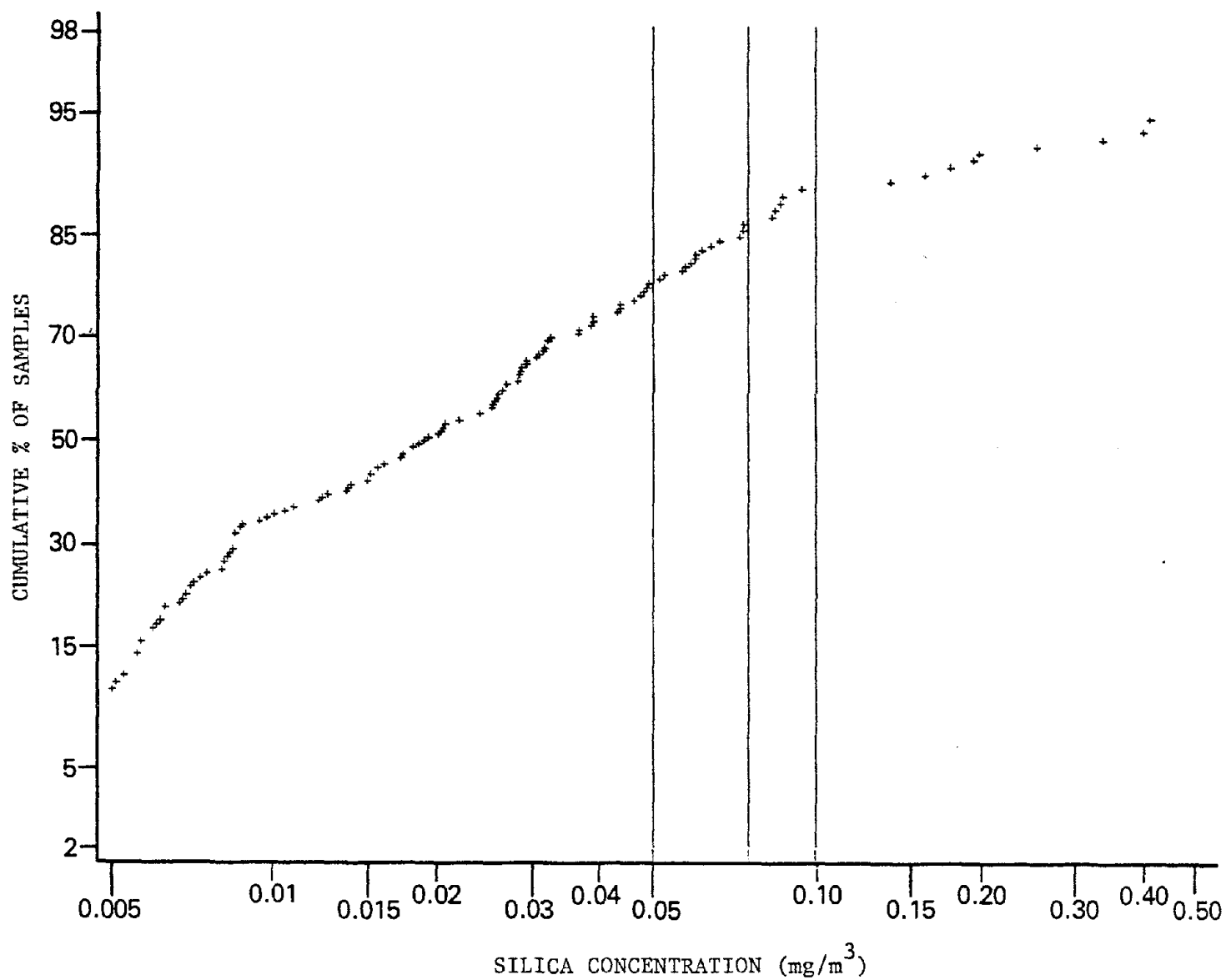
No. of samples: 4
 No. of mine ID's represented: 1
 No. of active sites in 1980: 31
 Percent of samples less than 0.05 mg/m³: 100
 Percent of samples less than 0.075 mg/m³: 100
 Percent of samples less than 0.1 mg/m³: 100

Figure A-8. Respirable quartz concentrations found
 in surface production operations in the
 copper industry group.



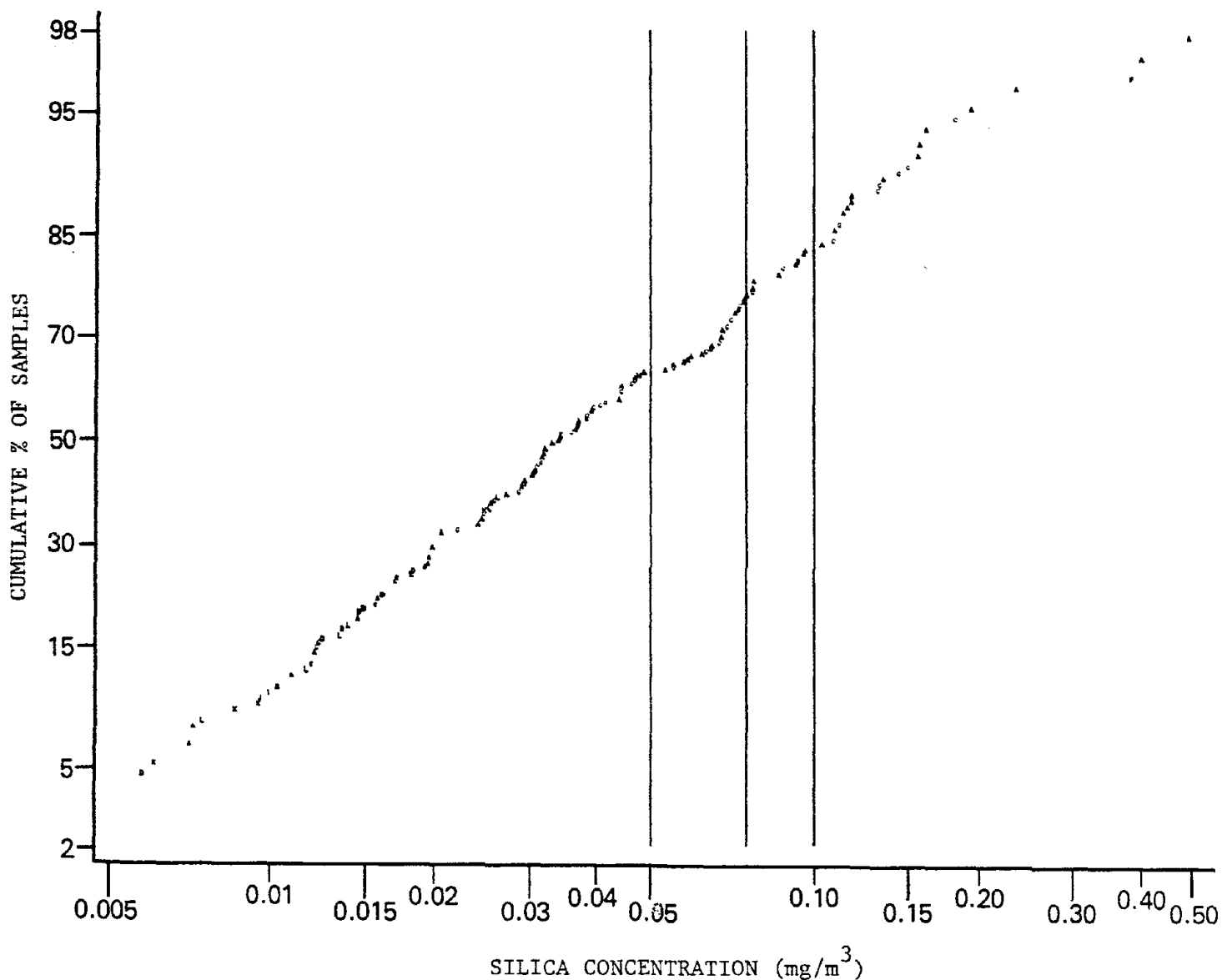
No. of samples: 23
No. of mine ID's represented: 4
No. of active sites in 1980: 19
Percent of samples less than 0.05 mg/m³: 61
Percent of samples less than 0.075 mg/m³: 91
Percent of samples less than 0.1 mg/m³: 91

Figure A-9. Respirable quartz concentrations found in underground production operations in the copper industry group.



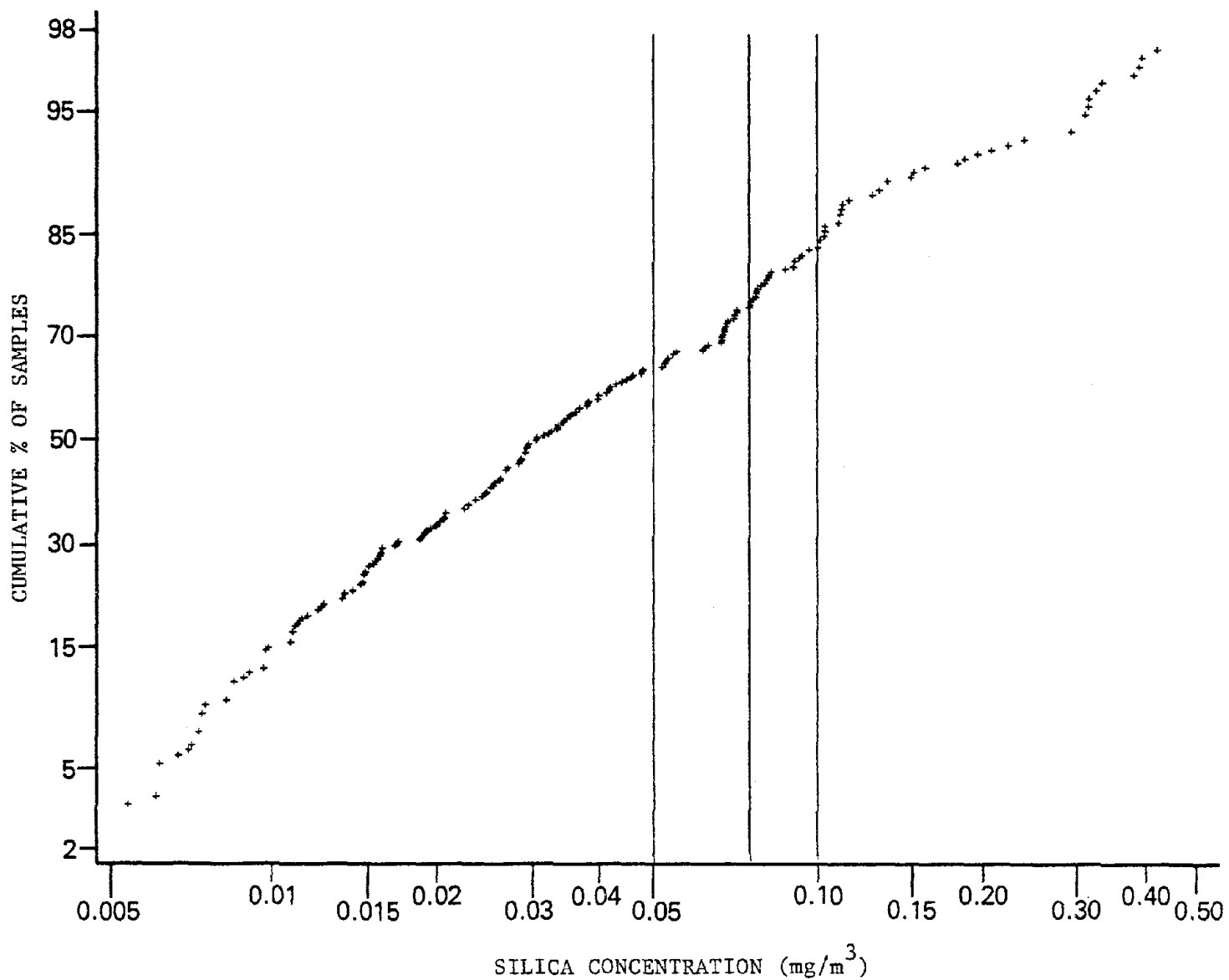
No. of samples: 161
 No. of mine ID's represented: 33
 No. of active sites in 1980: 31
 Percent of samples less than 0.05 mg/m³: 77
 Percent of samples less than 0.075 mg/m³: 85
 Percent of samples less than 0.1 mg/m³: 88

Figure A-10. Respirable quartz concentrations found in surface mobile transport operations in the copper industry group.



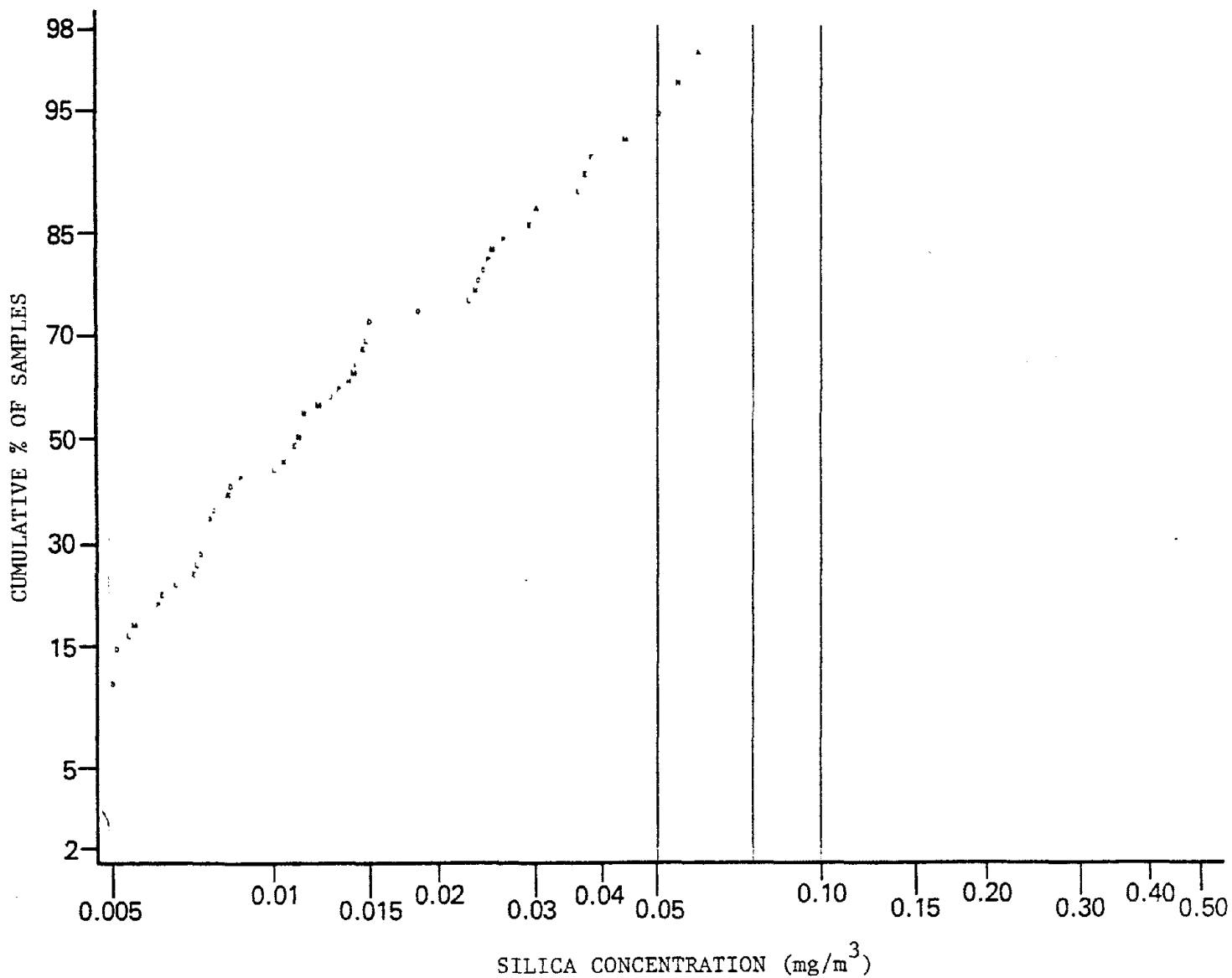
No. of samples: 197
No. of mine ID's represented: 12
No. of active sites in 1980: 19
Percent of samples less than 0.05 mg/m³: 63
Percent of samples less than 0.075 mg/m³: 75
Percent of samples less than 0.1 mg/m³: 82

Figure A-11. Respirable quartz concentrations found in underground mobile transport operations in the copper industry group.



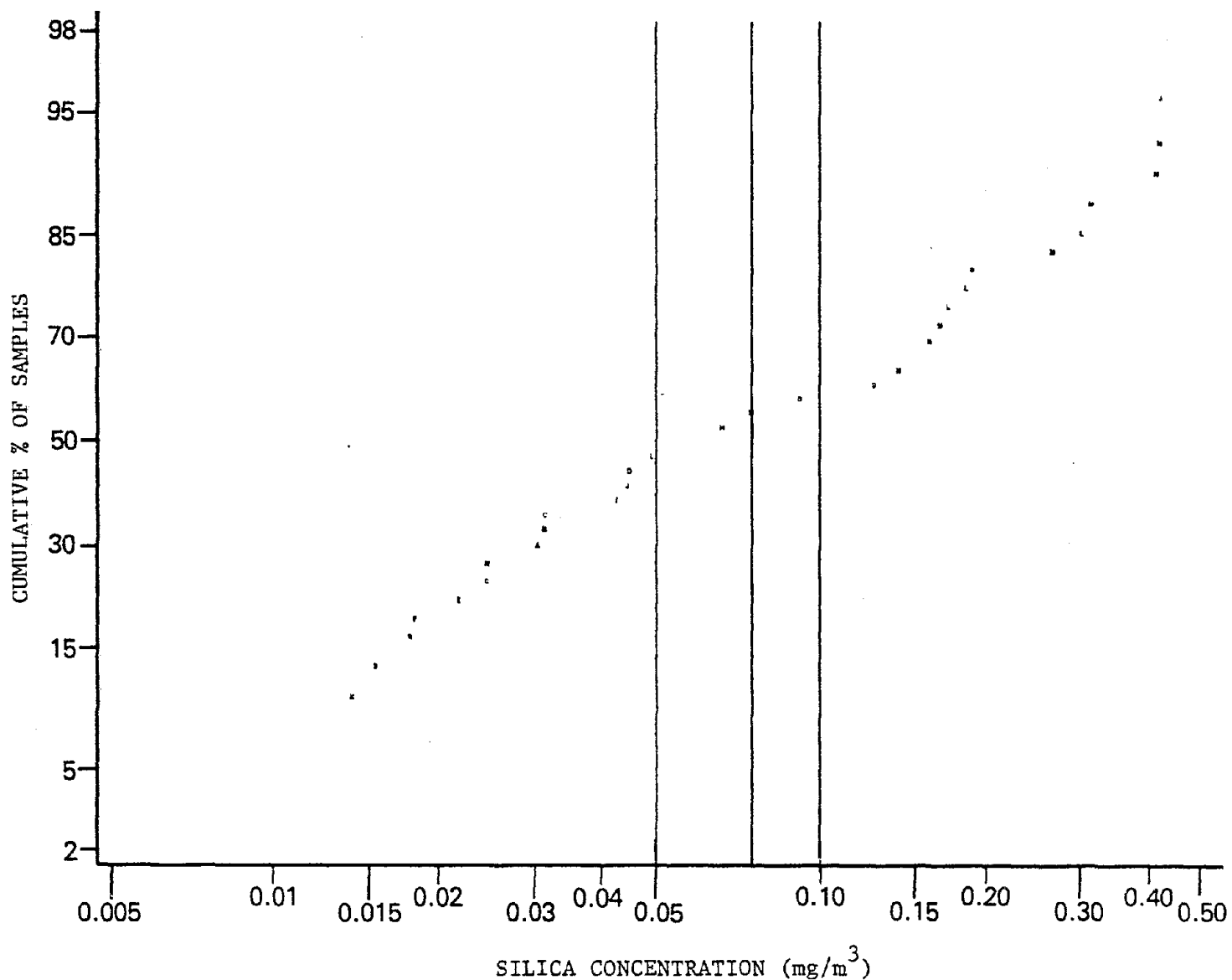
No. of samples: 249
 No. of mine ID's represented: 32
 No. of active sites in 1980: 82
 Percent of samples less than 0.05 mg/m³: 65
 Percent of samples less than 0.075 mg/m³: 75
 Percent of samples less than 0.1 mg/m³: 84

Figure A-12. Respirable quartz concentrations found in crushing, grinding, and sizing operations (surface and underground) in the copper industry group.



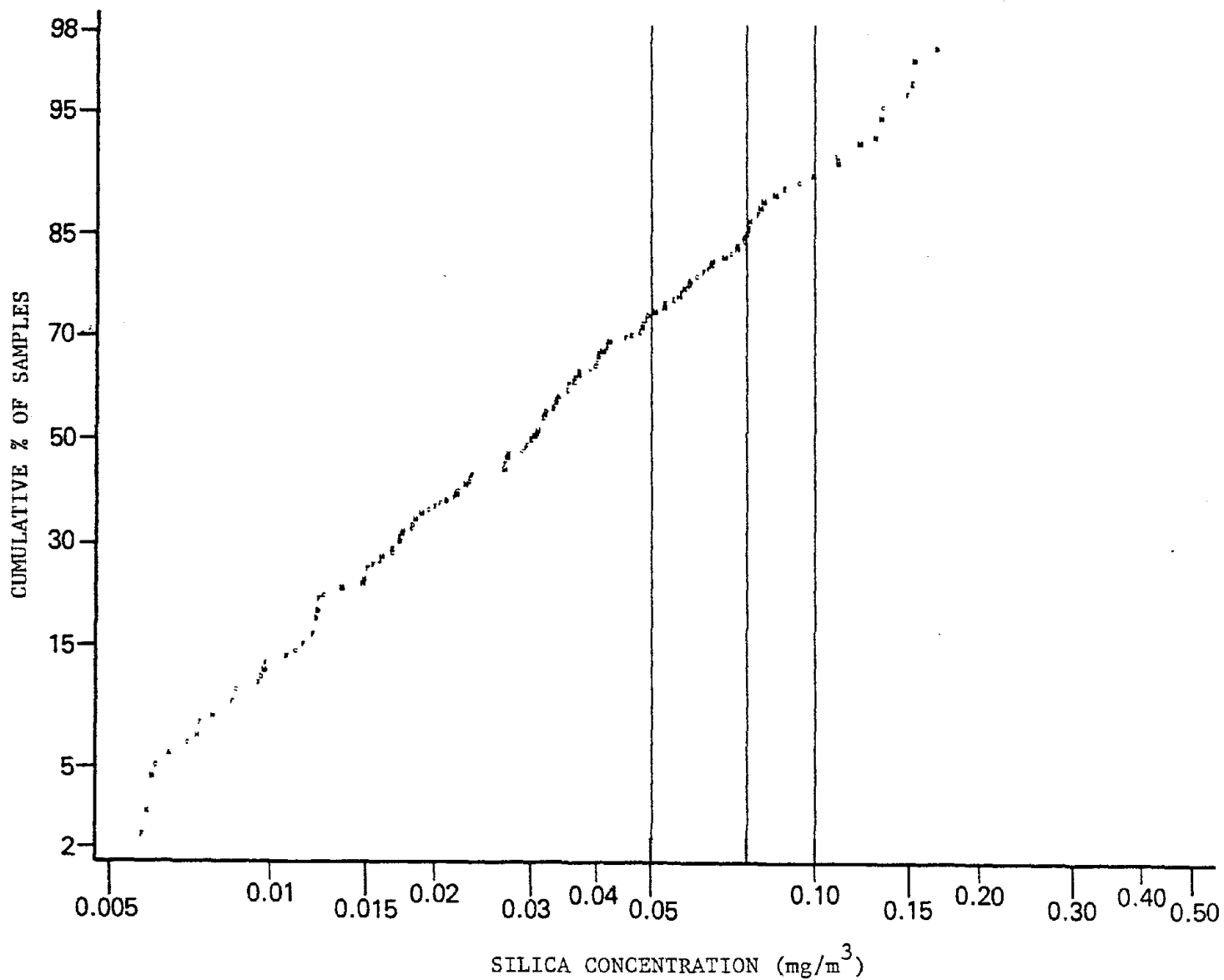
No. of samples: 66
 No. of mine ID's represented: 18
 No. of active sites in 1980: 82
 Percent of samples less than 0.05 mg/m³: 92
 Percent of samples less than 0.075 mg/m³: 100
 Percent of samples less than 0.1 mg/m³: 100

Figure A-13. Respirable quartz concentrations found in concentrating and finishing operations (surface and underground) in the copper industry group.



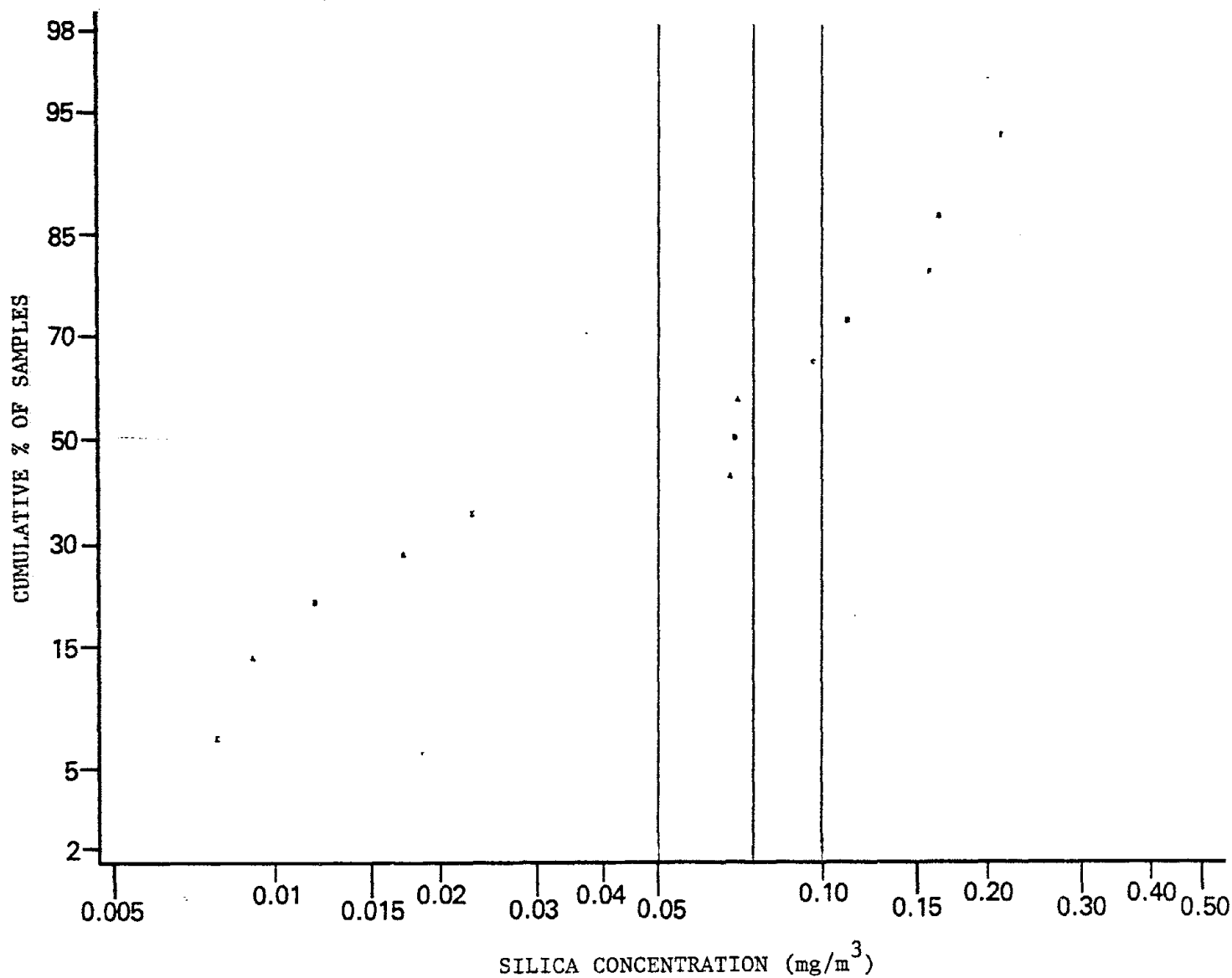
No. of samples: 37
 No. of mine ID's represented: 15
 No. of active sites in 1980: 269
 Percent of samples less than 0.05 mg/m³: 46
 Percent of samples less than 0.075 mg/m³: 54
 Percent of samples less than 0.1 mg/m³: 57

Figure A-14. Respirable quartz concentrations found in nonspecific surface operations in the gold and silver industry group.



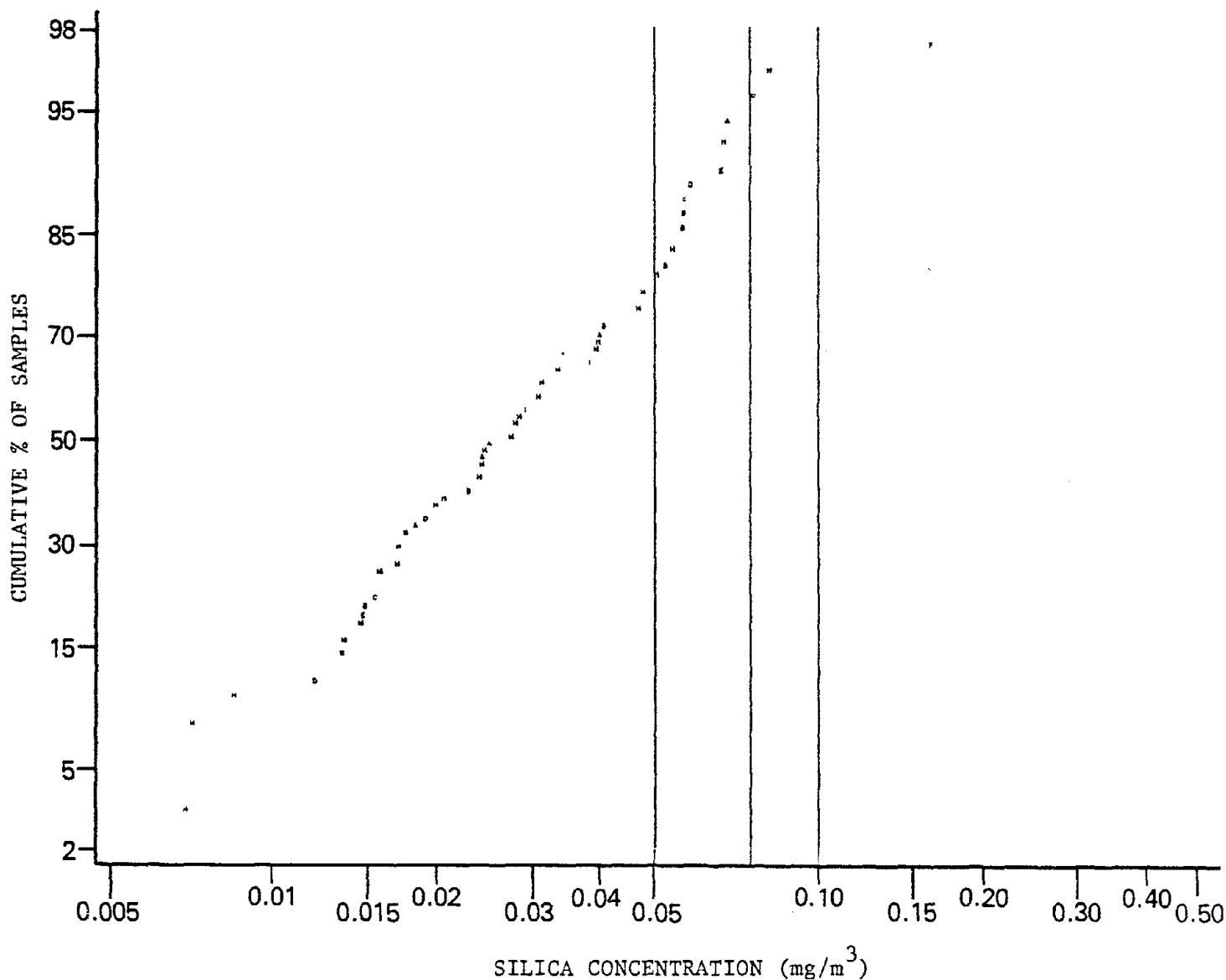
No. of samples: 174
No. of mine ID's represented: 15
No. of active sites in 1980: 113
Percent of samples less than 0.05 mg/m³: 72
Percent of samples less than 0.075 mg/m³: 83
Percent of samples less than 0.1 mg/m³: 89

Figure A-15. Respirable quartz concentrations found in nonspecific underground operations in the gold and silver industry group.



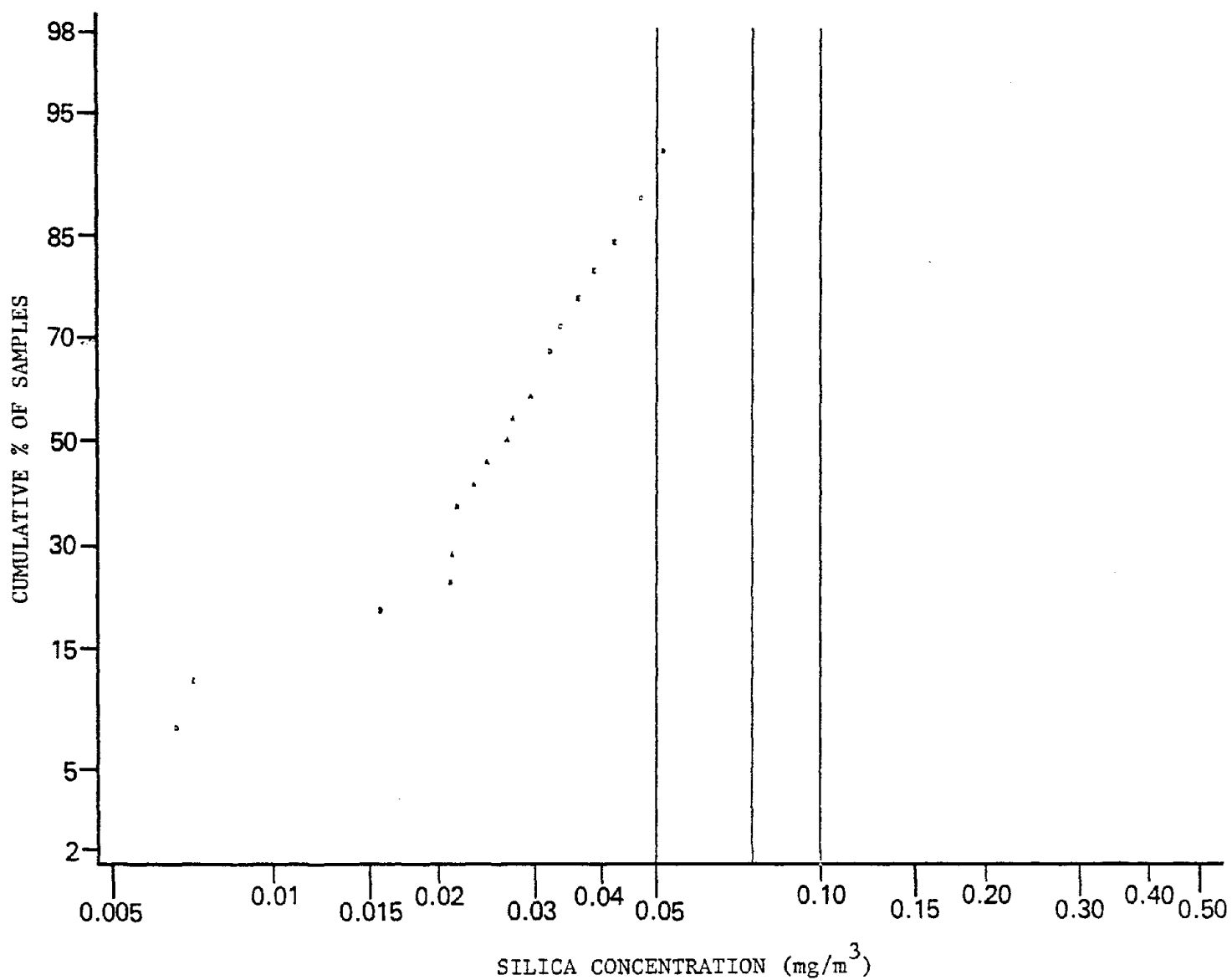
No. of samples: 14
No. of mine ID's represented: 6
No. of active sites in 1980: 73
Percent of samples less than 0.05 mg/m³: 36
Percent of samples less than 0.075 mg/m³: 57
Percent of samples less than 0.1 mg/m³: 64

Figure A-16. Respirable quartz concentrations found in surface drilling operations in the gold and silver industry group.



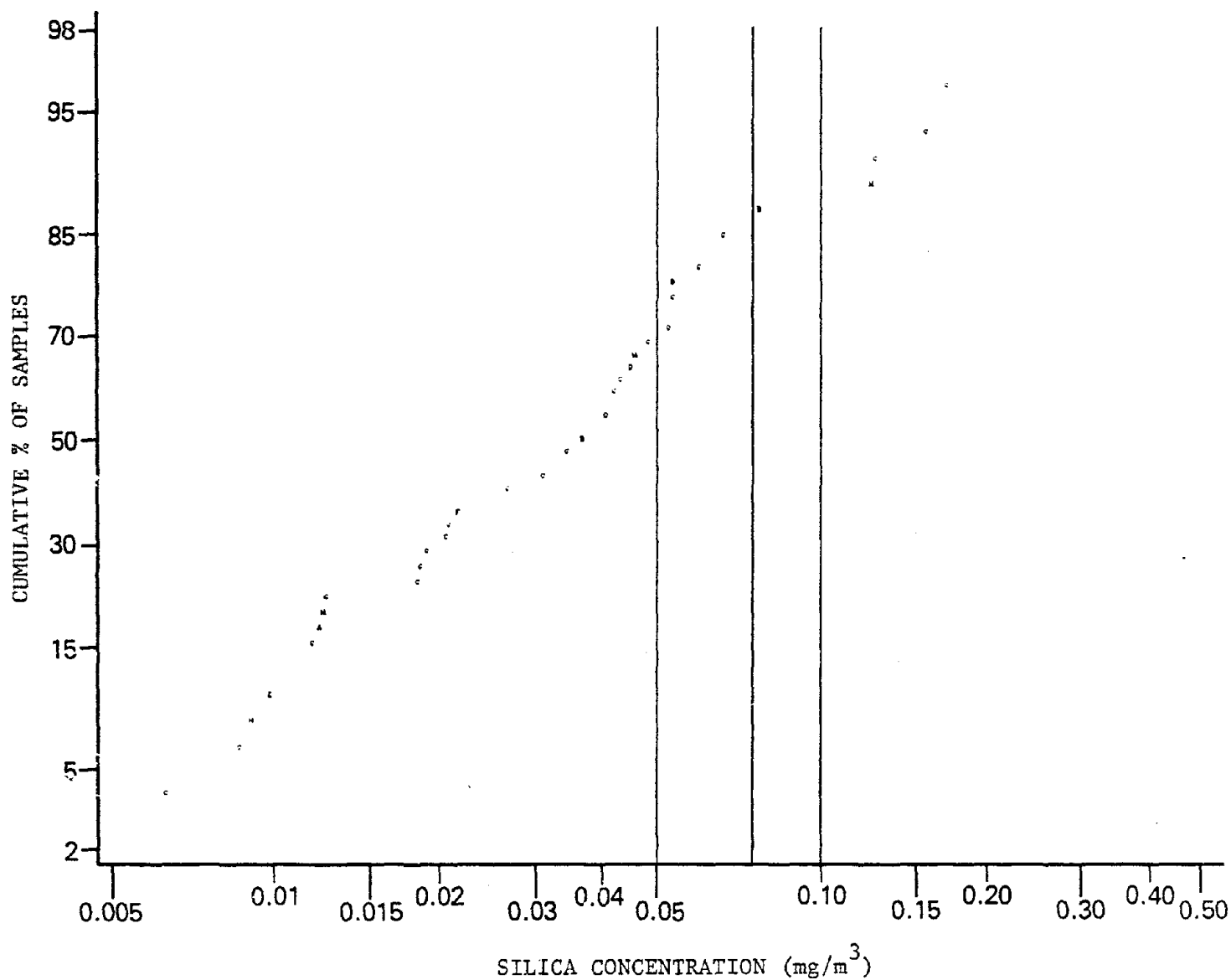
No. of samples: 79
 No. of mine ID's represented: 9
 No. of active sites in 1980: 113
 Percent of samples less than 0.05 mg/m³: 76
 Percent of samples less than 0.075 mg/m³: 94
 Percent of samples less than 0.1 mg/m³: 96

Figure A-17. Respirable quartz concentrations found in underground drilling operations in the gold and silver industry group.



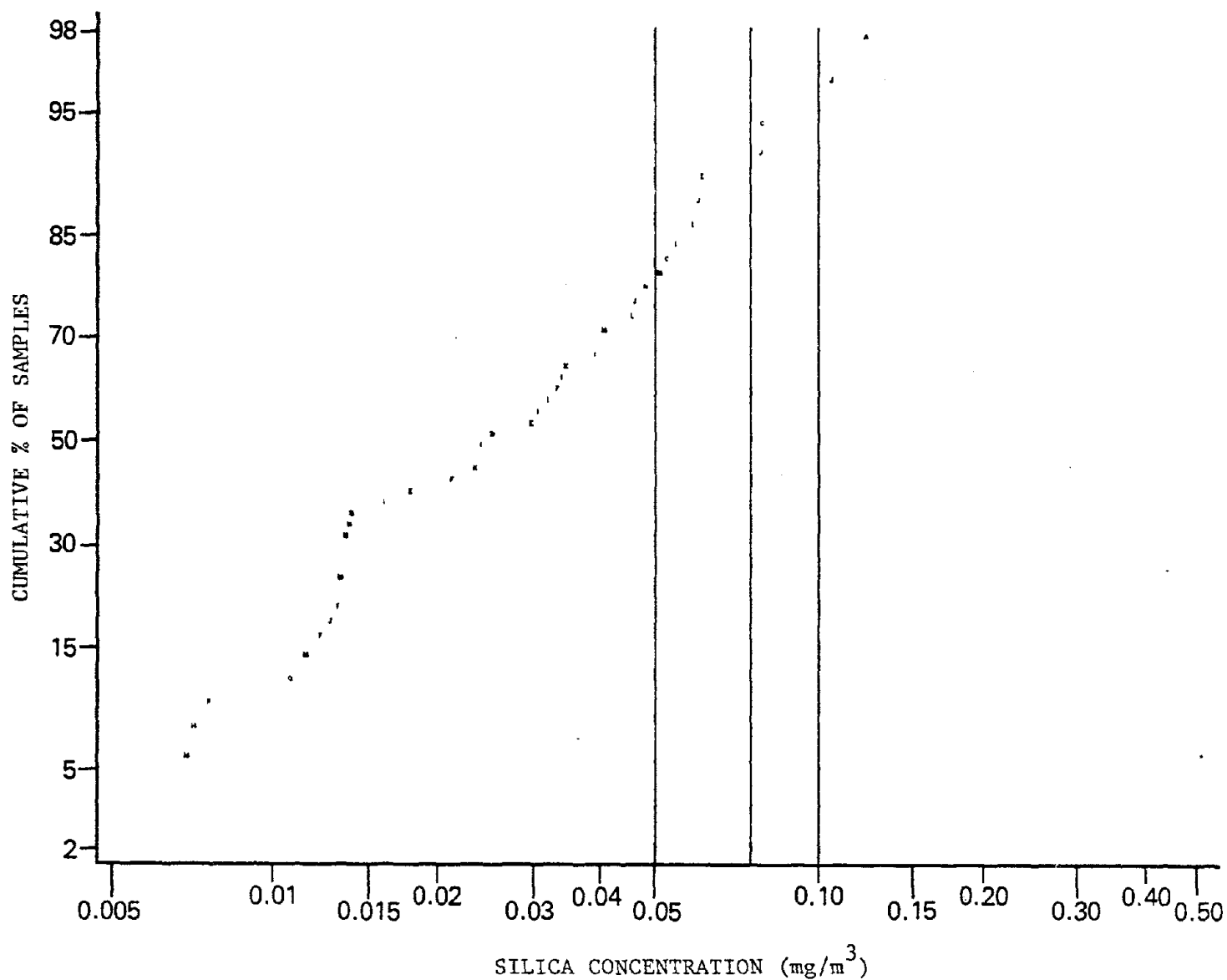
No. of samples: 24
 No. of mine ID's represented: 5
 No. of active sites in 1980: 113
 Percent of samples less than 0.05 mg/m³: 88
 Percent of samples less than 0.075 mg/m³: 92
 Percent of samples less than 0.1 mg/m³: 100

Figure A-18. Respirable quartz concentrations found in underground haulageway maintenance operations in the gold and silver industry group.



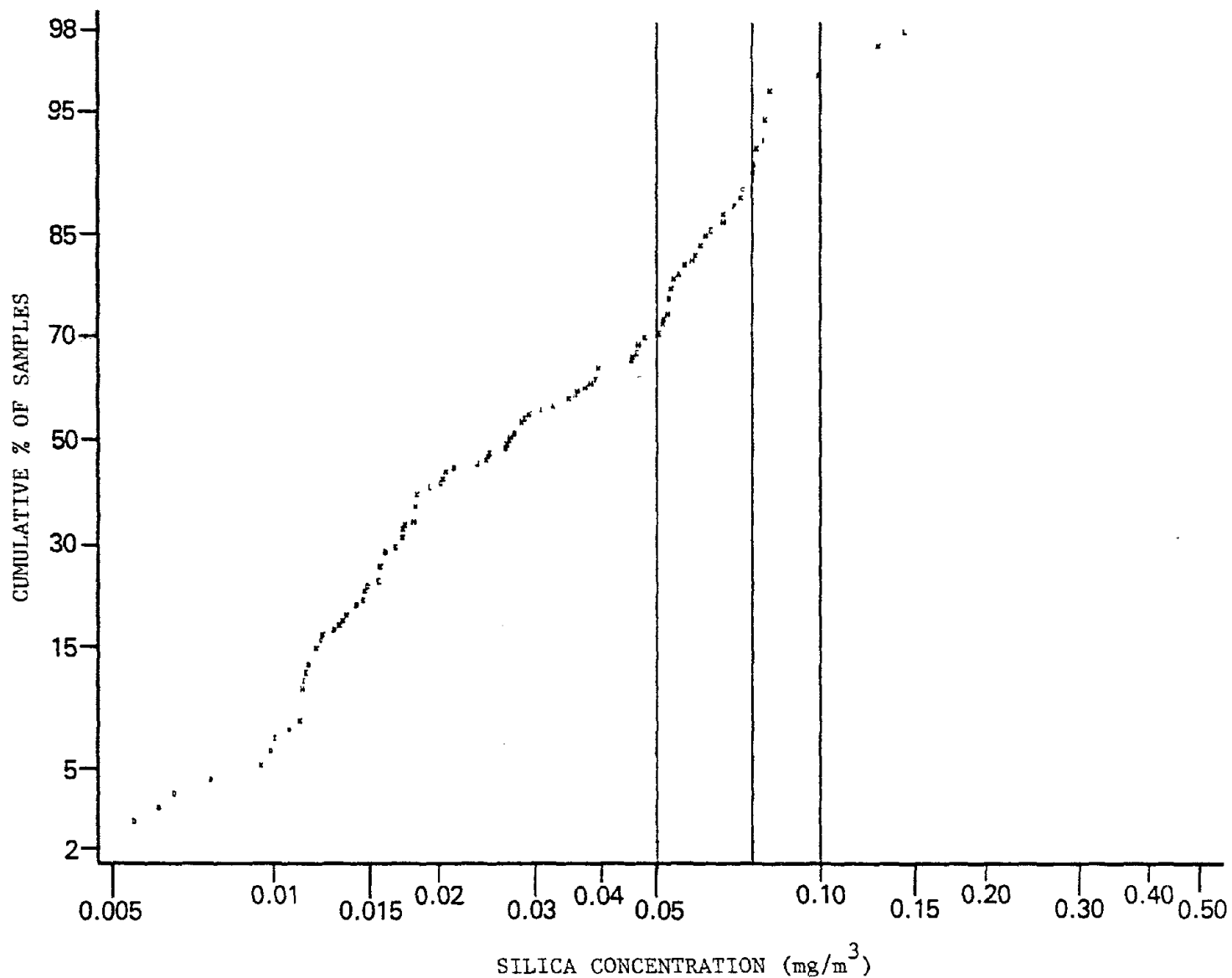
No. of samples: 44
 No. of mine ID's represented: 8
 No. of active sites in 1980: 113
 Percent of samples less than 0.05 mg/m³: 68
 Percent of samples less than 0.075 mg/m³: 84
 Percent of samples less than 0.1 mg/m³: 86

Figure A-19. Respirable quartz concentrations found in underground production operations in the gold and silver industry group.



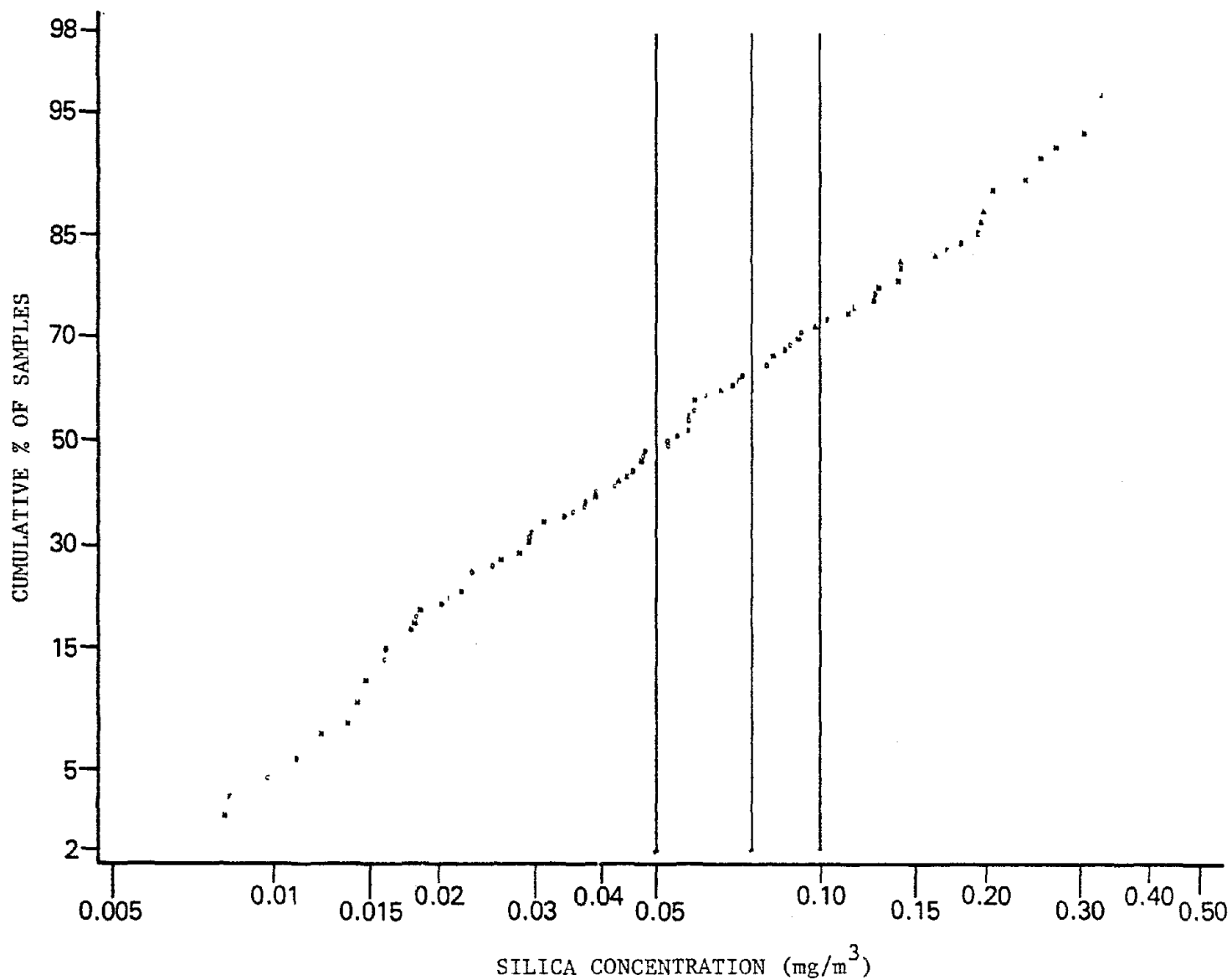
No. of samples: 47
No. of mine ID's represented: 15
No. of active sites in 1980: 73
Percent of samples less than 0.05 mg/m³: 77
Percent of samples less than 0.075 mg/m³: 89
Percent of samples less than 0.1 mg/m³: 94

Figure A-20. Respirable quartz concentrations found in surface mobile transport operations in the gold and silver industry group.



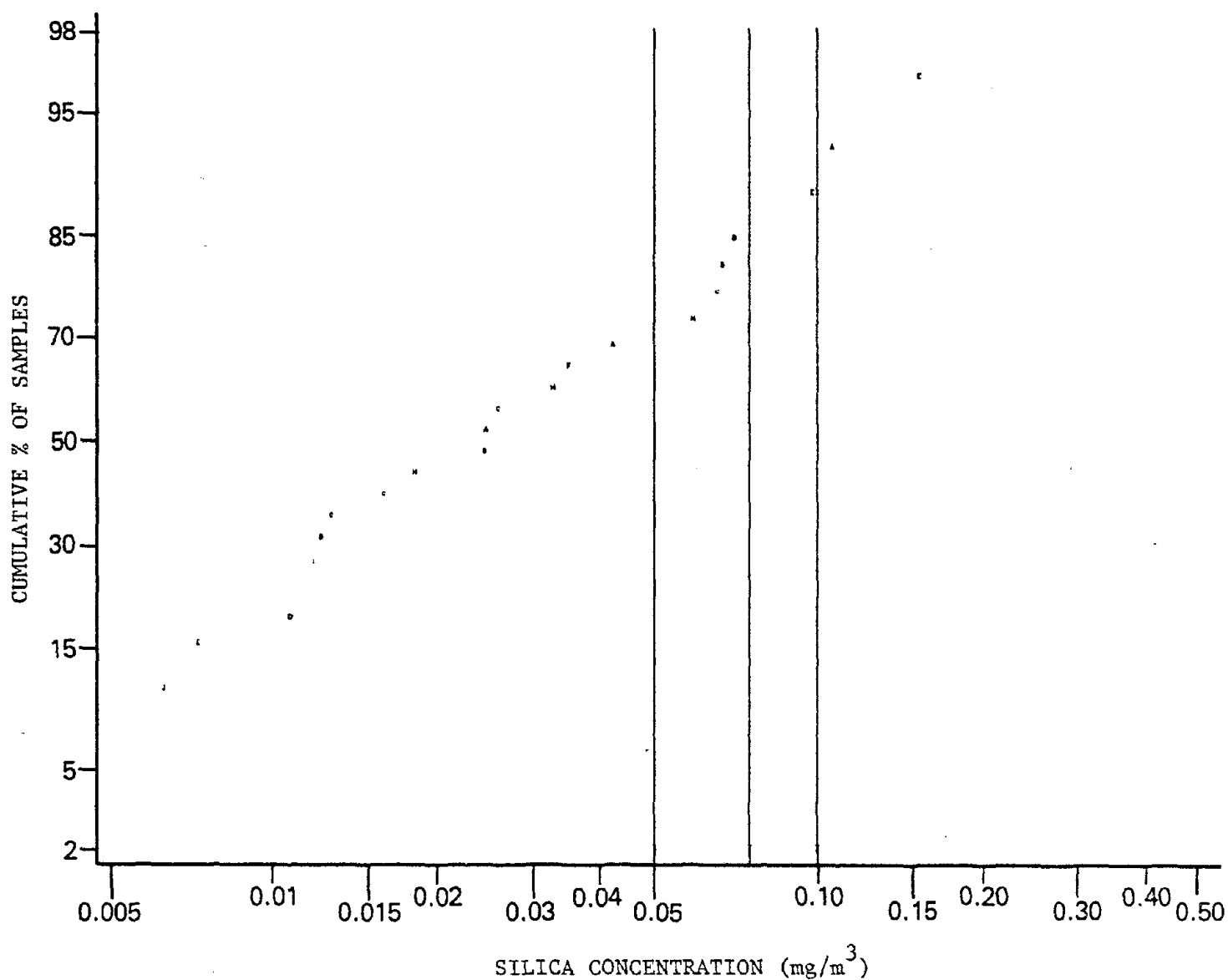
No. of samples: 139
 No. of mine ID's represented: 12
 No. of active sites in 1980: 113
 Percent of samples less than 0.05 mg/m³: 68
 Percent of samples less than 0.075 mg/m³: 83
 Percent of samples less than 0.1 mg/m³: 96

Figure A-21. Respirable quartz concentrations found in underground mobile transport operations in the gold and silver industry group.



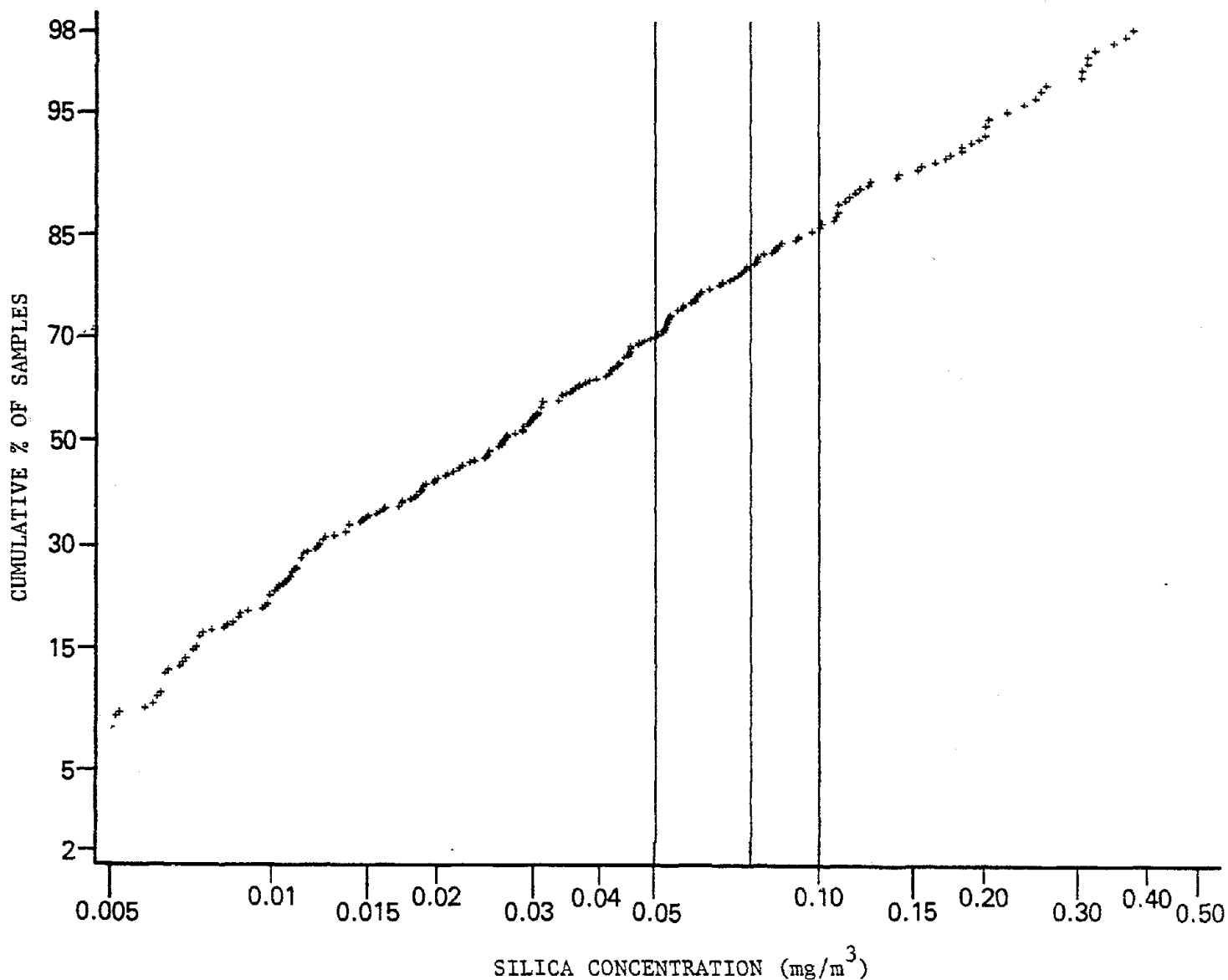
No. of samples: 106
 No. of mine ID's represented: 17
 No. of active sites in 1980: 269
 Percent of samples less than 0.05 mg/m³: 49
 Percent of samples less than 0.075 mg/m³: 63
 Percent of samples less than 0.1 mg/m³: 72

Figure A-22. Respirable quartz concentrations found in crushing, grinding, and sizing operations (surface and underground) in the gold and silver industry group.



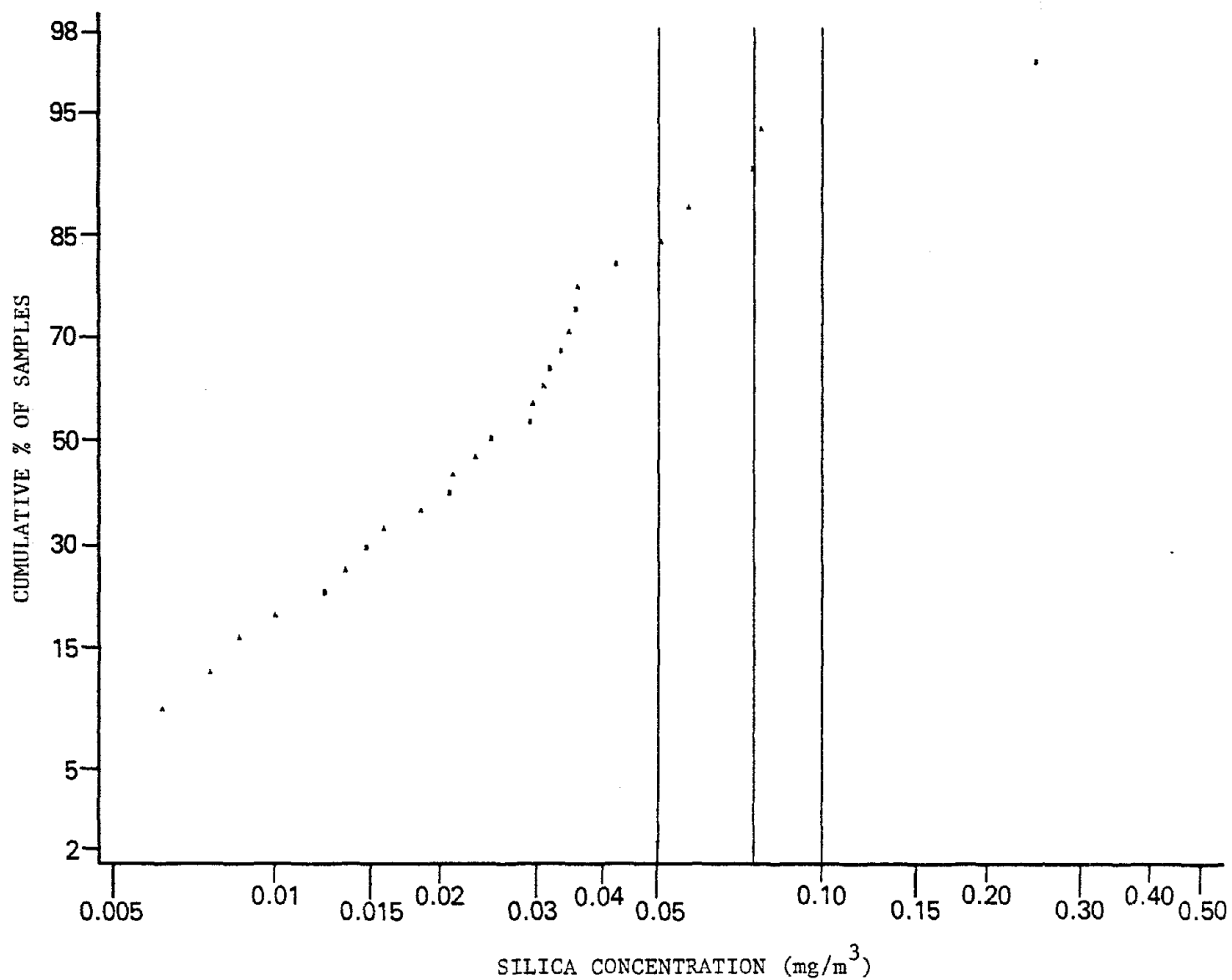
No. of samples: 25
 No. of mine ID's represented: 10
 No. of active sites in 1980: 269
 Percent of samples less than 0.05 mg/m³: 68
 Percent of samples less than 0.075 mg/m³: 84
 Percent of samples less than 0.1 mg/m³: 88

Figure A-23. Respirable quartz concentrations found in concentrating and finishing operations (surface and underground) in the gold and silver industry group.



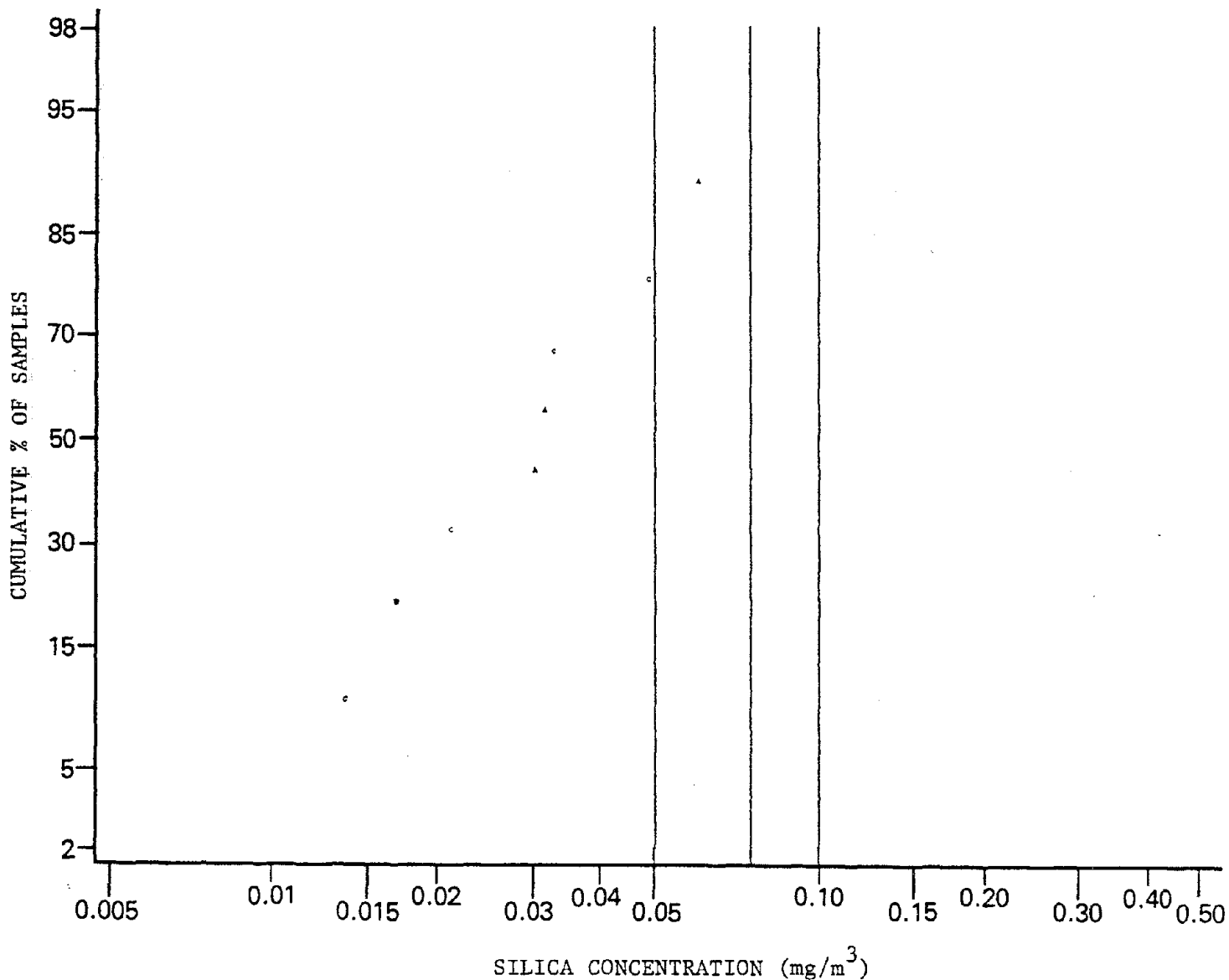
No. of samples: 294
No. of mine ID's represented: 26
No. of active sites in 1980: 58
Percent of samples less than 0.05 mg/m³: 68
Percent of samples less than 0.075 mg/m³: 79
Percent of samples less than 0.1 mg/m³: 84

Figure A-24. Respirable quartz concentrations found in nonspecific surface operations in the iron industry group.



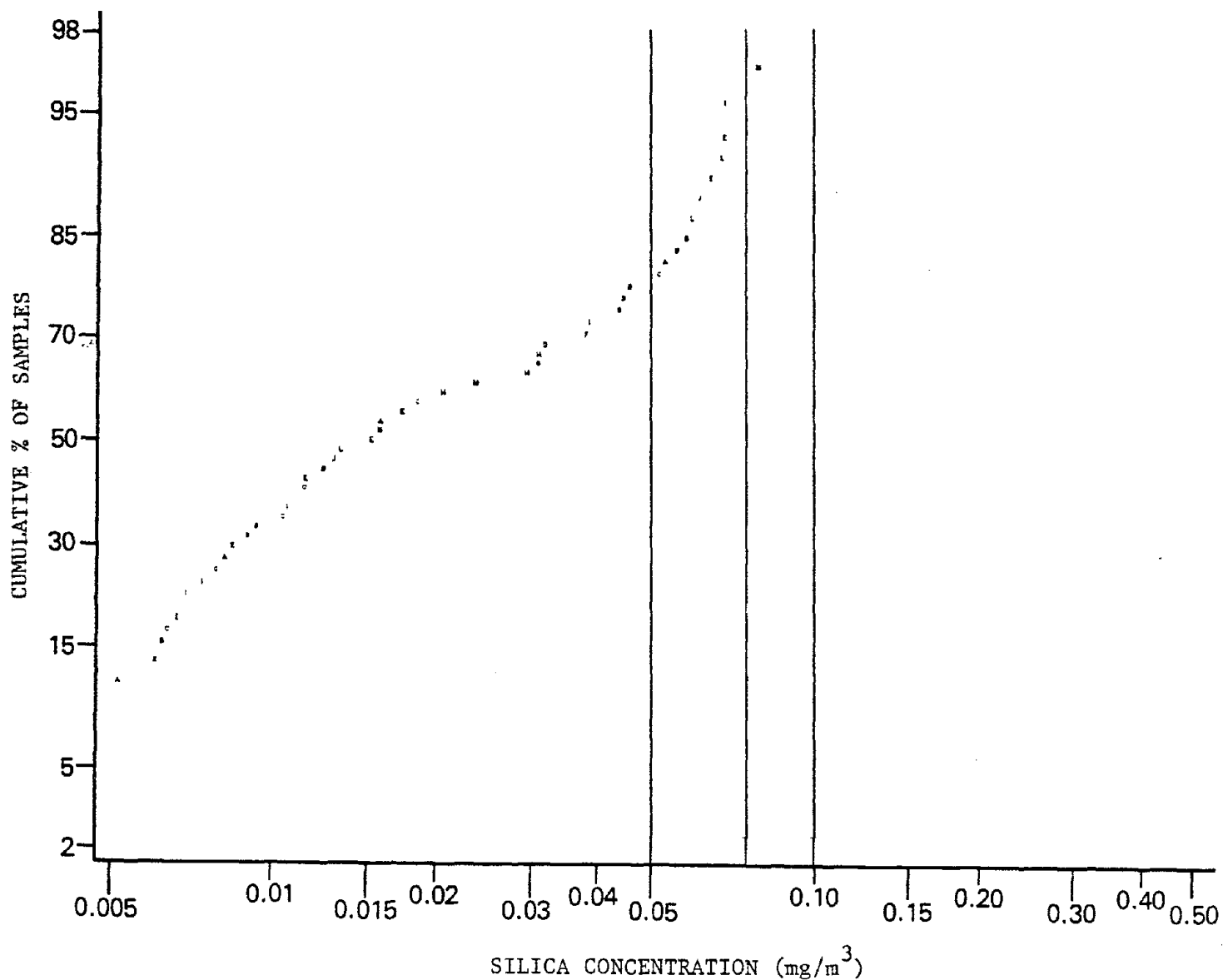
No. of samples: 30
 No. of mine ID's represented: 2
 No. of active sites in 1980: 7
 Percent of samples less than 0.05 mg/m³: 80
 Percent of samples less than 0.075 mg/m³: 90
 Percent of samples less than 0.1 mg/m³: 93

Figure A-25. Respirable quartz concentrations found in nonspecific underground operations in the iron industry group.



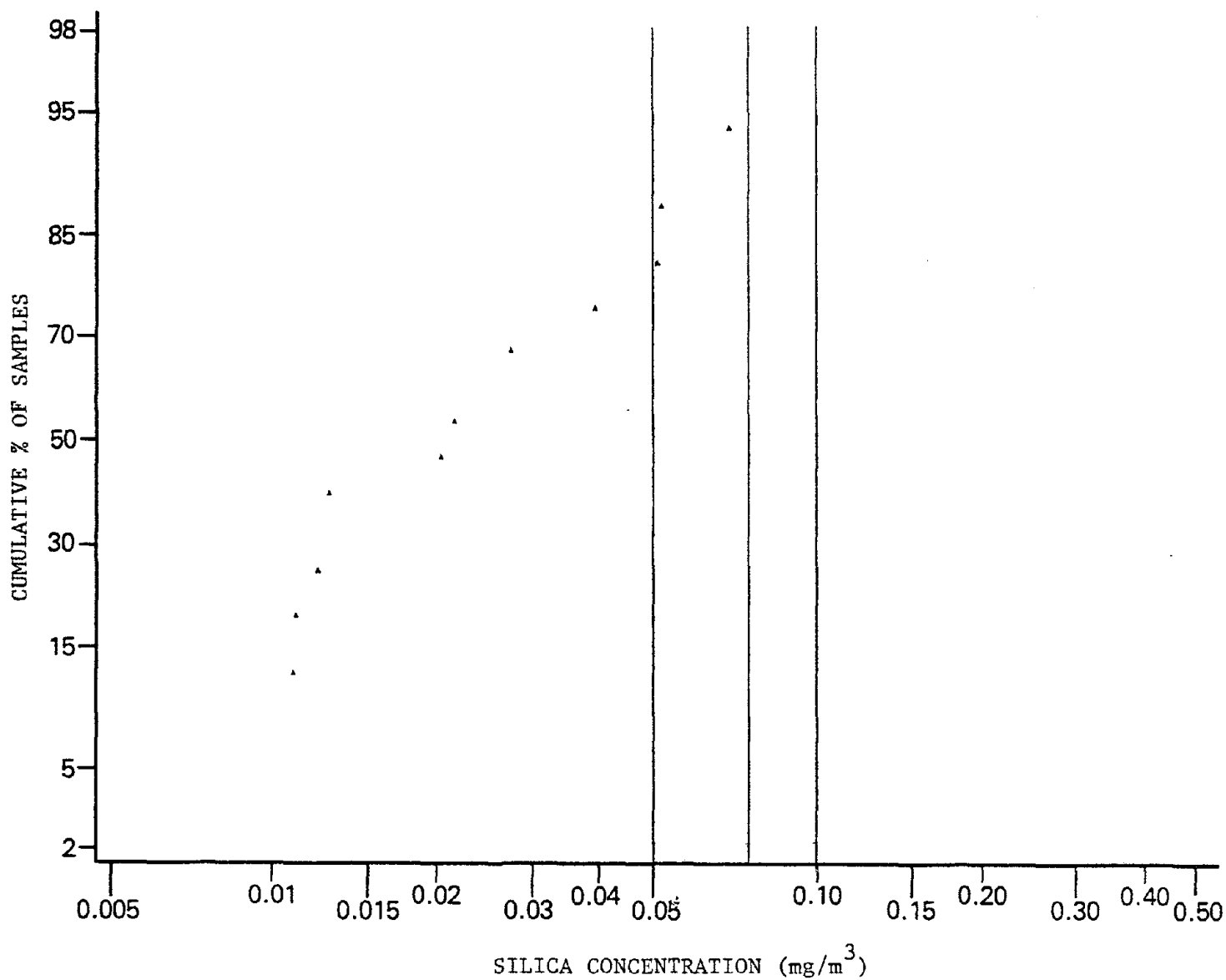
No. of samples: 9
 No. of mine ID's represented: 3
 No. of active sites in 1980: 58
 Percent of samples less than 0.05 mg/m³: 78
 Percent of samples less than 0.075 mg/m³: 100
 Percent of samples less than 0.1 mg/m³: 100

Figure A-26. Respirable quartz concentrations found in blasting operations (surface and underground) in the iron industry group.



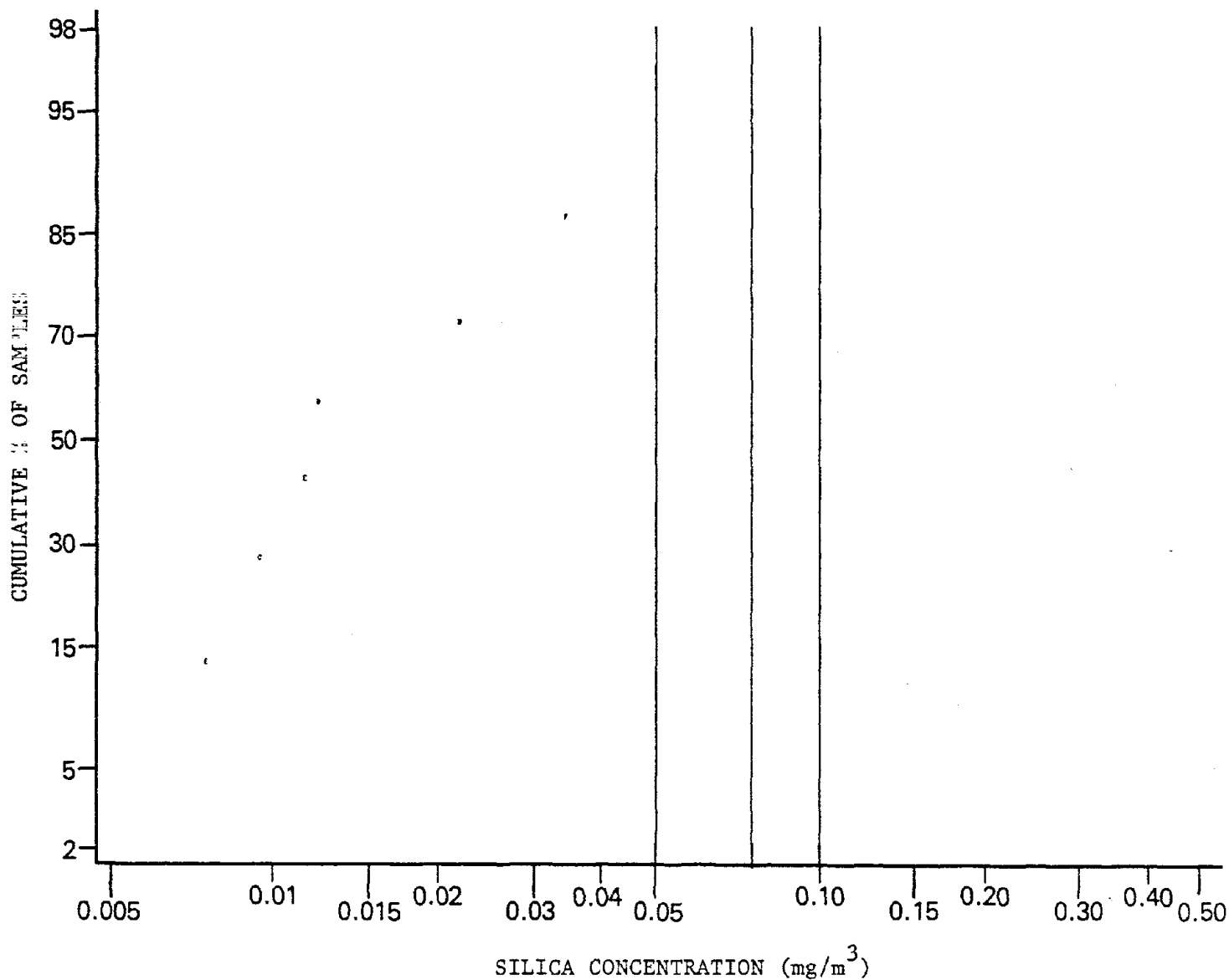
No. of samples: 56
 No. of mine ID's represented: 13
 No. of active sites in 1980: 31
 Percent of samples less than 0.05 mg/m³: 77
 Percent of samples less than 0.075 mg/m³: 95
 Percent of samples less than 0.1 mg/m³: 100

Figure A-27. Respirable quartz concentrations found in surface drilling operations in the iron industry group.



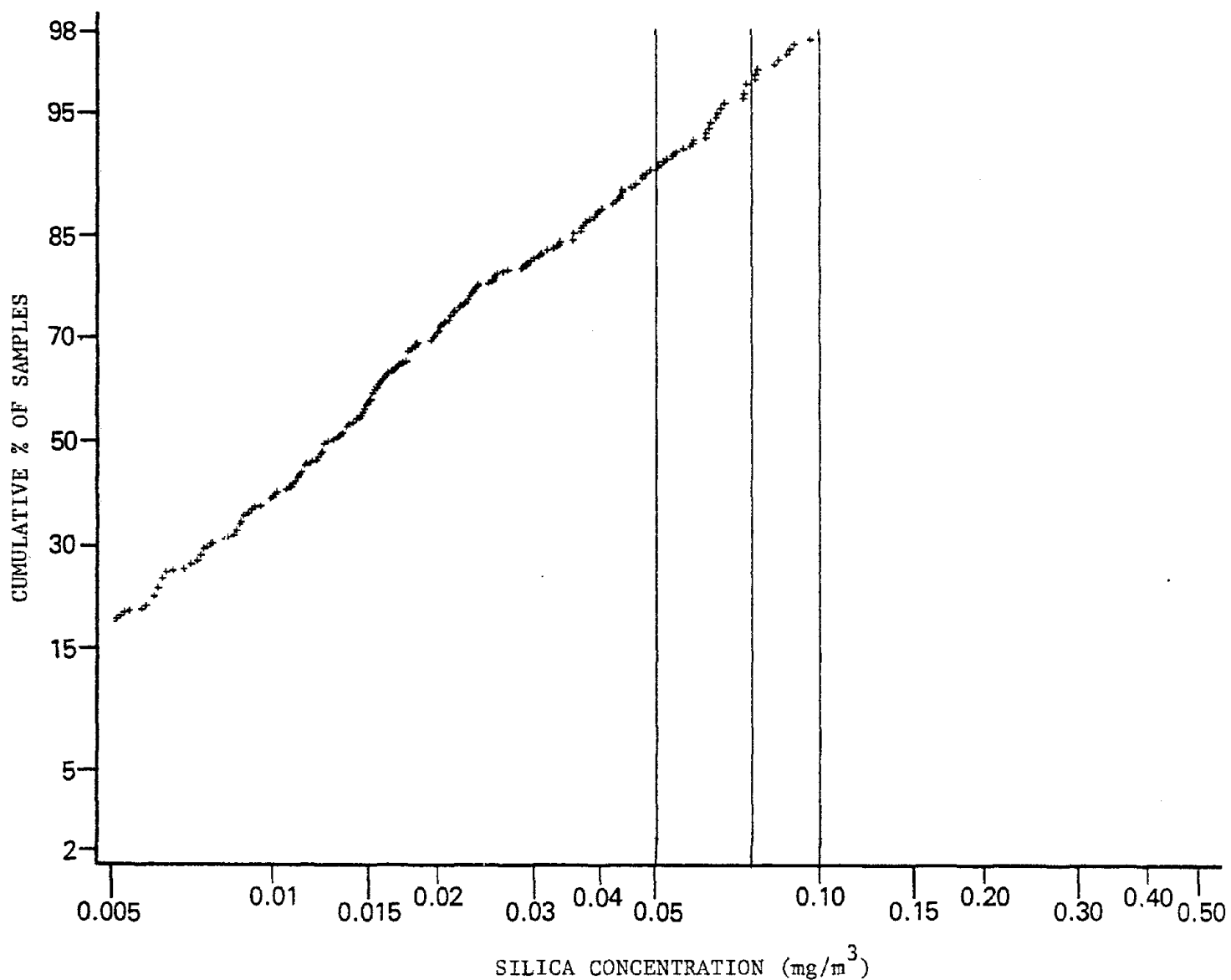
No. of samples: 15
 No. of mine ID's represented: 1
 No. of active sites in 1980: 7
 Percent of samples less than 0.05 mg/m³: 73
 Percent of samples less than 0.075 mg/m³: 100
 Percent of samples less than 0.1 mg/m³: 100

Figure A-28. Respirable quartz concentrations found in underground drilling operations in the iron industry group.



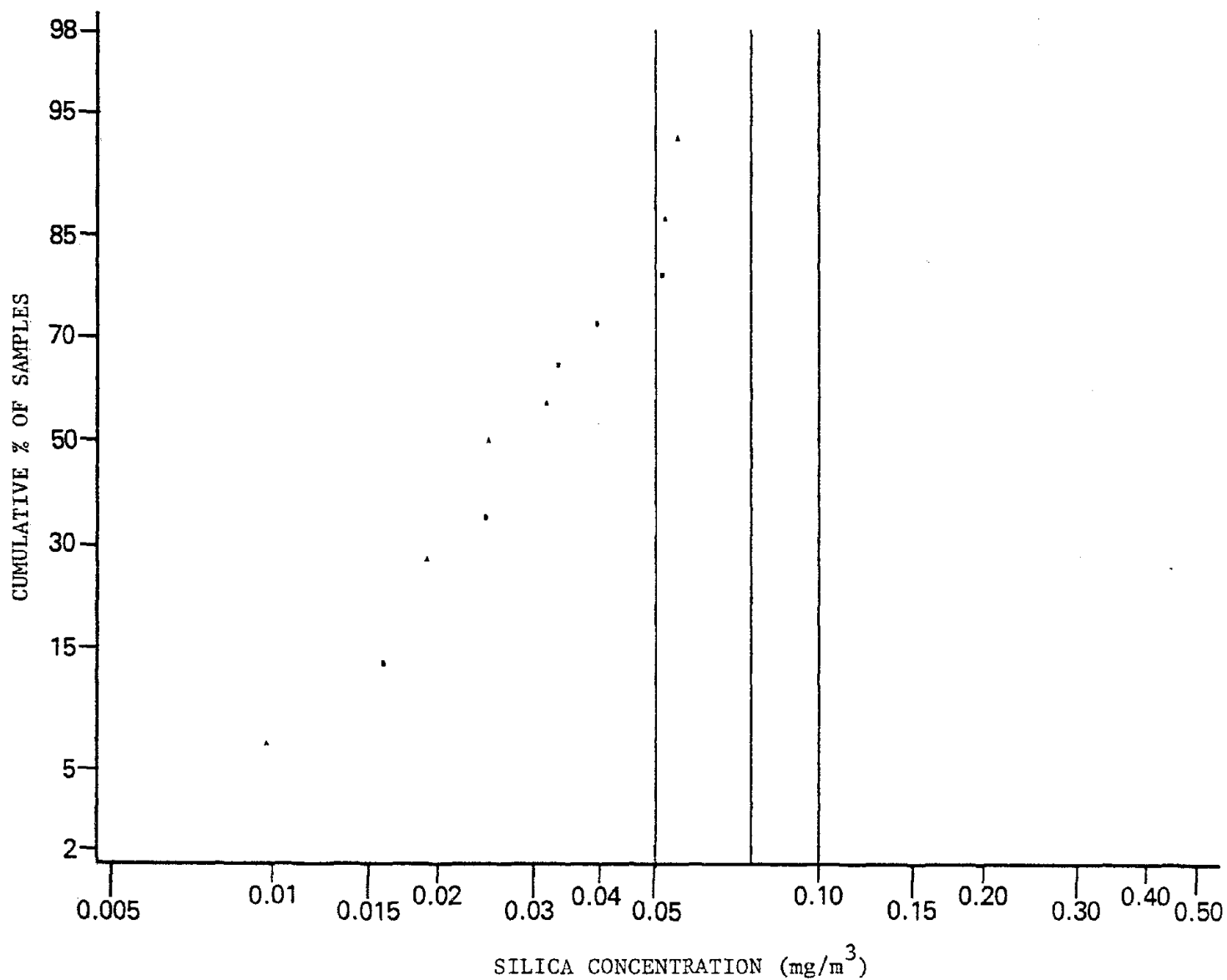
No. of samples: 7
 No. of mine ID's represented: 6
 No. of active sites in 1980: 31
 Percent of samples less than 0.05 mg/m³: 86
 Percent of samples less than 0.075 mg/m³: 86
 Percent of samples less than 0.1 mg/m³: 86

Figure A-29. Respirable quartz concentrations found in surface production operations in the iron industry group.



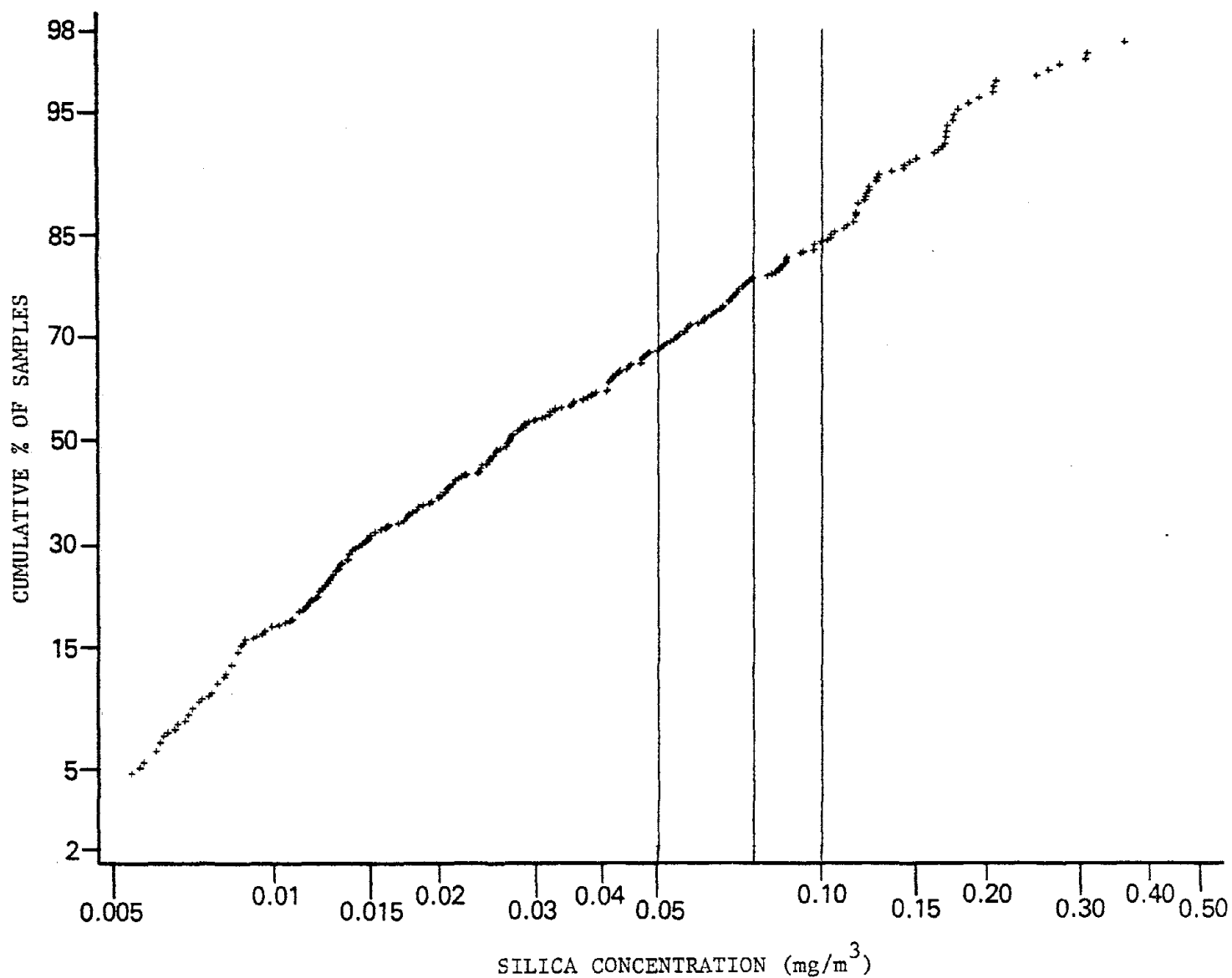
No. of samples: 415
 No. of mine ID's represented: 24
 No. of active sites in 1980: 31
 Percent of samples less than 0.05 mg/m³: 90
 Percent of samples less than 0.075 mg/m³: 96
 Percent of samples less than 0.1 mg/m³: 98

Figure A-30. Respirable quartz concentrations found in surface mobile transport operations in the iron industry group.



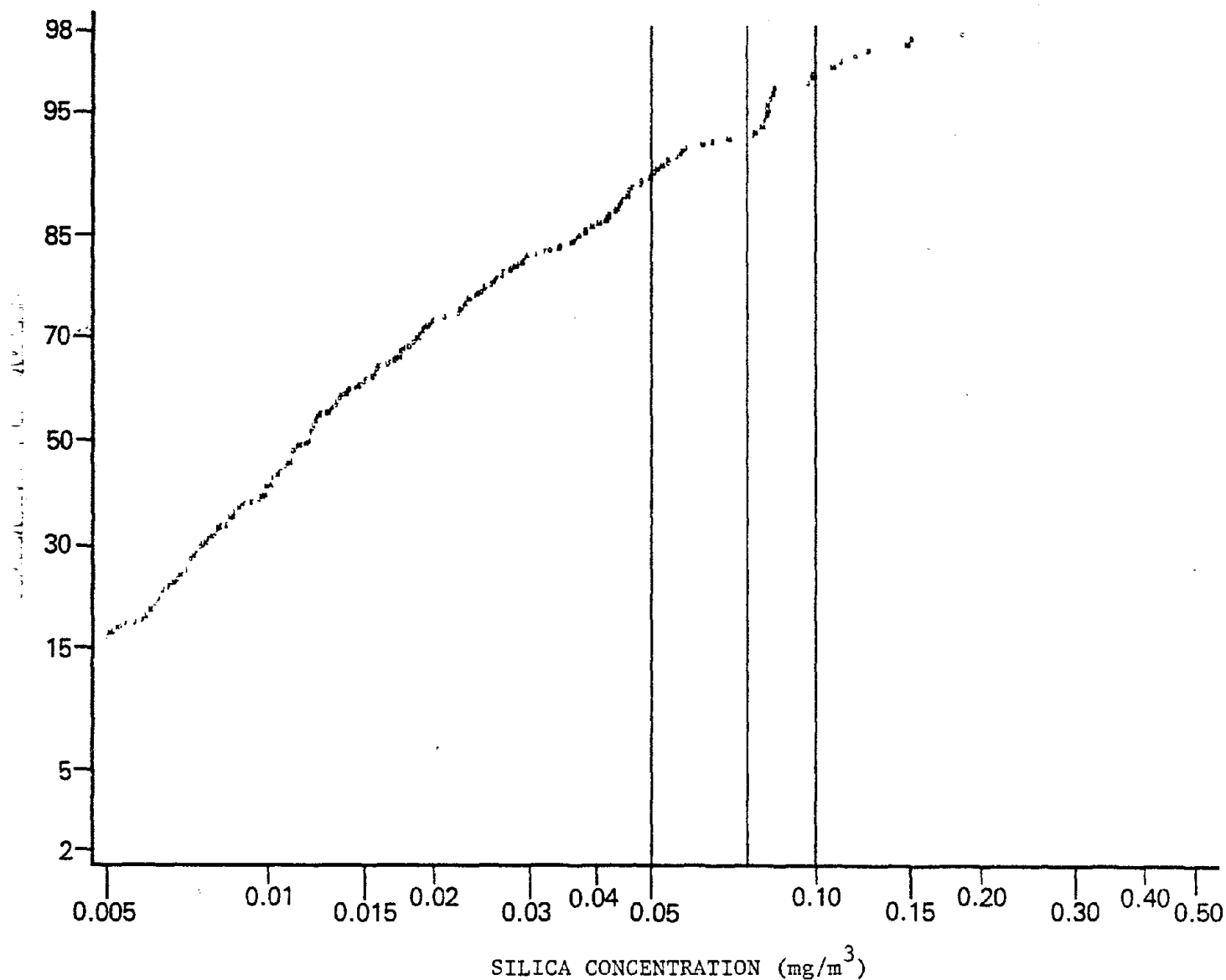
No. of samples: 14
 No. of mine ID's represented: 2
 No. of active sites in 1980: 7
 Percent of samples less than 0.05 mg/m³: 71
 Percent of samples less than 0.075 mg/m³: 93
 Percent of samples less than 0.1 mg/m³: 100

Figure A-31. Respirable quartz concentrations found in underground mobile transport operations in the iron industry group.



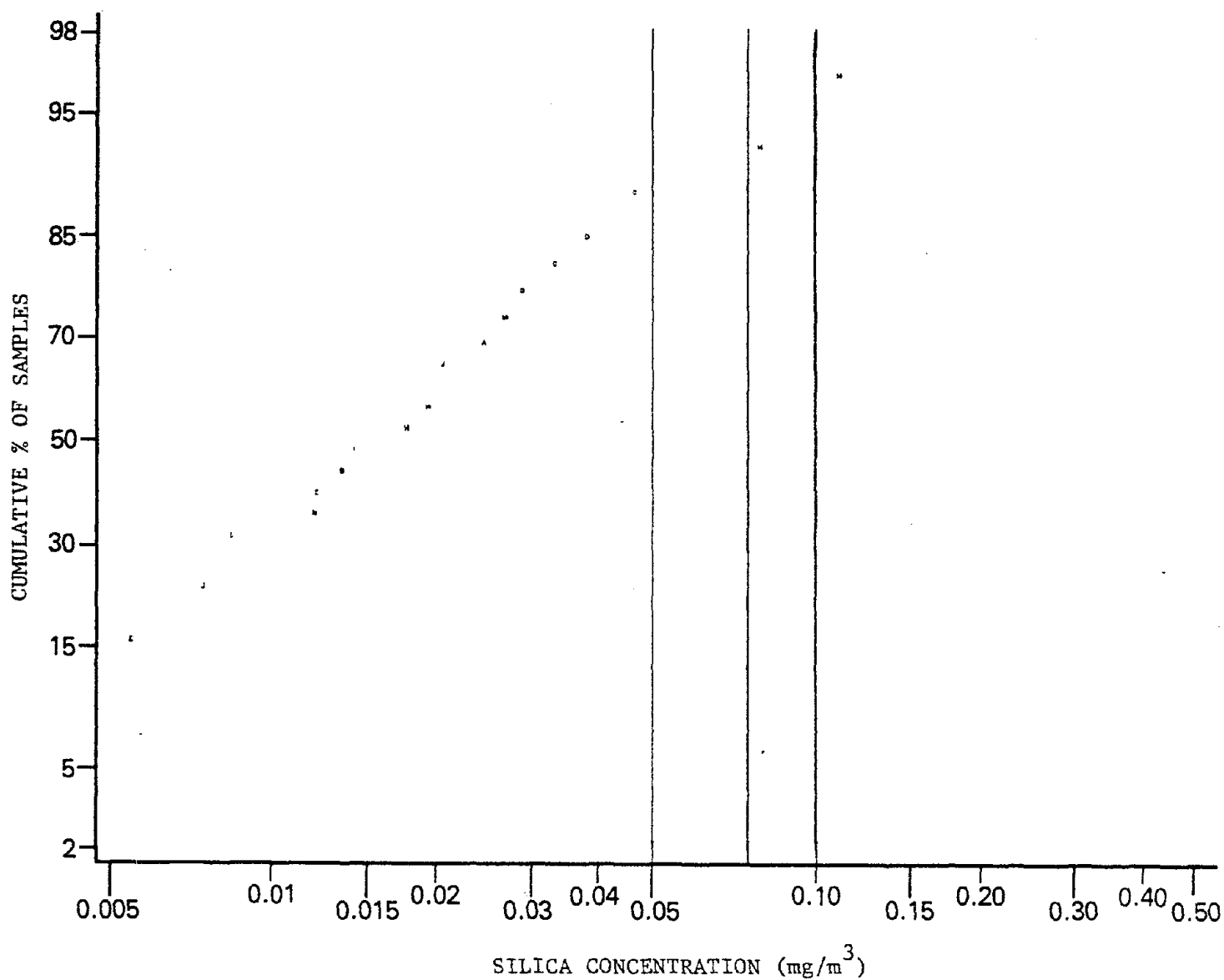
No. of samples: 360
 No. of mine ID's represented: 28
 No. of active sites in 1980: 58
 Percent of samples less than 0.05 mg/m³: 67
 Percent of samples less than 0.075 mg/m³: 78
 Percent of samples less than 0.1 mg/m³: 84

Figure A-32. Respirable quartz concentrations found in crushing, grinding, and sizing operations (surface and underground) in the iron industry group.



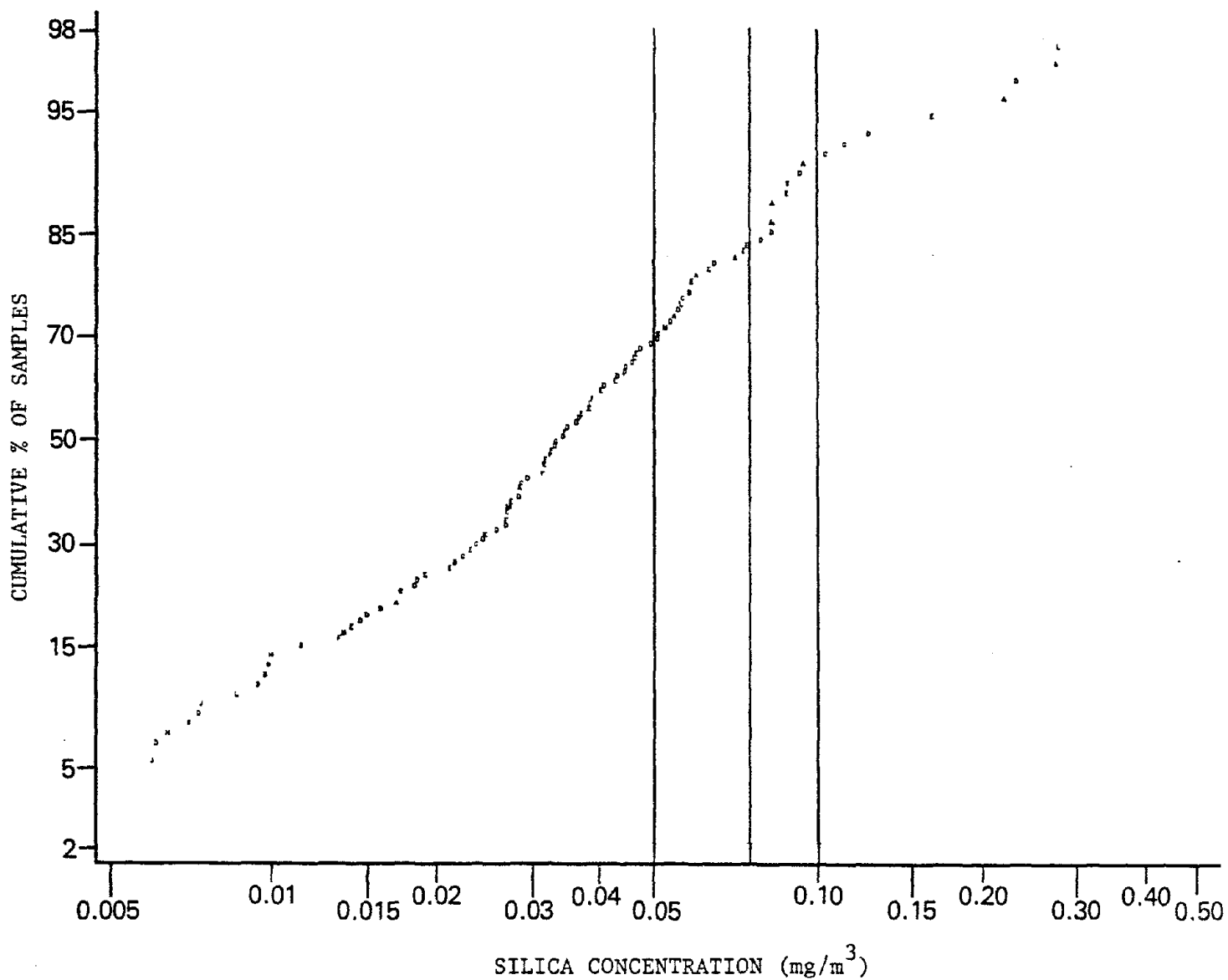
No. of samples: 375
 No. of mine ID's represented: 18
 No. of active sites in 1980: 58
 Percent of samples less than $0.05 \text{ mg}/\text{m}^3$: 89
 Percent of samples less than $0.075 \text{ mg}/\text{m}^3$: 93
 Percent of samples less than $0.1 \text{ mg}/\text{m}^3$: 96

Figure A-33. Respirable quartz concentrations found in concentrating and finishing operations (surface and underground) in the iron industry group.



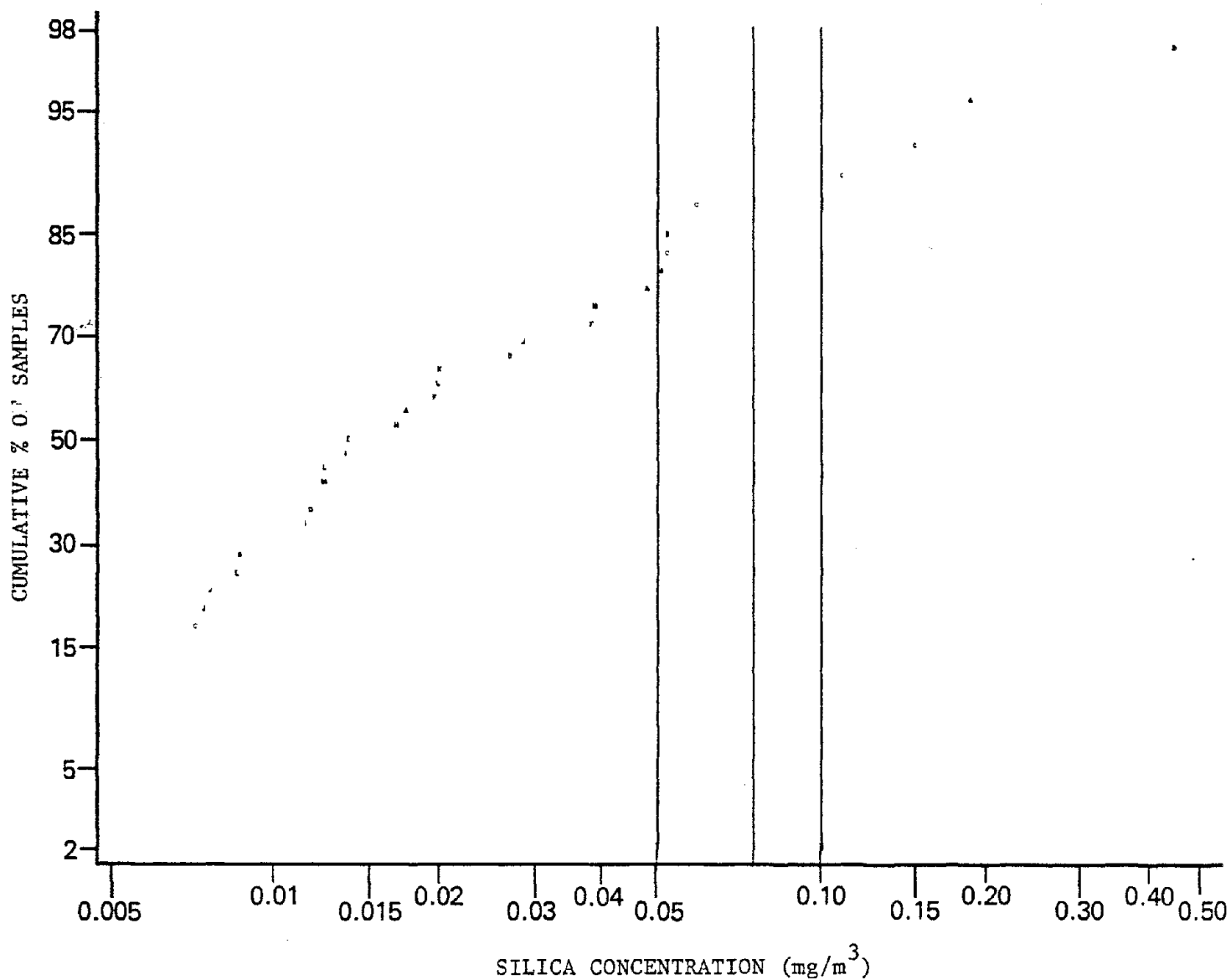
No. of samples: 25
 No. of mine ID's represented: 14
 No. of active sites in 1980: 70
 Percent of samples less than 0.05 mg/m³: 88
 Percent of samples less than 0.075 mg/m³: 88
 Percent of samples less than 0.1 mg/m³: 92

Figure A-34. Respirable quartz concentrations found in nonspecific surface operations in the lead and zinc industry group.



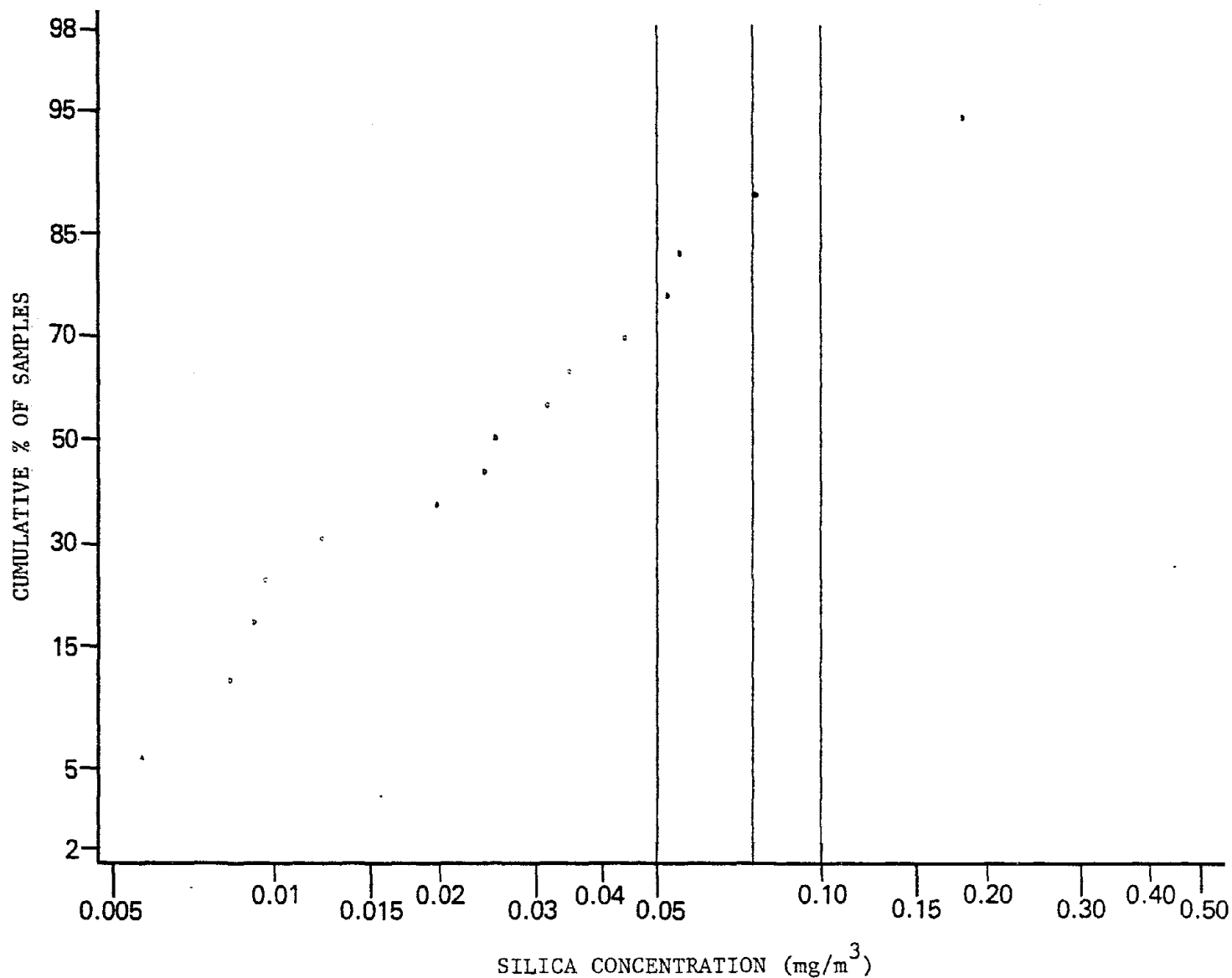
No. of samples: 115
 No. of mine ID's represented: 14
 No. of active sites in 1980: 49
 Percent of samples less than 0.05 mg/m³: 68
 Percent of samples less than 0.075 mg/m³: 83
 Percent of samples less than 0.1 mg/m³: 90

Figure A-35. Respirable quartz concentrations found in nonspecific underground operations in the lead and zinc industry group.



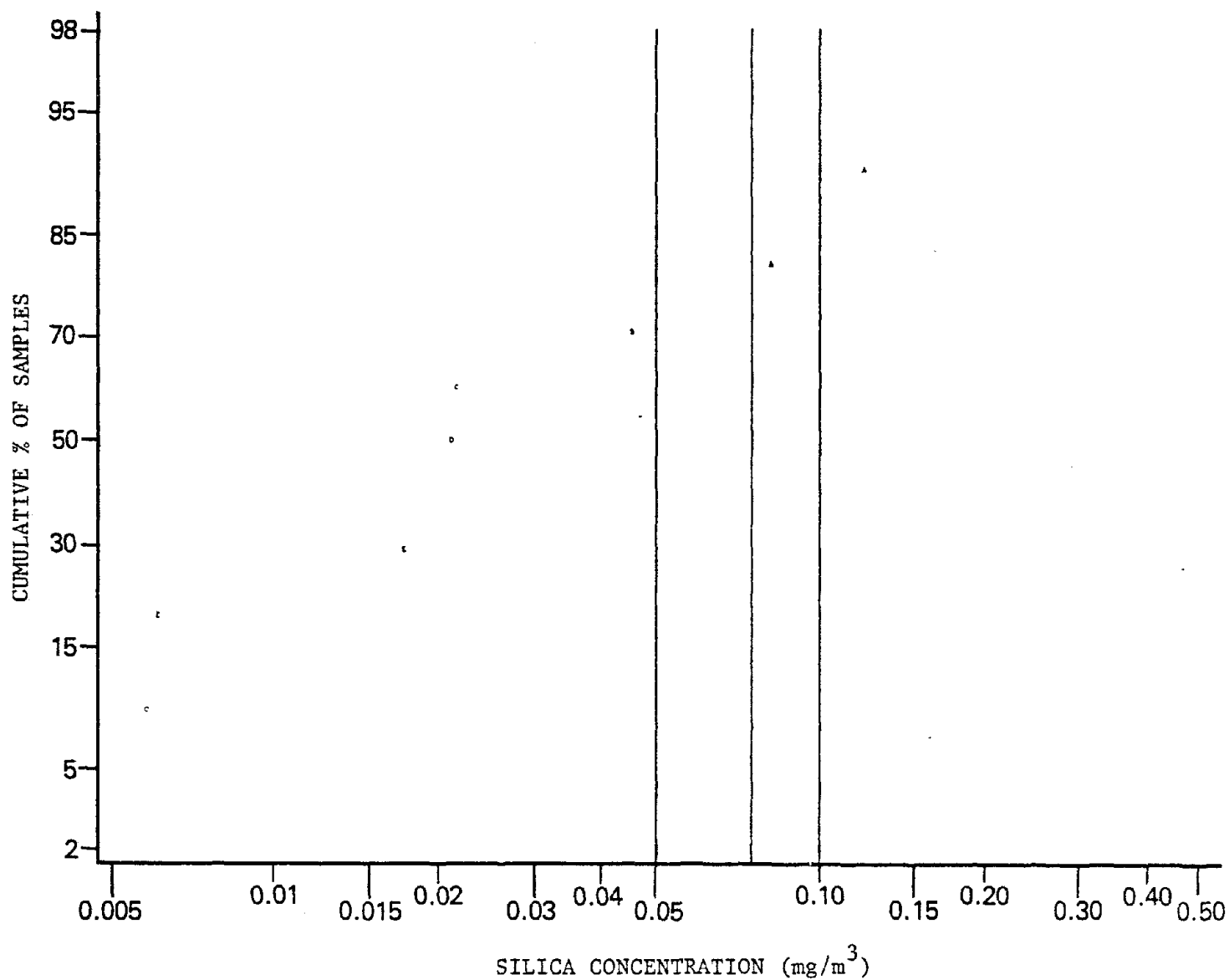
No. of samples: 38
No. of mine ID's represented: 14
No. of active sites in 1980: 49
Percent of samples less than 0.05 mg/m³: 76
Percent of samples less than 0.075 mg/m³: 87
Percent of samples less than 0.1 mg/m³: 87

Figure A-36. Respirable quartz concentrations found in underground drilling operations in the lead and zinc industry group.



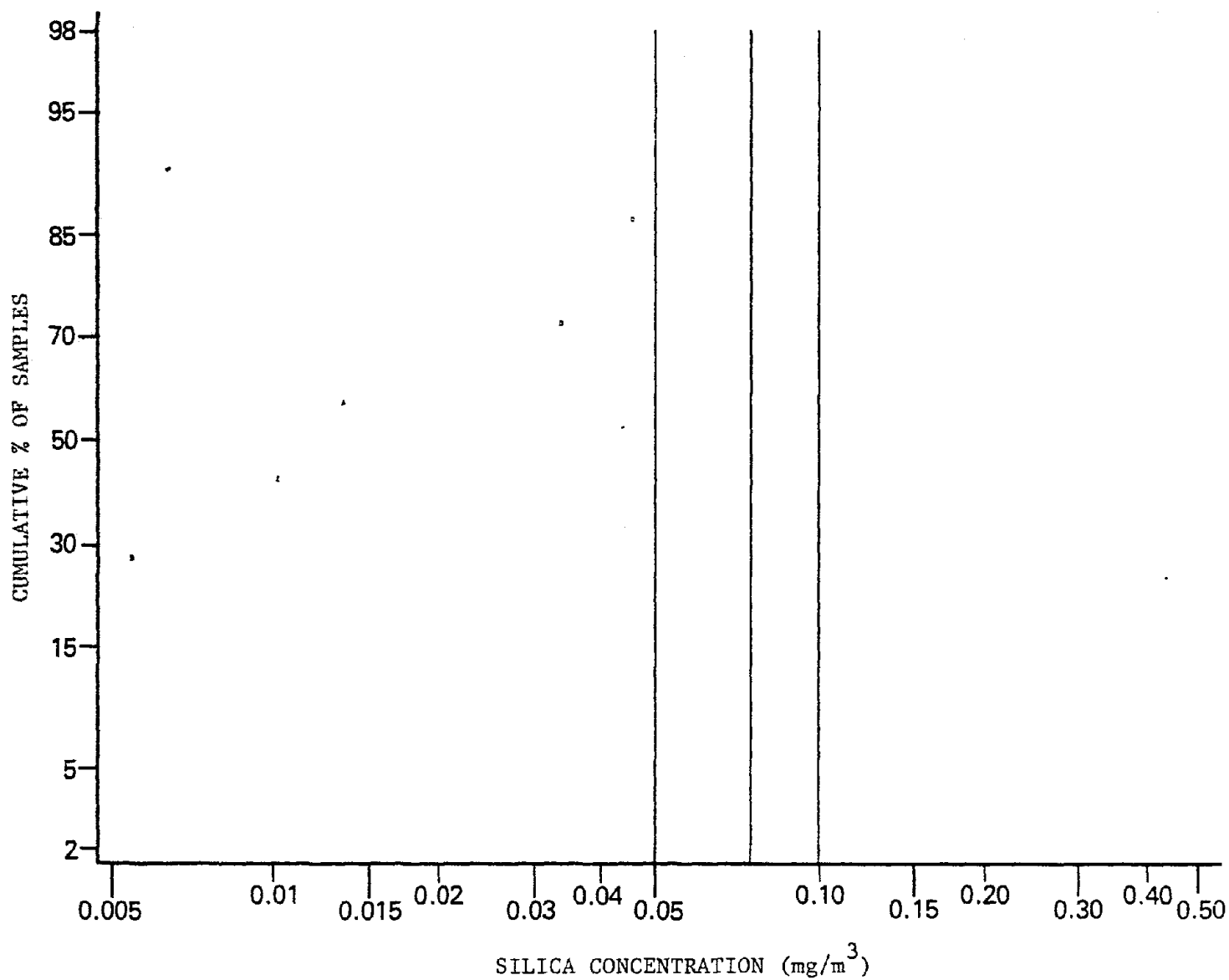
No. of samples: 16
 No. of mine ID's represented: 4
 No. of active sites in 1980: 49
 Percent of samples less than 0.05 mg/m³: 69
 Percent of samples less than 0.075 mg/m³: 81
 Percent of samples less than 0.1 mg/m³: 88

Figure A-37. Respirable quartz concentrations found in underground haulageway maintenance operations in the lead and zinc industry group.



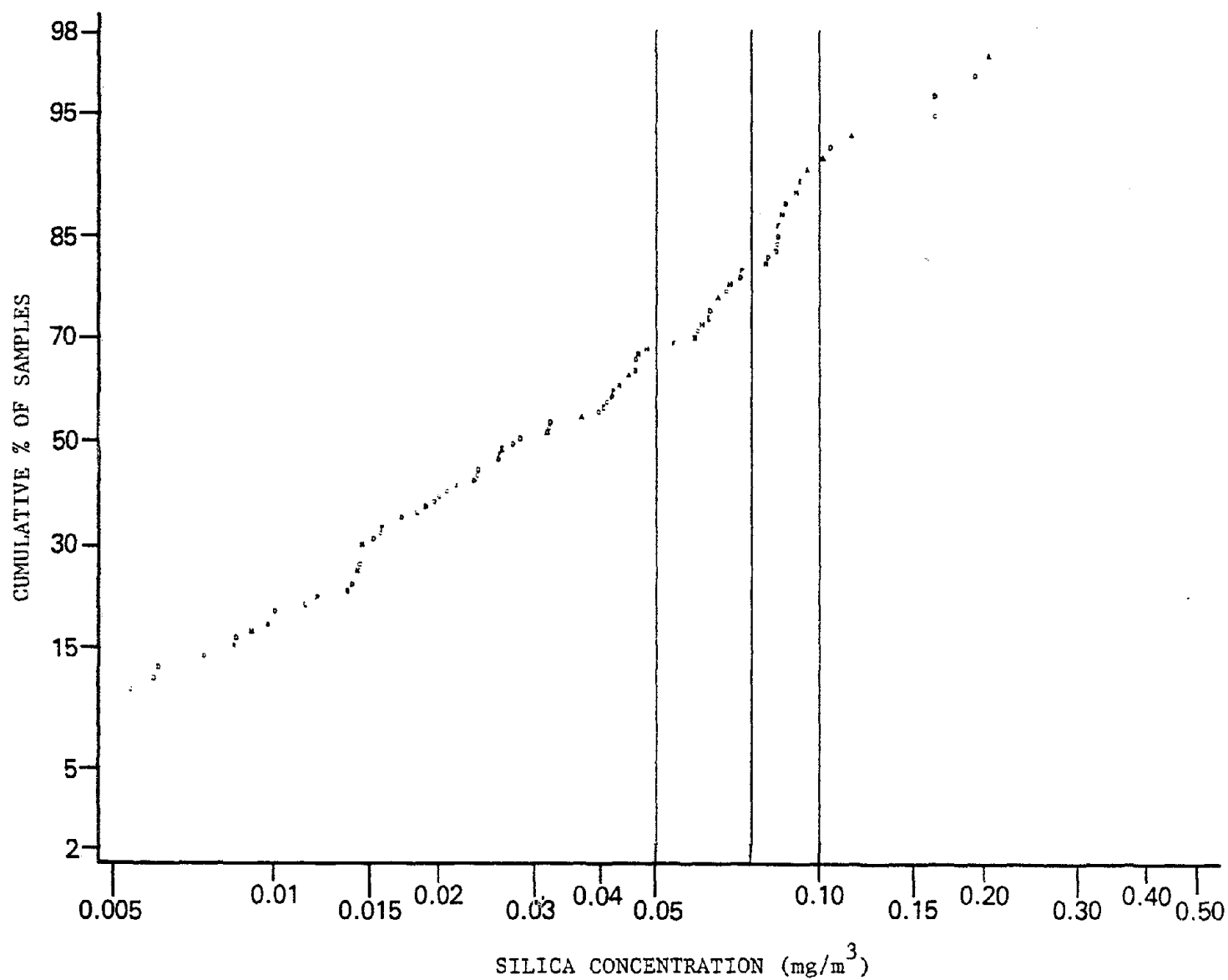
No. of samples: 10
 No. of mine ID's represented: 5
 No. of active sites in 1980: 49
 Percent of samples less than 0.05 mg/m³: 70
 Percent of samples less than 0.075 mg/m³: 70
 Percent of samples less than 0.1 mg/m³: 80

Figure A-38. Respirable quartz concentrations found in underground production operations in the lead and zinc industry group.



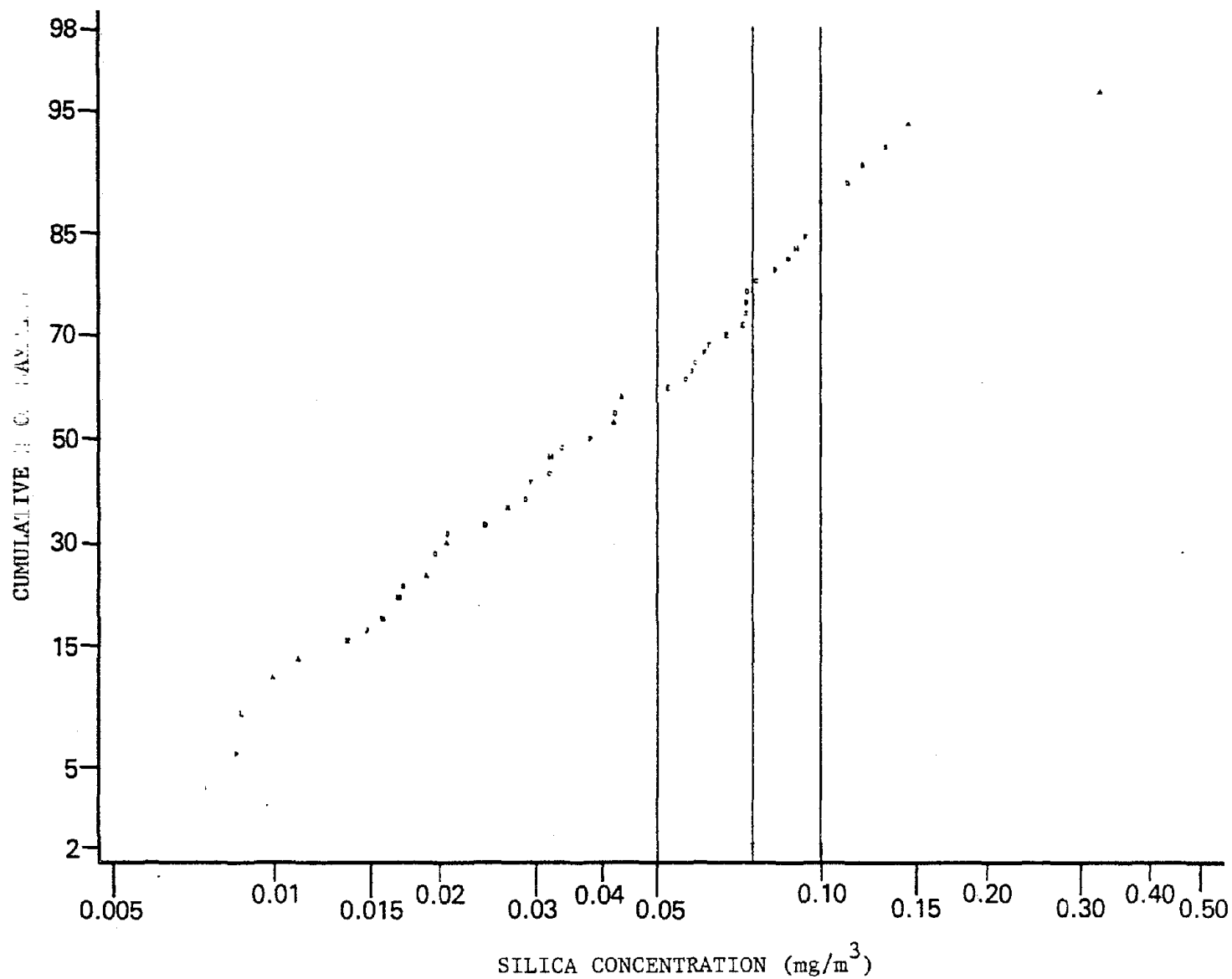
No. of samples: 7
 No. of mine ID's represented: 6
 No. of active sites in 1980: 5
 Percent of samples less than 0.05 mg/m³: 86
 Percent of samples less than 0.075 mg/m³: 86
 Percent of samples less than 0.1 mg/m³: 100

Figure A-39. Respirable quartz concentrations found in surface mobile transport operations in the lead and zinc industry group.



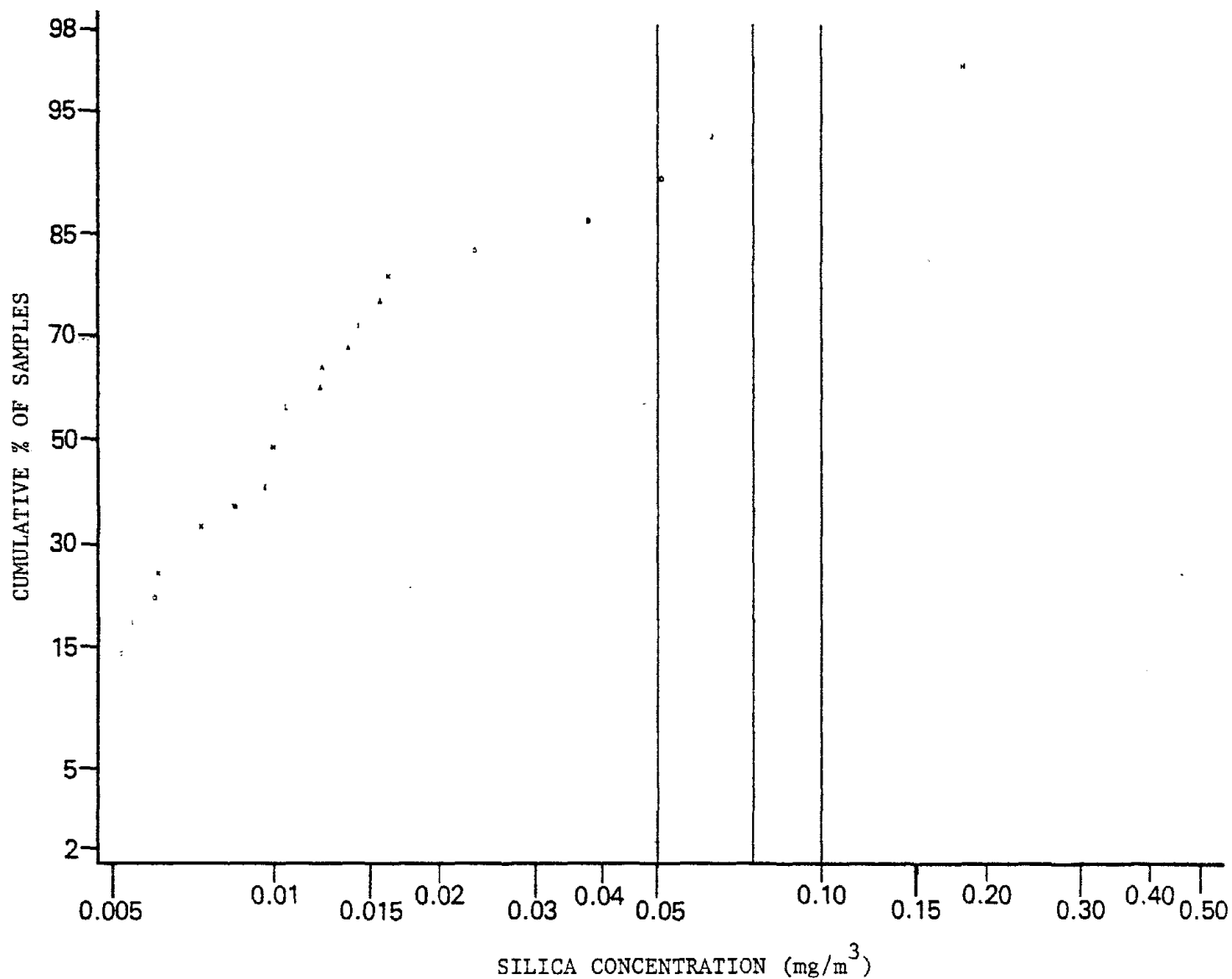
No. of samples: 101
 No. of mine ID's represented: 19
 No. of active sites in 1980: 49
 Percent of samples less than 0.05 mg/m³: 67
 Percent of samples less than 0.075 mg/m³: 79
 Percent of samples less than 0.1 mg/m³: 90

Figure A-40. Respirable quartz concentrations found in underground mobile transport operations in the lead and zinc industry group.



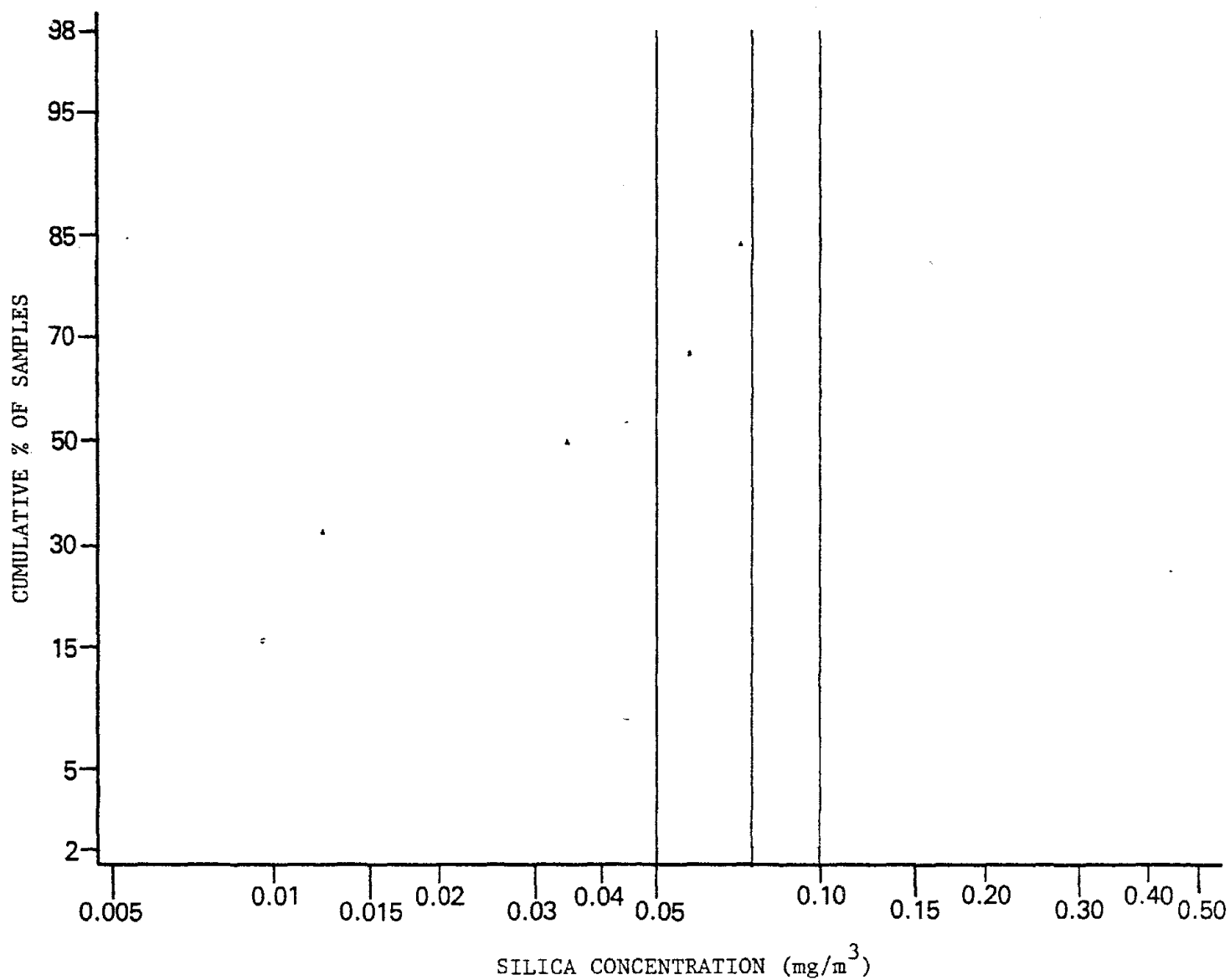
No. of samples: 62
 No. of mine ID's represented: 22
 No. of active sites in 1980: 70
 Percent of samples less than 0.05 mg/m³: 58
 Percent of samples less than 0.075 mg/m³: 76
 Percent of samples less than 0.1 mg/m³: 87

Figure A-41. Respirable quartz concentrations found in crushing, grinding, and sizing operations (surface and underground) in the lead and zinc industry group.



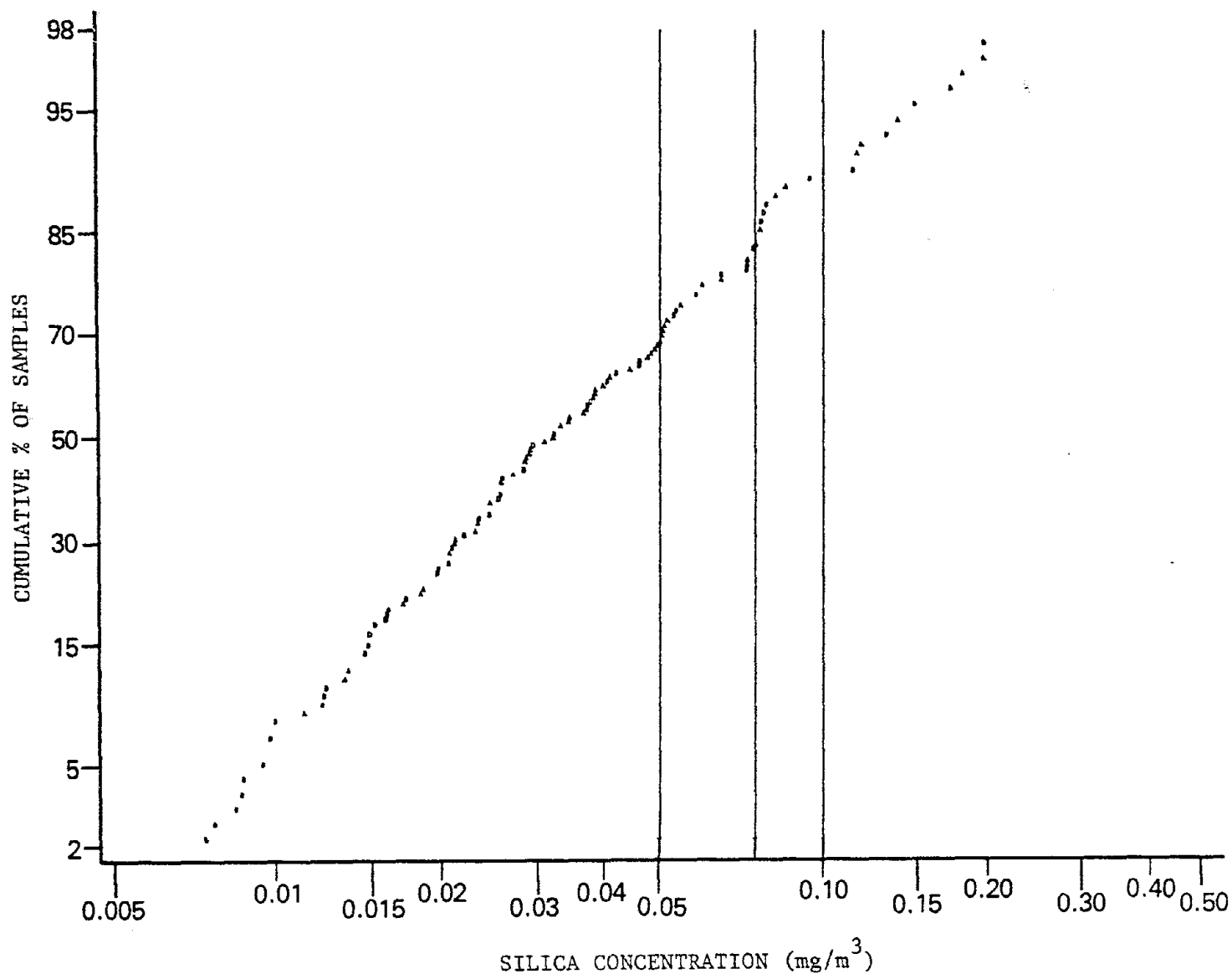
No. of samples: 27
 No. of mine ID's represented: 16
 No. of active sites in 1980: 70
 Percent of samples less than 0.05 mg/m³: 85
 Percent of samples less than 0.075 mg/m³: 93
 Percent of samples less than 0.1 mg/m³: 93

Figure A-42. Respirable quartz concentrations found in
 concentrating and finishing operations
 (surface and underground) in the lead
 and zinc industry group.



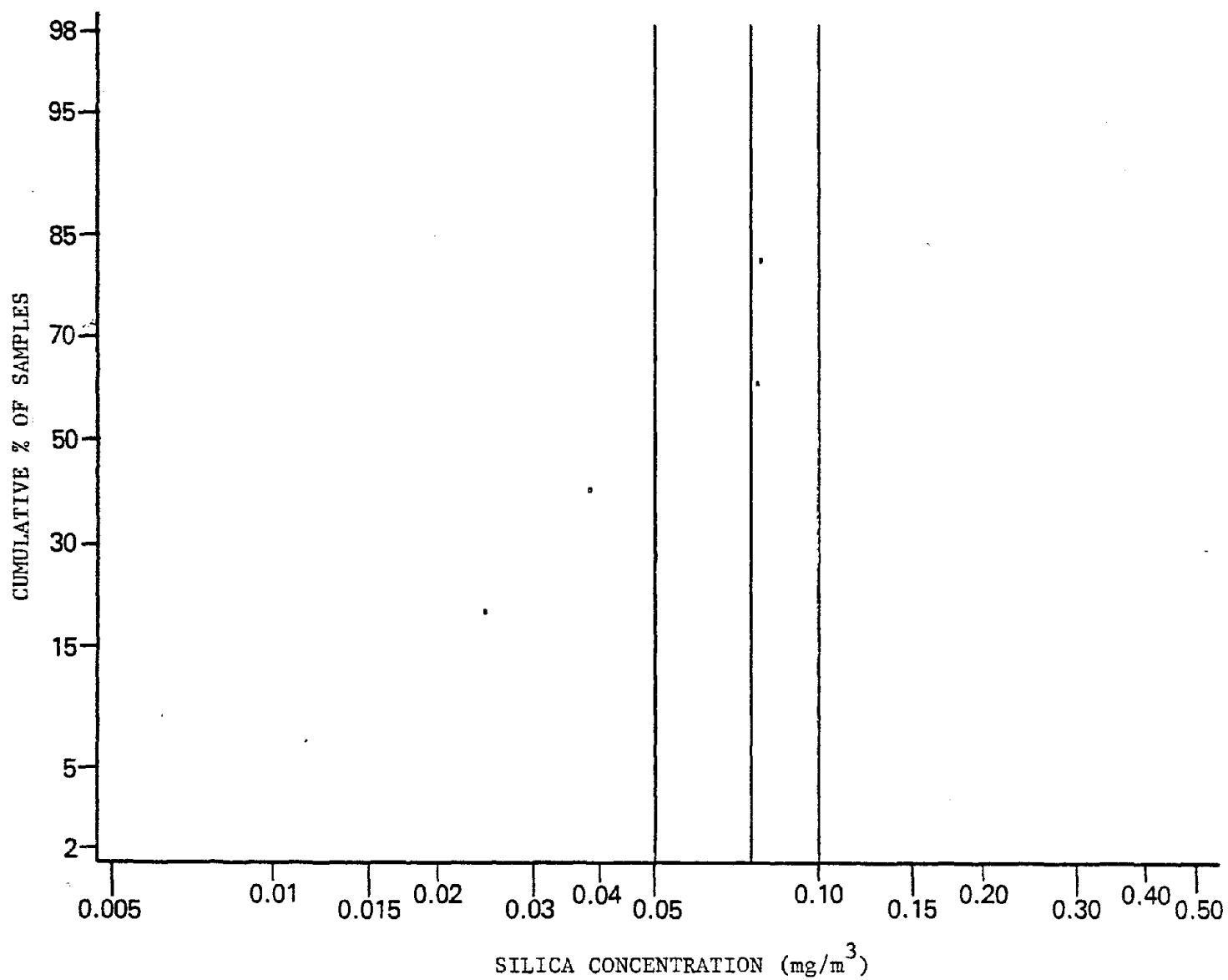
No. of samples: 6
No. of mine ID's represented: 3
No. of active sites in 1980: 13
Percent of samples less than 0.05 mg/m³: 50
Percent of samples less than 0.075 mg/m³: 83
Percent of samples less than 0.1 mg/m³: 100

Figure A-43. Respirable quartz concentrations found in nonspecific surface operations in the molybdenum industry group.



No. of samples: 132
 No. of mine ID's represented: 5
 No. of active sites in 1980: 8
 Percent of samples less than 0.05 mg/m³: 68
 Percent of samples less than 0.075 mg/m³: 83
 Percent of samples less than 0.1 mg/m³: 89

Figure A-44. Respirable quartz concentrations found in nonspecific underground operations in the molybdenum industry group.



No. of samples: 5
No. of mine ID's represented: 2
No. of active sites in 1980: 13
Percent of samples less than 0.05 mg/m³: 40
Percent of samples less than 0.075 mg/m³: 40
Percent of samples less than 0.1 mg/m³: 100

Figure A-45. Respirable quartz concentrations found in blasting operations (surface and underground) in the molybdenum industry group.

Respirable quartz sample data (mg/m ³ silica)	Establishment (mine ID)

0.0037	0164
0.0062	2256
0.0184	0164
0.0380	2256

No. of samples: 4

No. of mine ID's represented: 2

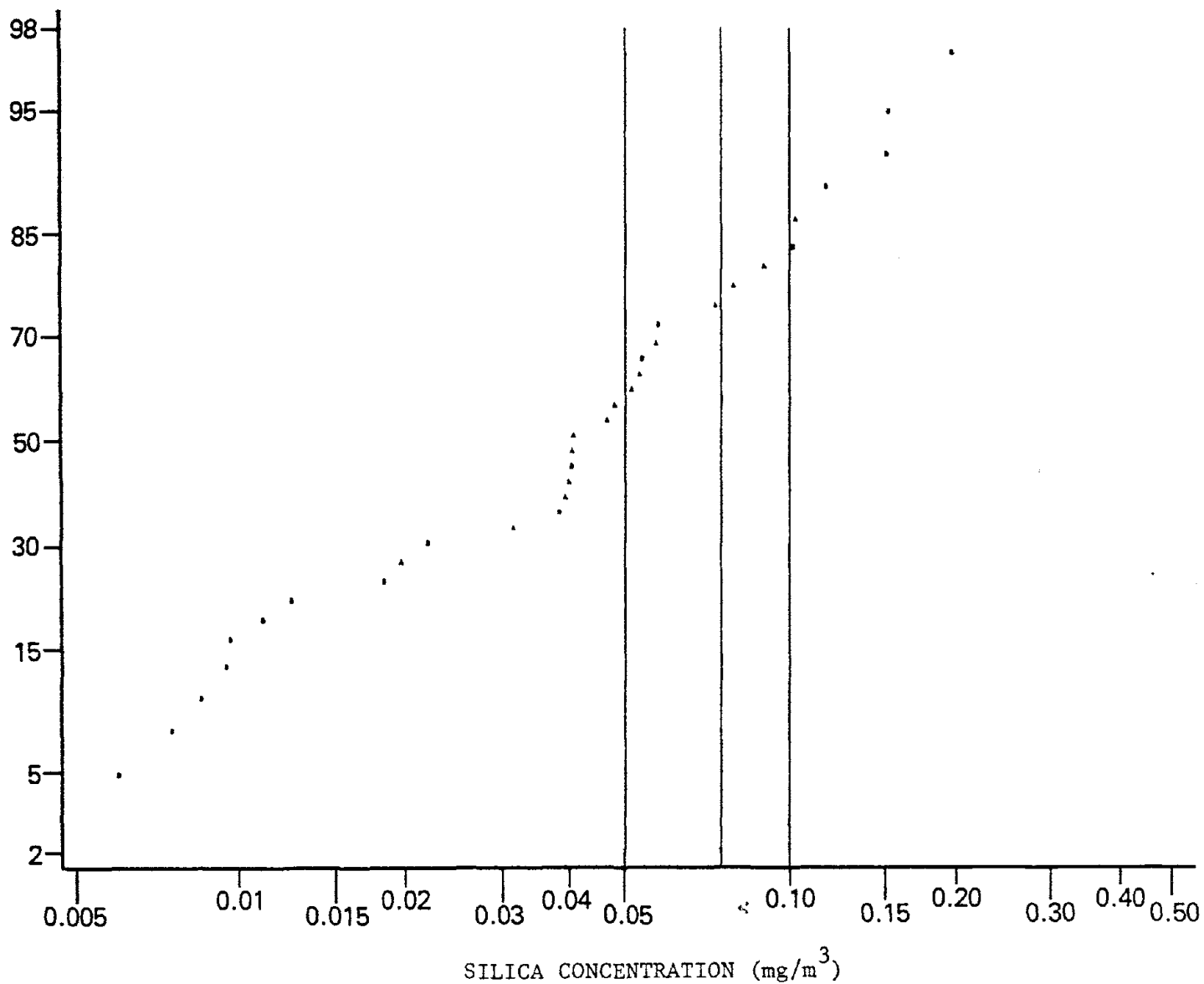
No. of active sites in 1980: 3

Percent of samples less than 0.05 mg/m³: 100

Percent of samples less than 0.075 mg/m³: 100

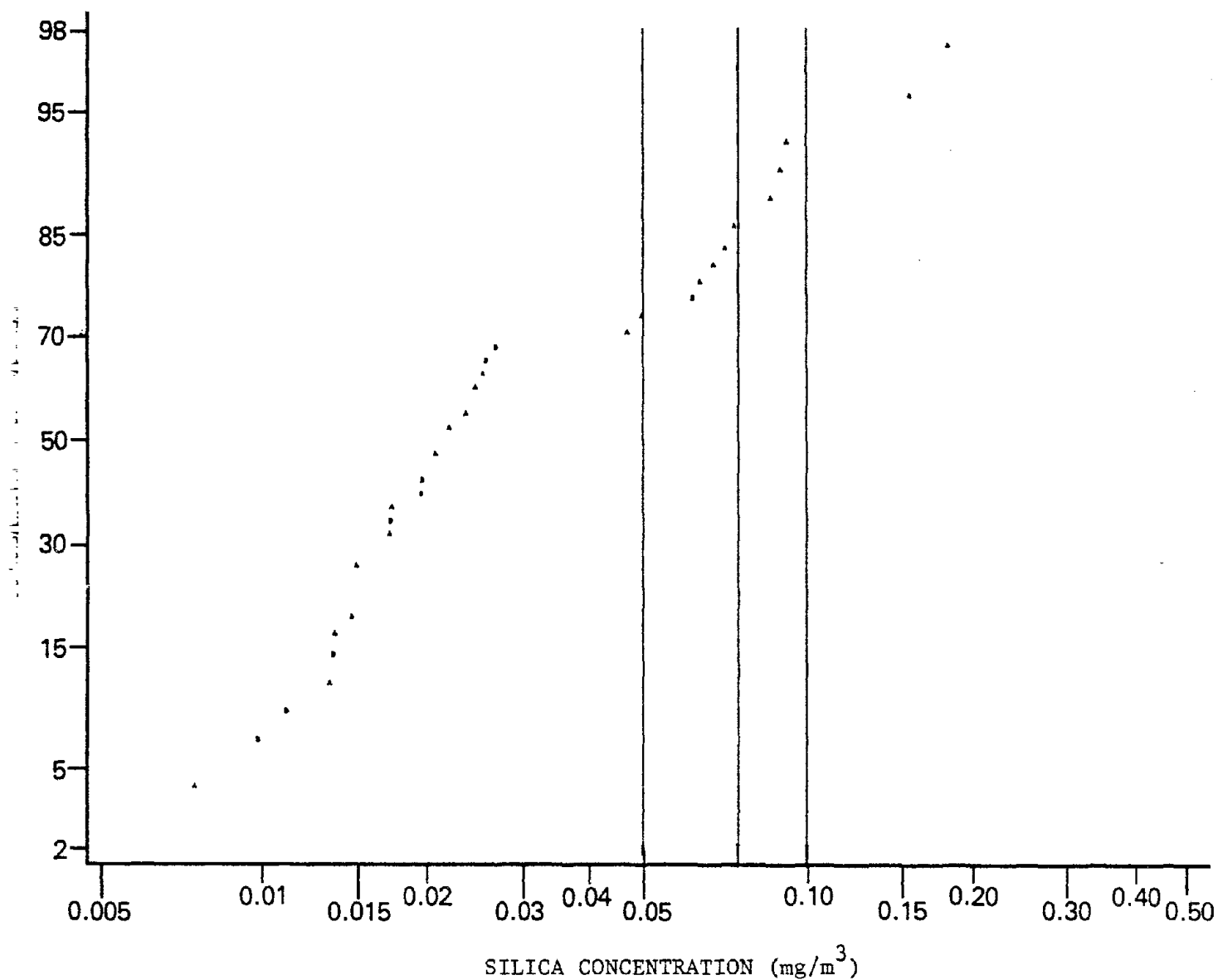
Percent of samples less than 0.1 mg/m³: 100

Figure A-46. Respirable quartz concentrations found in surface drilling operations in the molybdenum industry group.



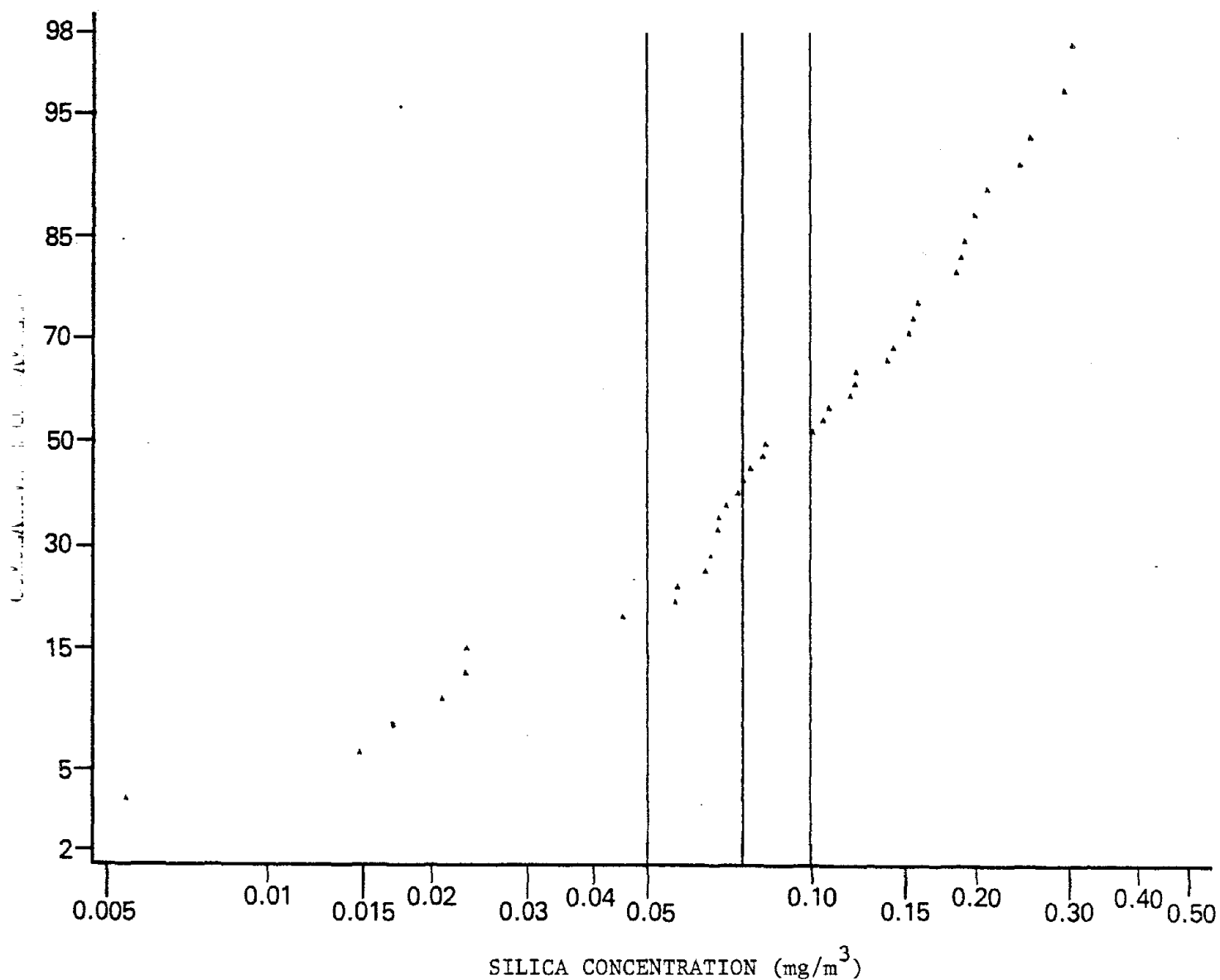
No. of samples: 35
 No. of mine ID's represented: 2
 No. of active sites in 1980: 8
 Percent of samples less than 0.05 mg/m³: 57
 Percent of samples less than 0.075 mg/m³: 74
 Percent of samples less than 0.1 mg/m³: 80

Figure A-47. Respirable quartz concentrations found in underground drilling operations in the molybdenum industry group.



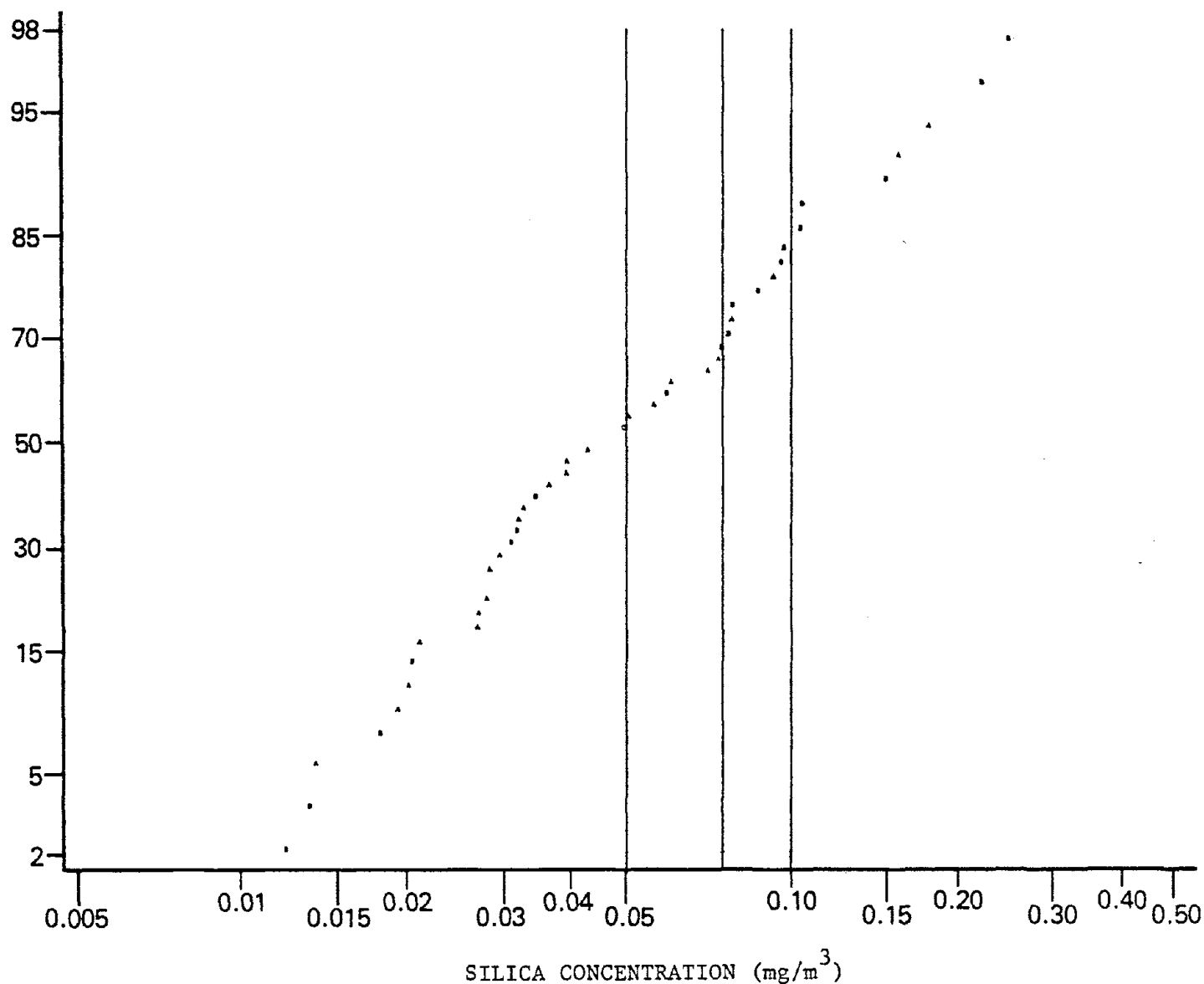
No. of samples: 40
 No. of mine ID's represented: 3
 No. of active sites in 1980: 8
 Percent of samples less than 0.05 mg/m³: 72
 Percent of samples less than 0.075 mg/m³: 85
 Percent of samples less than 0.1 mg/m³: 92

Figure A-48. Respirable quartz concentrations found in underground haulage maintenance operations in the molybdenum industry group.



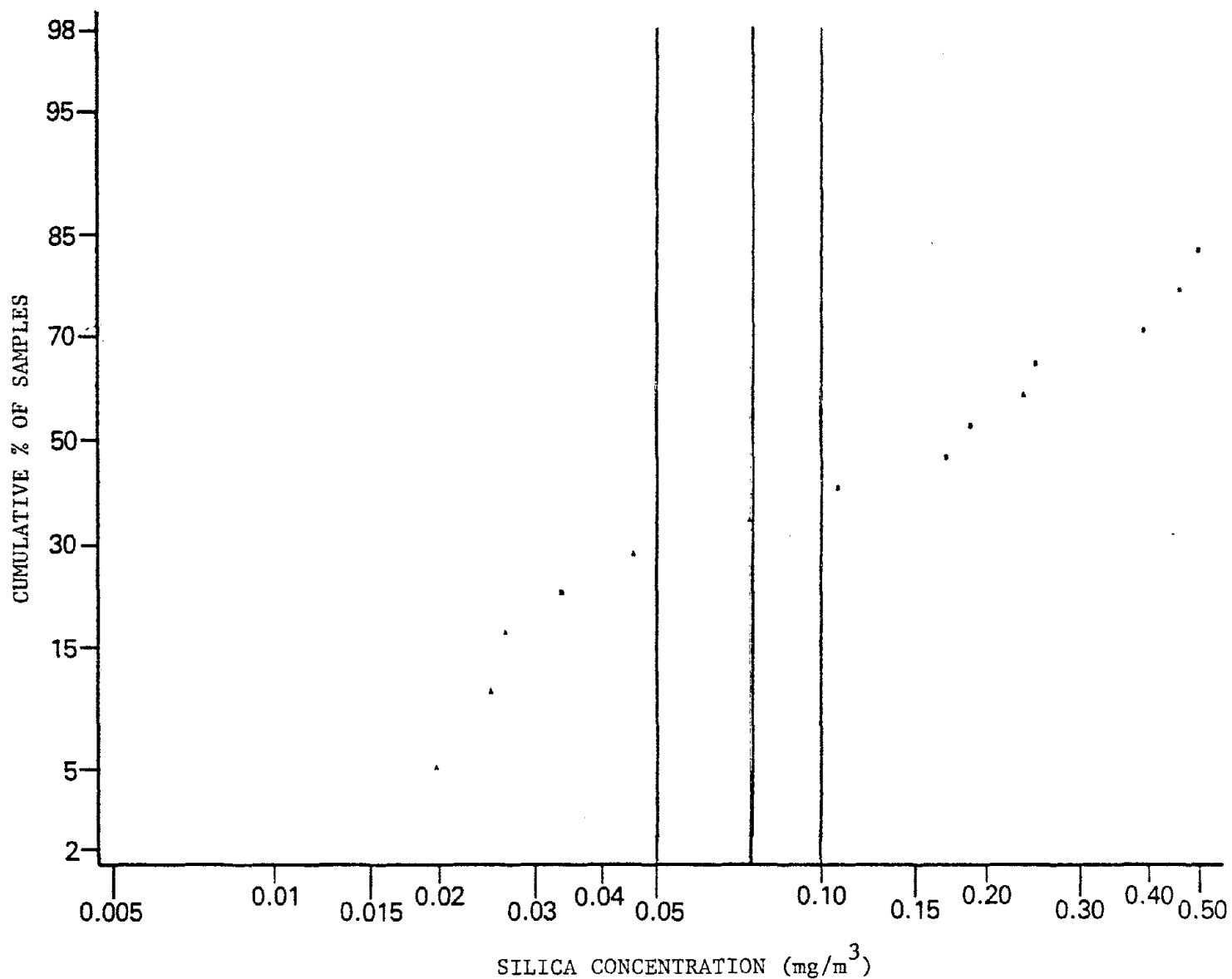
No. of samples: 44
 No. of mine ID's represented: 2
 No. of active sites in 1980: 8
 Percent of samples less than 0.05 mg/m³: 20
 Percent of samples less than 0.075 mg/m³: 41
 Percent of samples less than 0.1 mg/m³: 50

Figure A-49. Respirable quartz concentrations found in underground production operations in the molybdenum industry group.



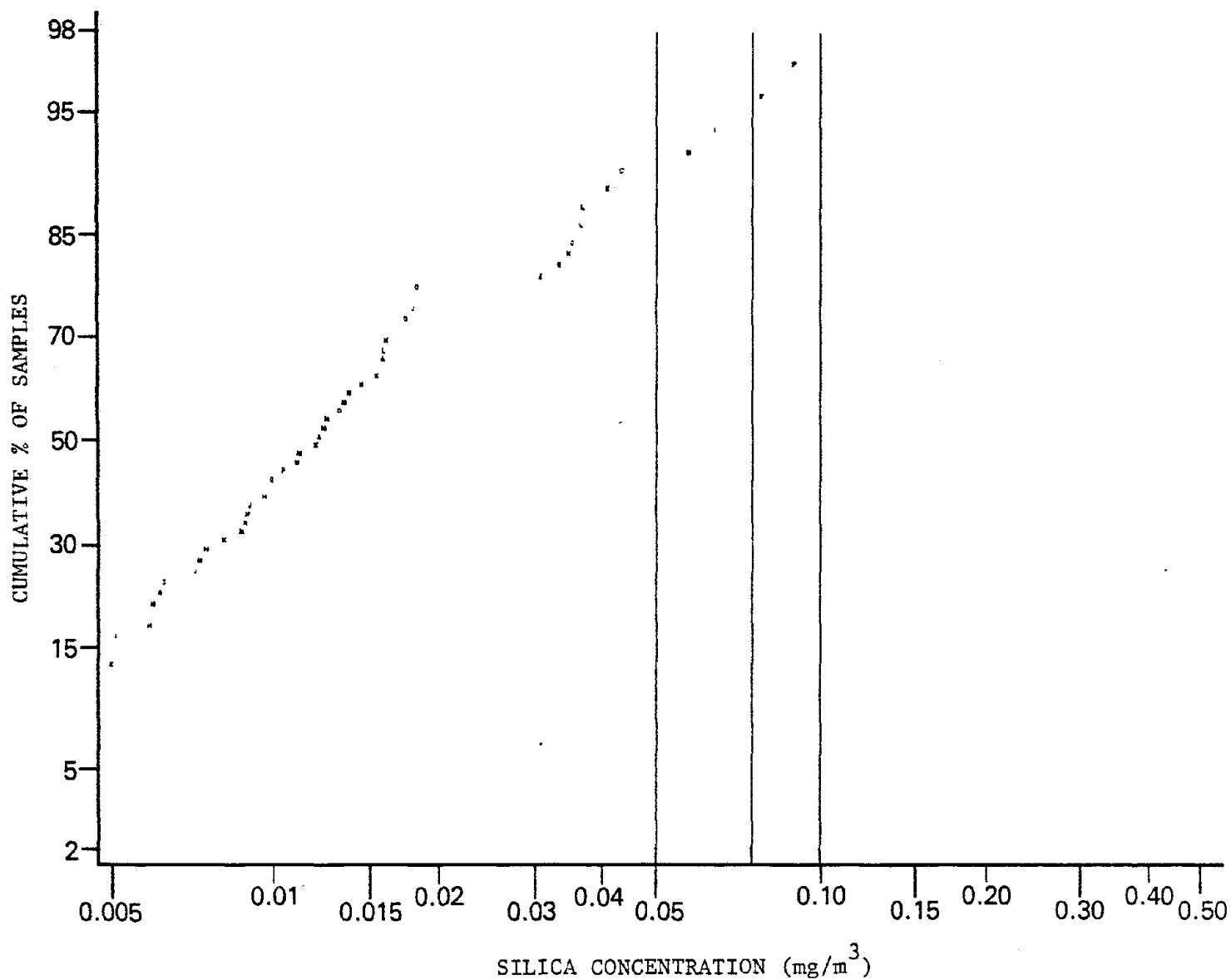
No. of samples: 47
 No. of mine ID's represented: 3
 No. of active sites in 1980: 8
 Percent of samples less than 0.05 mg/m³: 53
 Percent of samples less than 0.075 mg/m³: 68
 Percent of samples less than 0.1 mg/m³: 83

Figure A-50. Respirable quartz concentrations found in underground mobile transport operations in the molybdenum industry group.



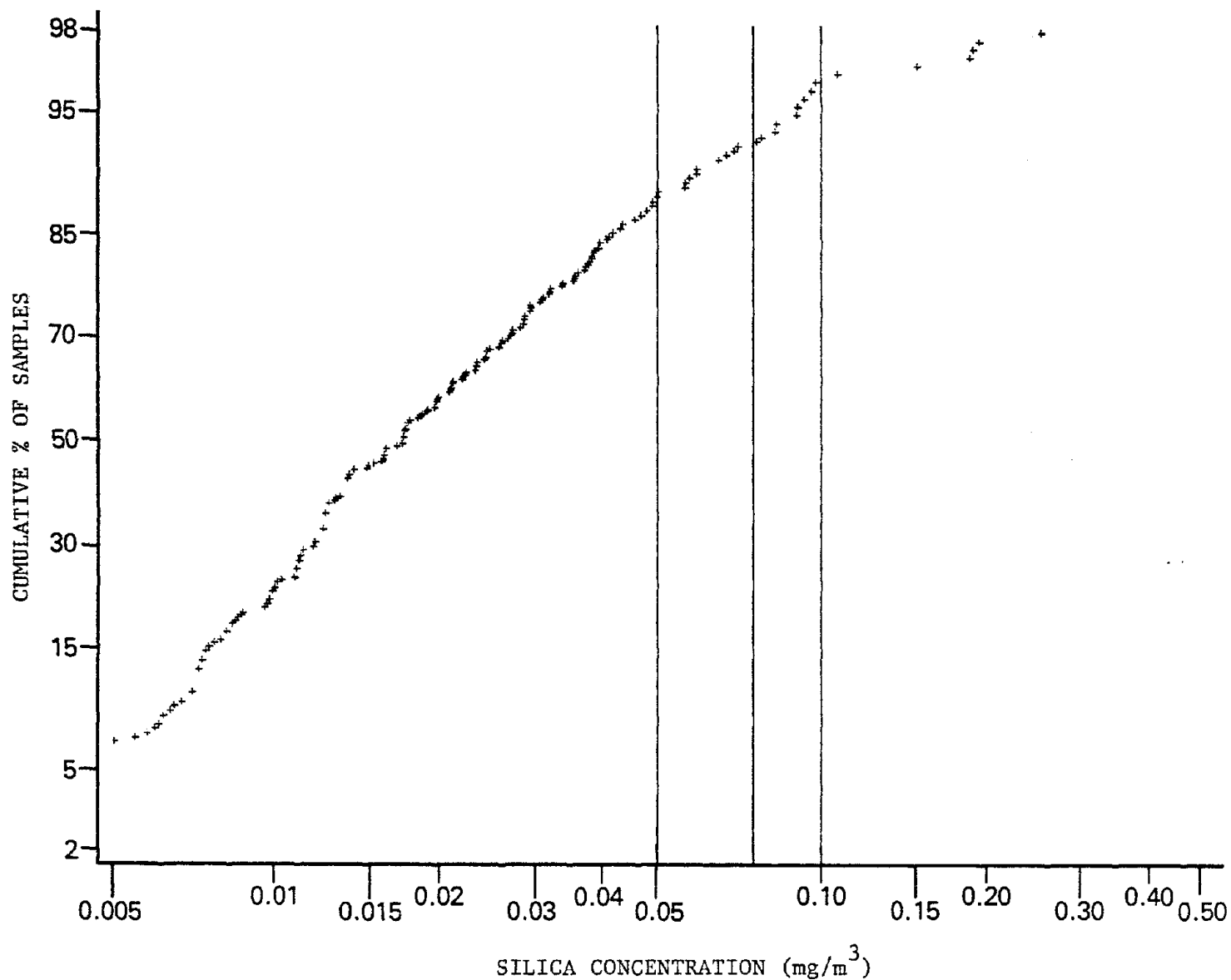
No. of samples: 17
 No. of mine ID's represented: 2
 No. of active sites in 1980: 13
 Percent of samples less than 0.05 mg/m³: 29
 Percent of samples less than 0.075 mg/m³: 35
 Percent of samples less than 0.1 mg/m³: 35

Figure A-51. Respirable quartz concentrations found in crushing, grinding, and sizing operations (surface and underground) in the molybdenum industry group.



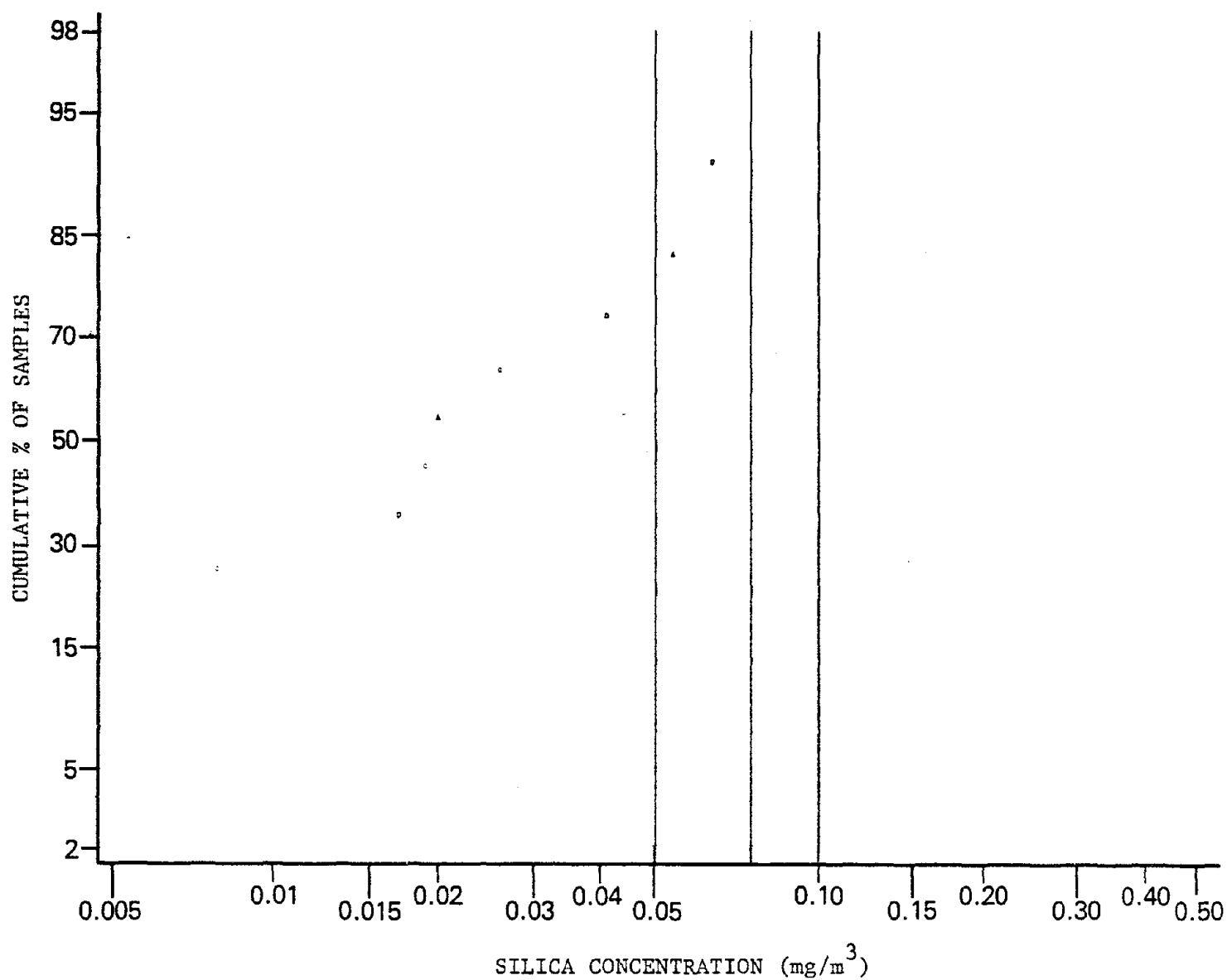
No. of samples: 62
 No. of mine ID's represented: 19
 No. of active sites in 1980: 233
 Percent of samples less than 0.05 mg/m³: 90
 Percent of samples less than 0.075 mg/m³: 94
 Percent of samples less than 0.1 mg/m³: 98

Figure A-52. Respirable quartz concentrations found in nonspecific surface operations in the uranium industry group.



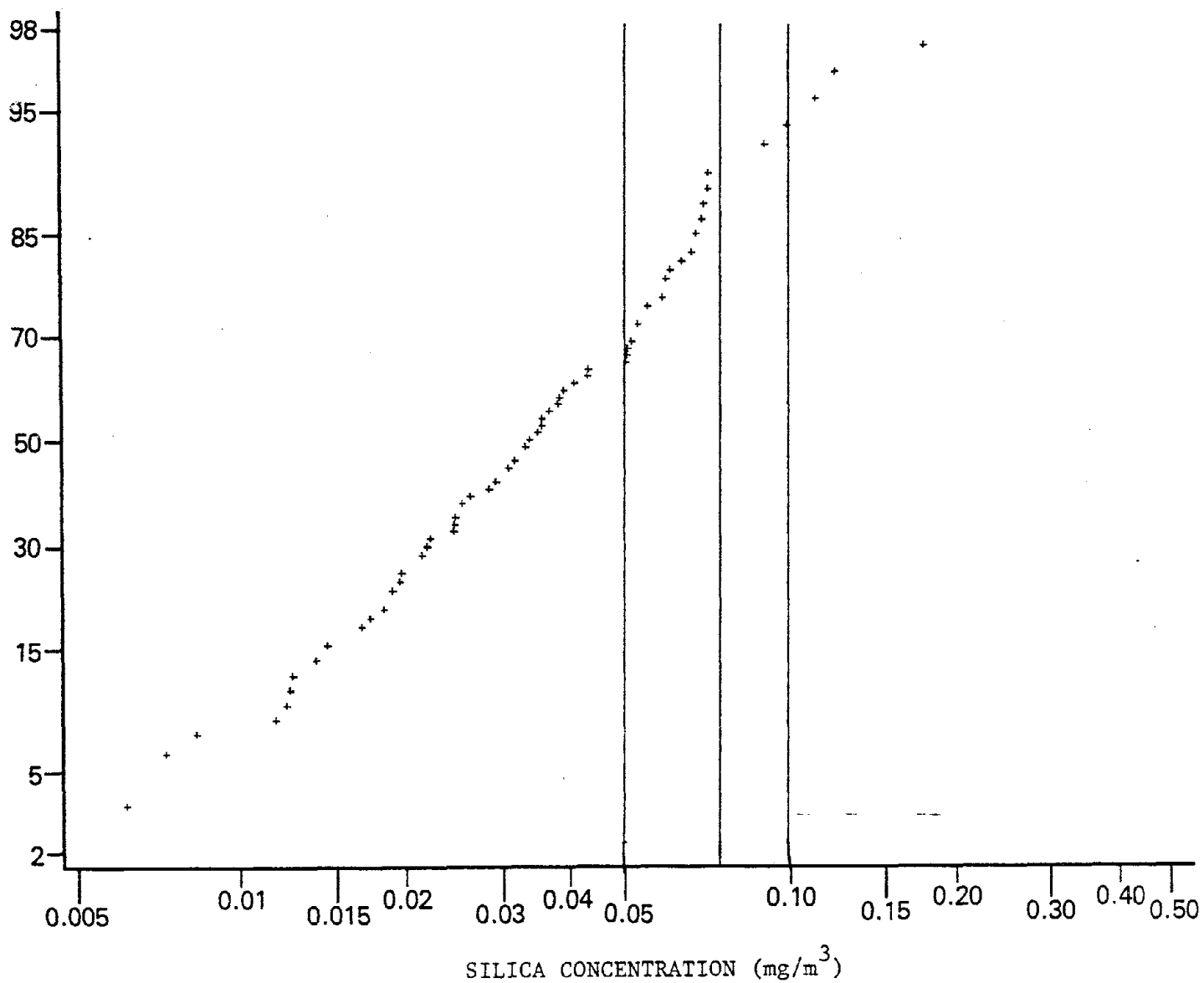
No. of samples: 248
 No. of mine ID's represented: 50
 No. of active sites in 1980: 155
 Percent of samples less than 0.05 mg/m³: 88
 Percent of samples less than 0.075 mg/m³: 92
 Percent of samples less than 0.1 mg/m³: 96

Figure A-53. Respirable quartz concentrations found in nonspecific underground operations in the uranium industry group.



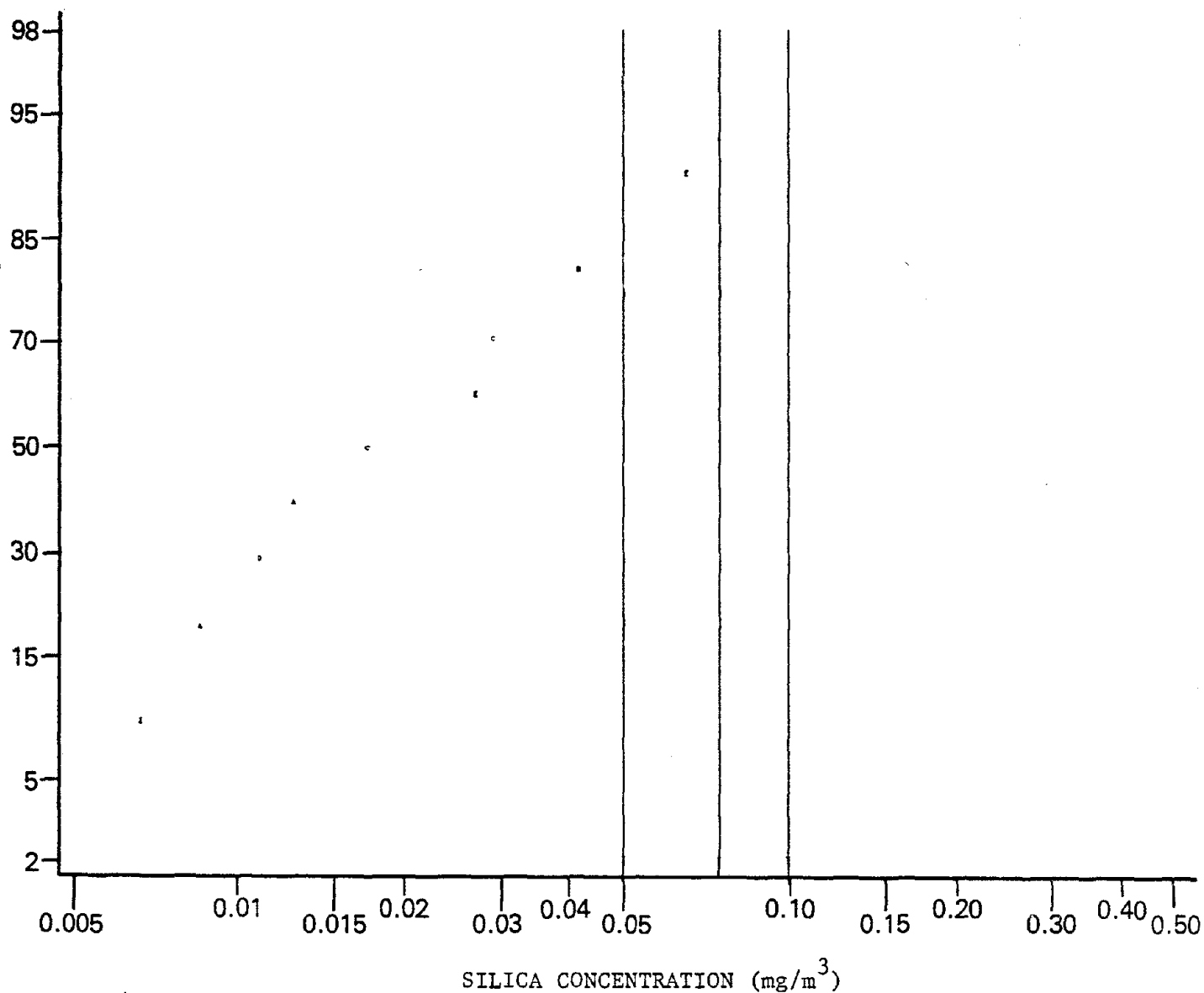
No. of samples: 11
 No. of mine ID's represented: 4
 No. of active sites in 1980: 34
 Percent of samples less than 0.05 mg/m³: 73
 Percent of samples less than 0.075 mg/m³: 91
 Percent of samples less than 0.1 mg/m³: 91

Figure A-54. Respirable quartz concentrations found in surface drilling operations in the uranium industry group.



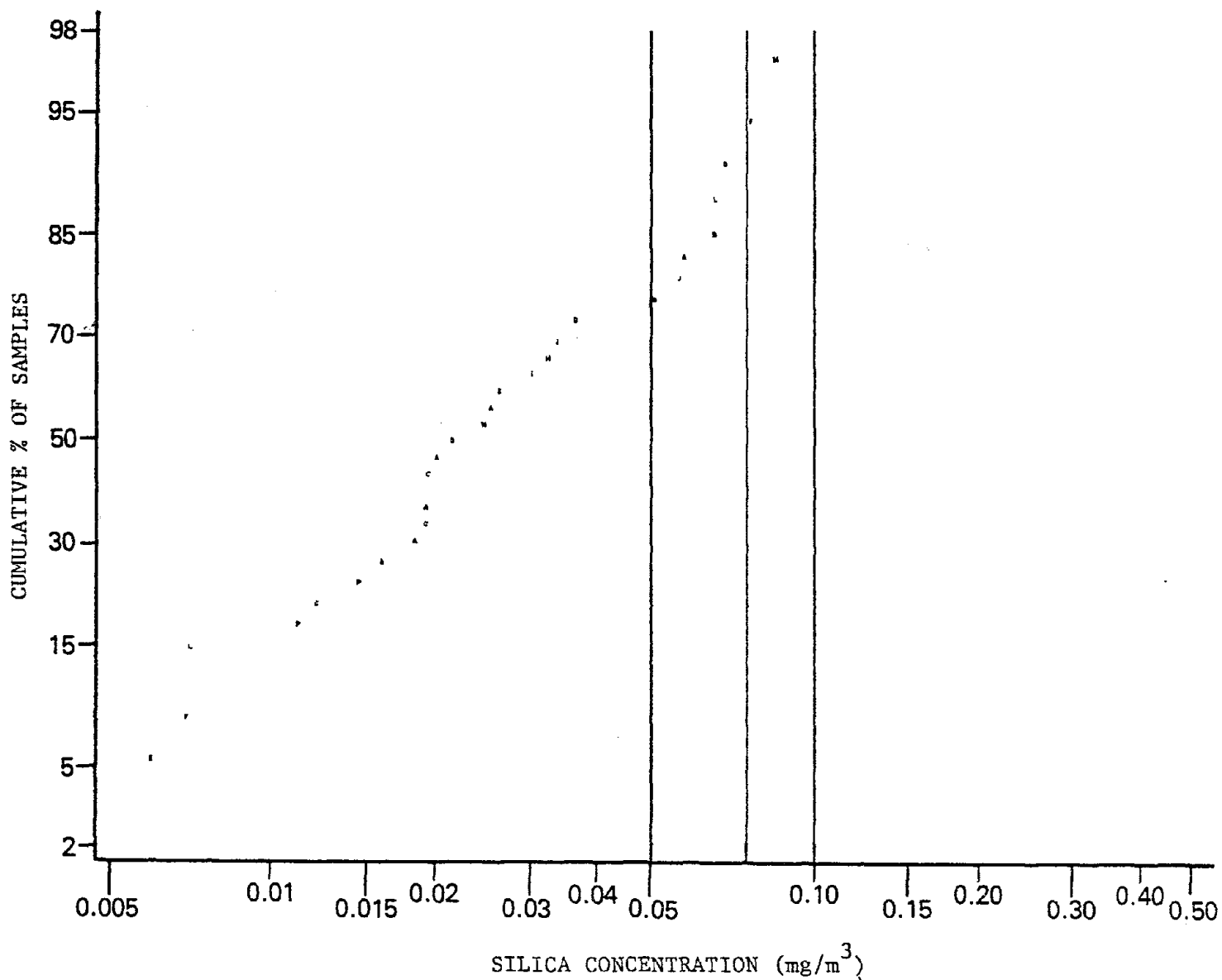
No. of samples: 76
 No. of mine ID's represented: 26
 No. of active sites in 1980: 155
 Percent of samples less than 0.05 mg/m³: 63
 Percent of samples less than 0.075 mg/m³: 89
 Percent of samples less than 0.1 mg/m³: 93

Figure A-55. Respirable quartz concentrations found in underground drilling operations in the uranium industry group.



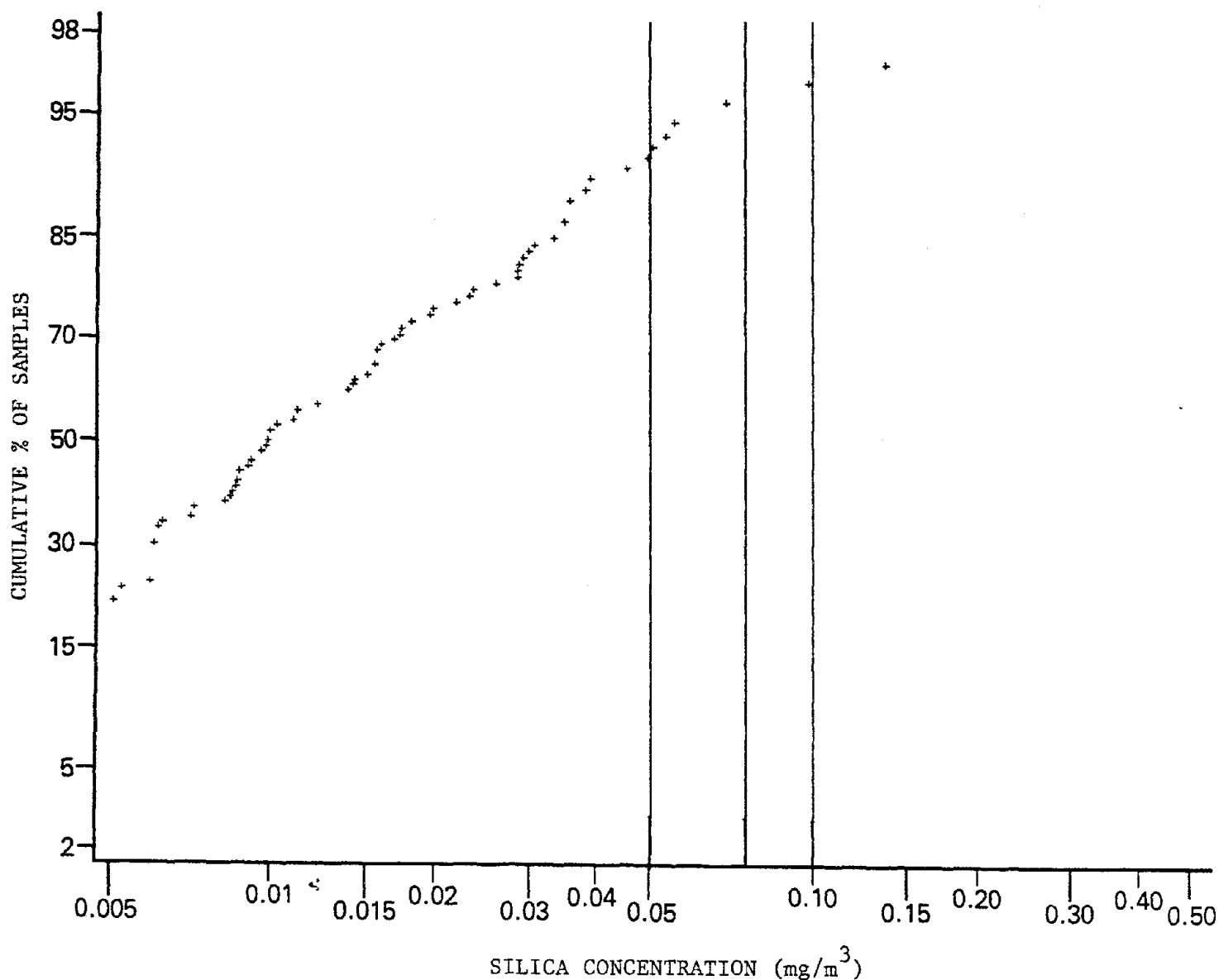
No. of samples: 10
 No. of mine ID's represented: 5
 No. of active sites in 1980: 155
 Percent of samples less than 0.05 mg/m³: 80
 Percent of samples less than 0.075 mg/m³: 100
 Percent of samples less than 0.1 mg/m³: 100

Figure A-56. Respirable quartz concentrations found in underground haulageway maintenance operations in the uranium industry group.



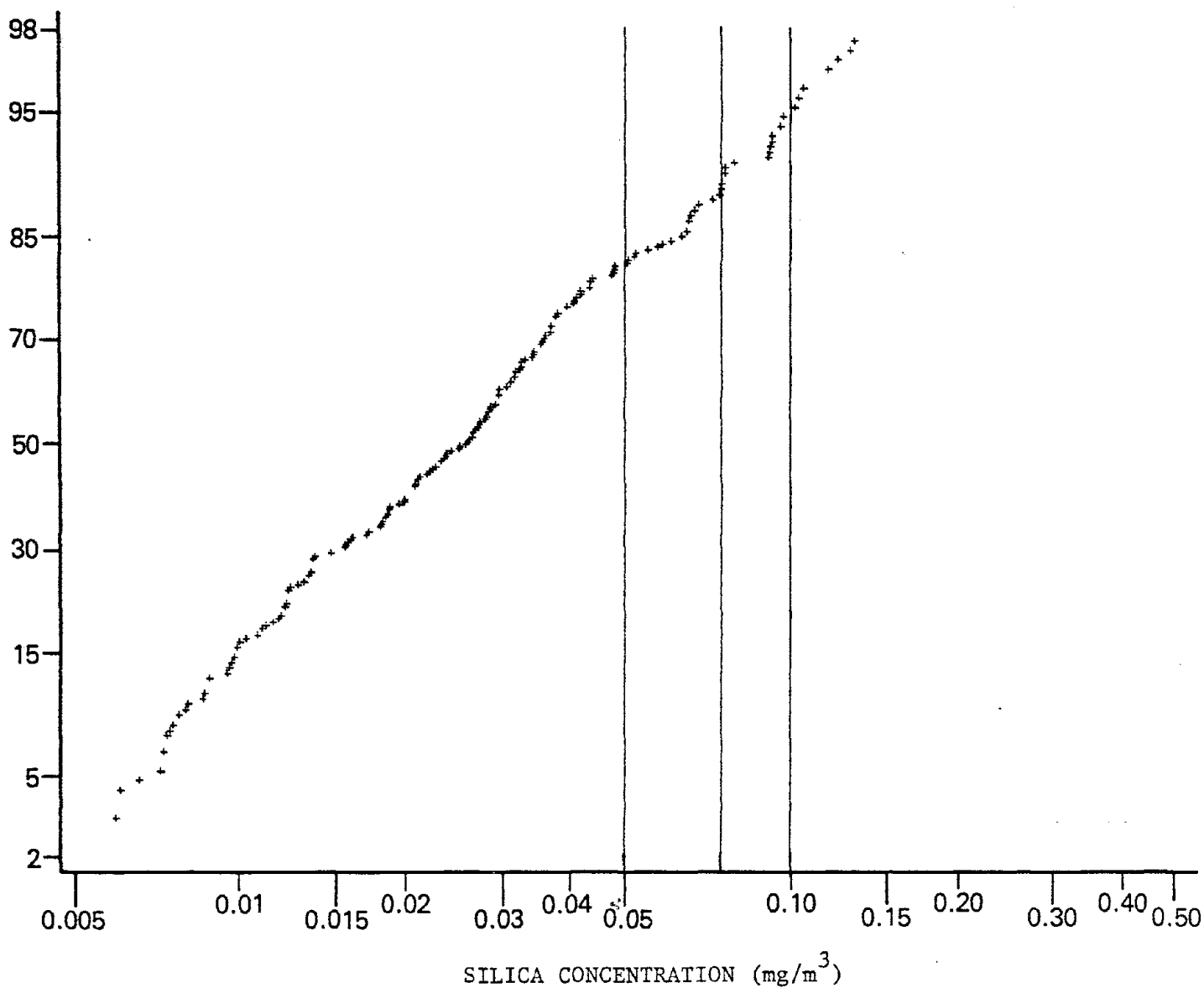
No. of samples: 32
 No. of mine ID's represented: 17
 No. of active sites in 1980: 155
 Percent of samples less than 0.05 mg/m³: 72
 Percent of samples less than 0.075 mg/m³: 91
 Percent of samples less than 0.1 mg/m³: 97

Figure A-57. Respirable quartz concentrations found in underground production operations in the uranium industry group.



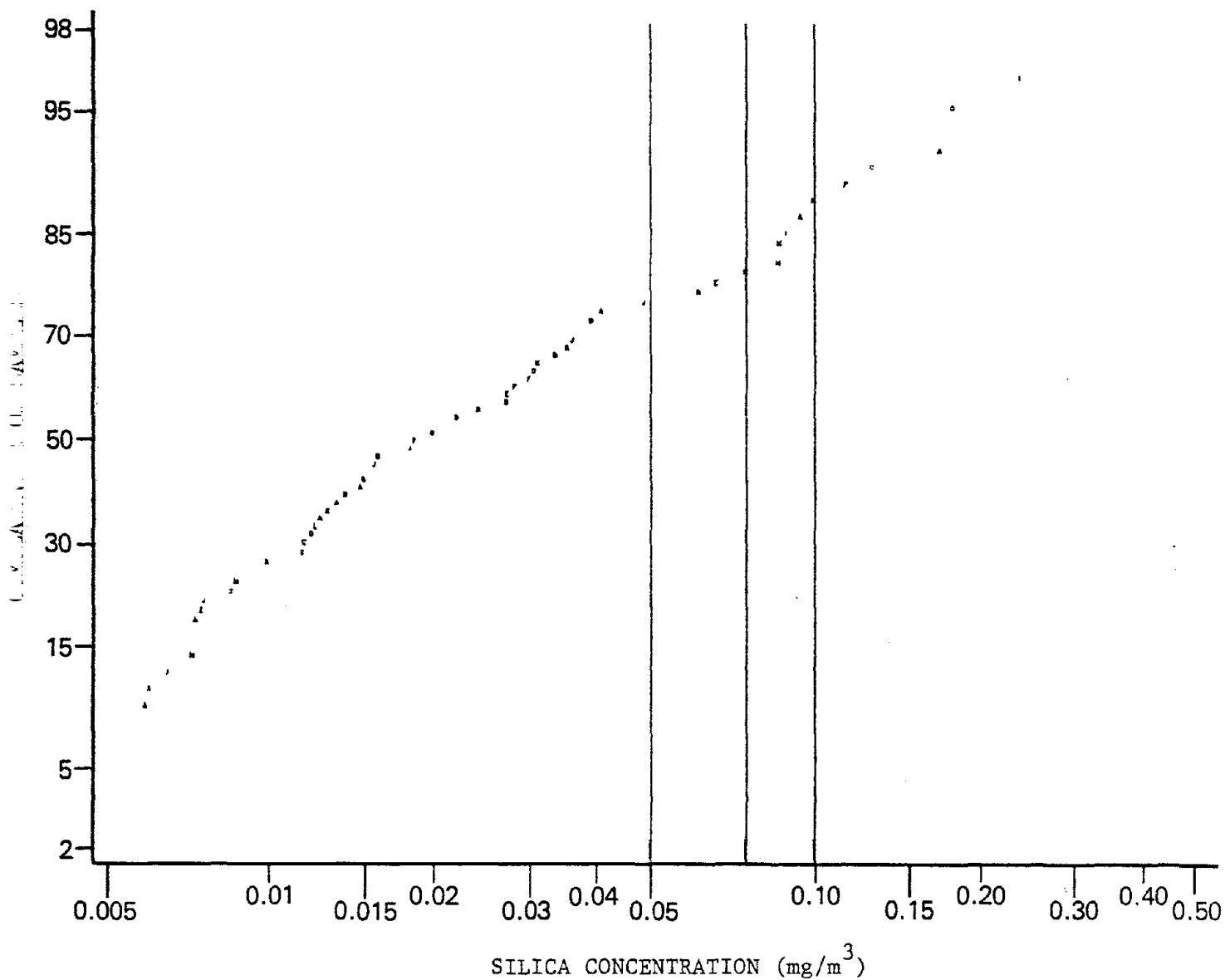
No. of samples: 106
 No. of mine ID's represented: 26
 No. of active sites in 1980: 34
 Percent of samples less than 0.05 mg/m³: 91
 Percent of samples less than 0.075 mg/m³: 94
 Percent of samples less than 0.1 mg/m³: 95

Figure A-58. Respirable quartz concentrations found in surface mobile transport operations in the uranium industry group.



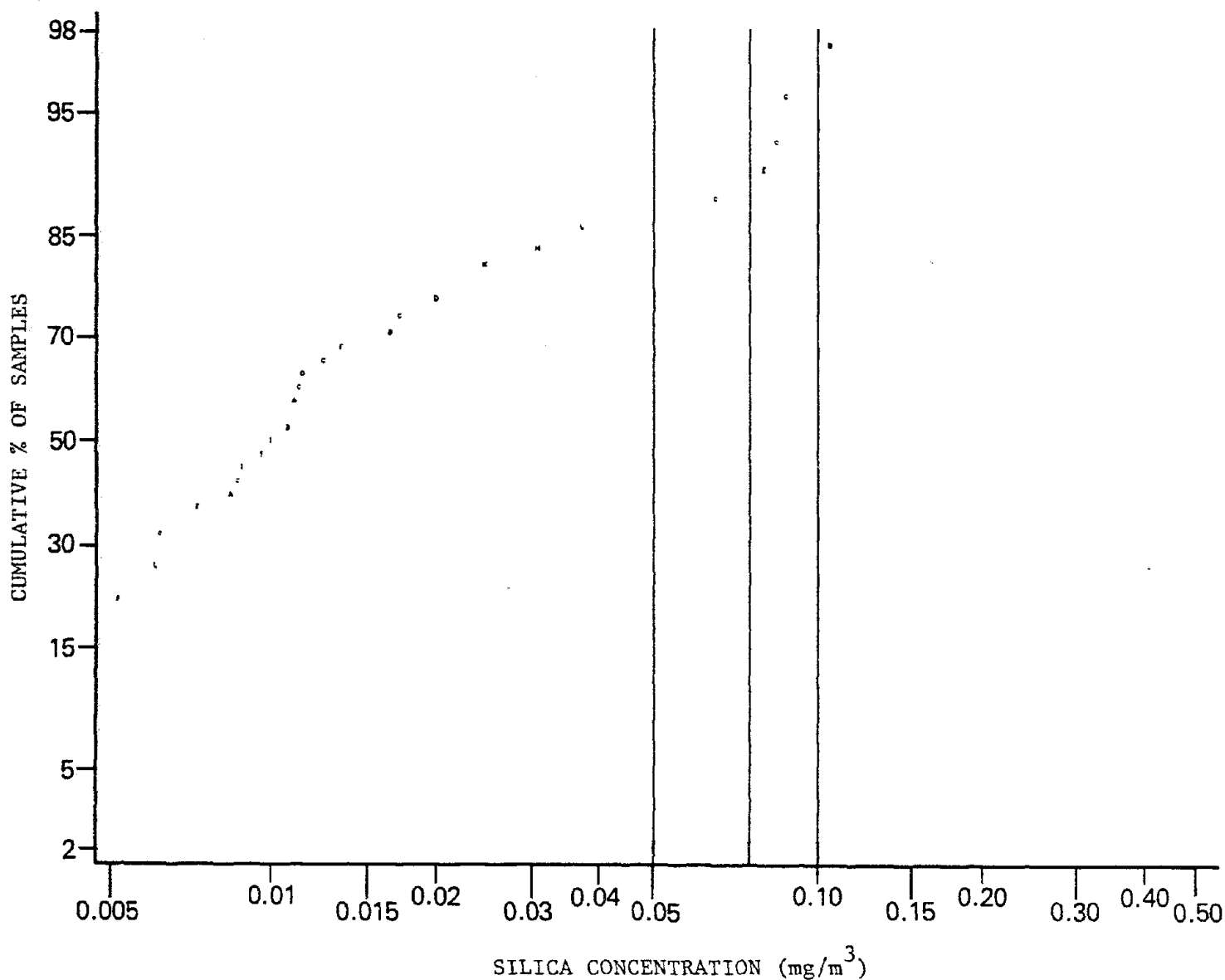
No. of samples: 216
 No. of mine ID's represented: 49
 No. of active sites in 1980: 155
 Percent of samples less than 0.05 mg/m^3 : 80
 Percent of samples less than 0.075 mg/m^3 : 88
 Percent of samples less than 0.1 mg/m^3 : 94

Figure A-59. Respirable quartz concentrations found in underground mobile transport operations in the uranium industry group.



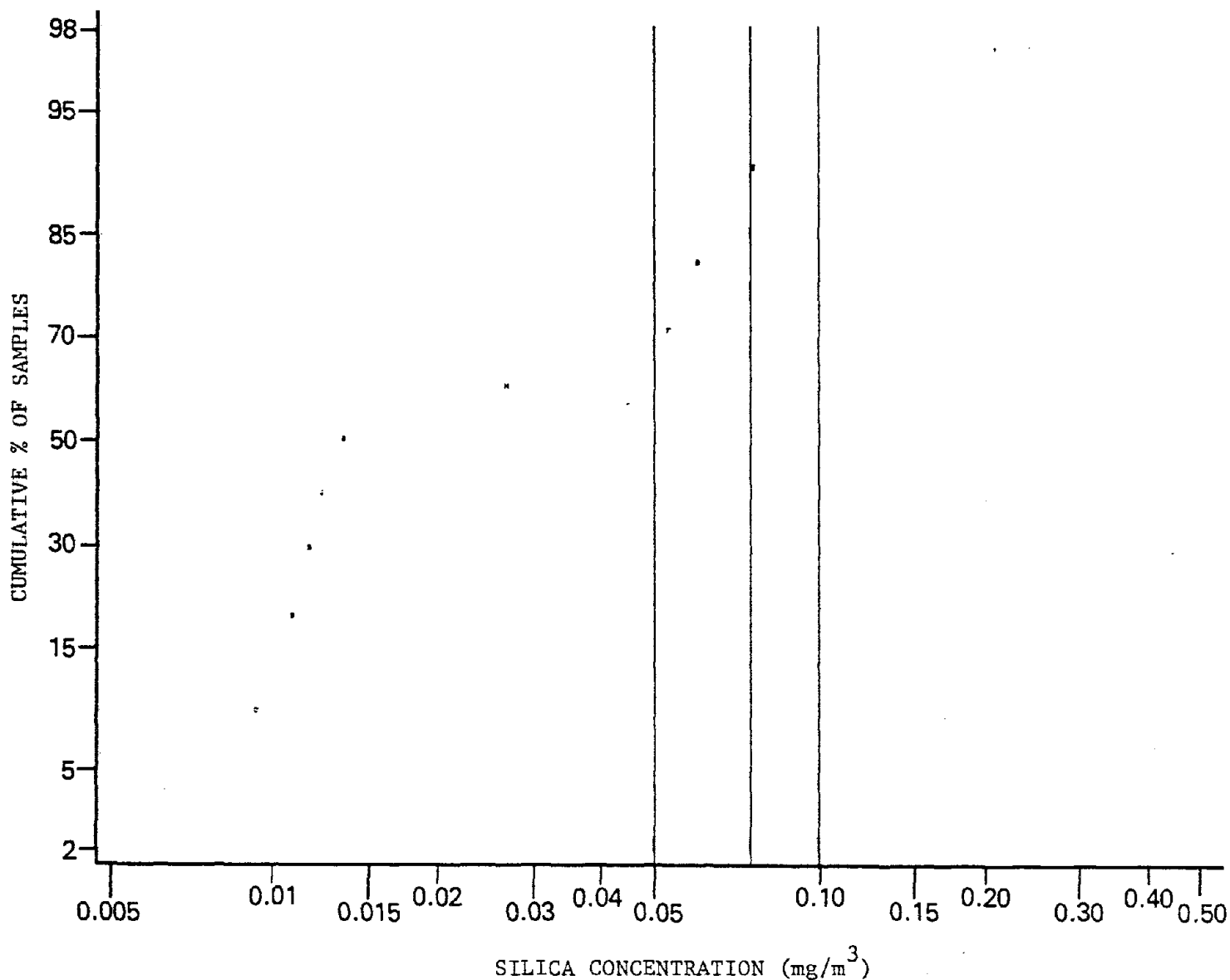
No. of samples: 69
 No. of mine ID's represented: 20
 No. of active sites in 1980: 233
 Percent of samples less than 0.05 mg/m³: 74
 Percent of samples less than 0.075 mg/m³: 78
 Percent of samples less than 0.1 mg/m³: 87

Figure A-60. Respirable quartz concentrations found in crushing, grinding, and sizing operations (surface and underground) in the uranium industry group.



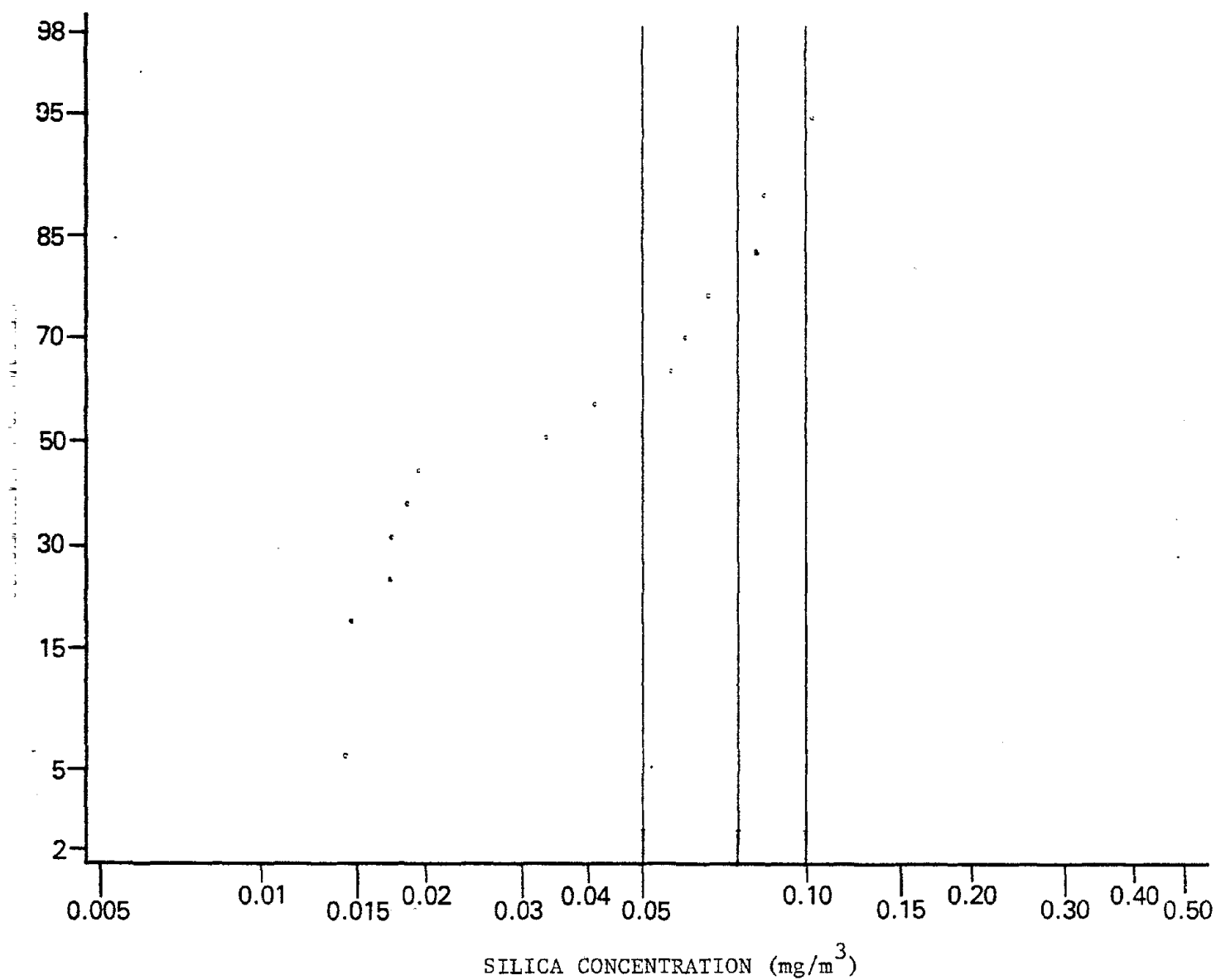
No. of samples: 40
 No. of mine ID's represented: 12
 No. of active sites in 1980: 233
 Percent of samples less than 0.05 mg/m³: 85
 Percent of samples less than 0.075 mg/m³: 88
 Percent of samples less than 0.1 mg/m³: 95

Figure A-61. Respirable quartz concentrations found in concentrating and finishing operations (surface and underground) in the uranium industry group.



No. of samples: 10
No. of mine ID's represented: 8
No. of active sites in 1980: 58
Percent of samples less than 0.05 mg/m³: 60
Percent of samples less than 0.075 mg/m³: 80
Percent of samples less than 0.1 mg/m³: 90

Figure A-62. Respirable quartz concentrations found in nonspecific surface operations in the other metals industry group.



No. of samples: 16
No. of mine ID's represented: 3
No. of active sites in 1980: 12
Percent of samples less than 0.05 mg/m³: 56
Percent of samples less than 0.075 mg/m³: 75
Percent of samples less than 0.1 mg/m³: 88

Figure A-63. Respirable quartz concentrations found in nonspecific underground operations in the other metals industry group.

Respirable quartz sample data (mg/m ³ silica)	Establishment (mine ID)
Surface locations	
0.0048	2542 (rare earths)
0.0057	2542 (rare earths)
0.0890	0646 (mercury)
0.3235	0646 (mercury)
0.7702	0646 (mercury)
Underground locations	
0.0185	0899 (tungsten)
0.0236	0899 (tungsten)
0.0368	0899 (tungsten)

	<u>Surface</u>	<u>Underground</u>
No. samples	5	3
No. of mine ID's represented	2	1
No. of active sites in 1980	22	12
Percent of samples less than 0.05 mg/m ³	40	100
Percent of samples less than 0.075 mg/m ³	40	100
Percent of samples less than 0.1 mg/m ³	60	100

Figure A-64. Respirable quartz concentrations found in drilling operations in the other metals industry group.

Respirable quartz sample data (mg/m ³ silica)	Establishment (mine ID)
Surface locations	
0.0051	429 (tungsten)
Underground locations	
0.0135	176
0.0135	176 (antimony)
0.0257	176
0.0295	176
0.0295	176
0.0310	176
0.0332	899 (tungsten)
0.0583	176
0.0774	176

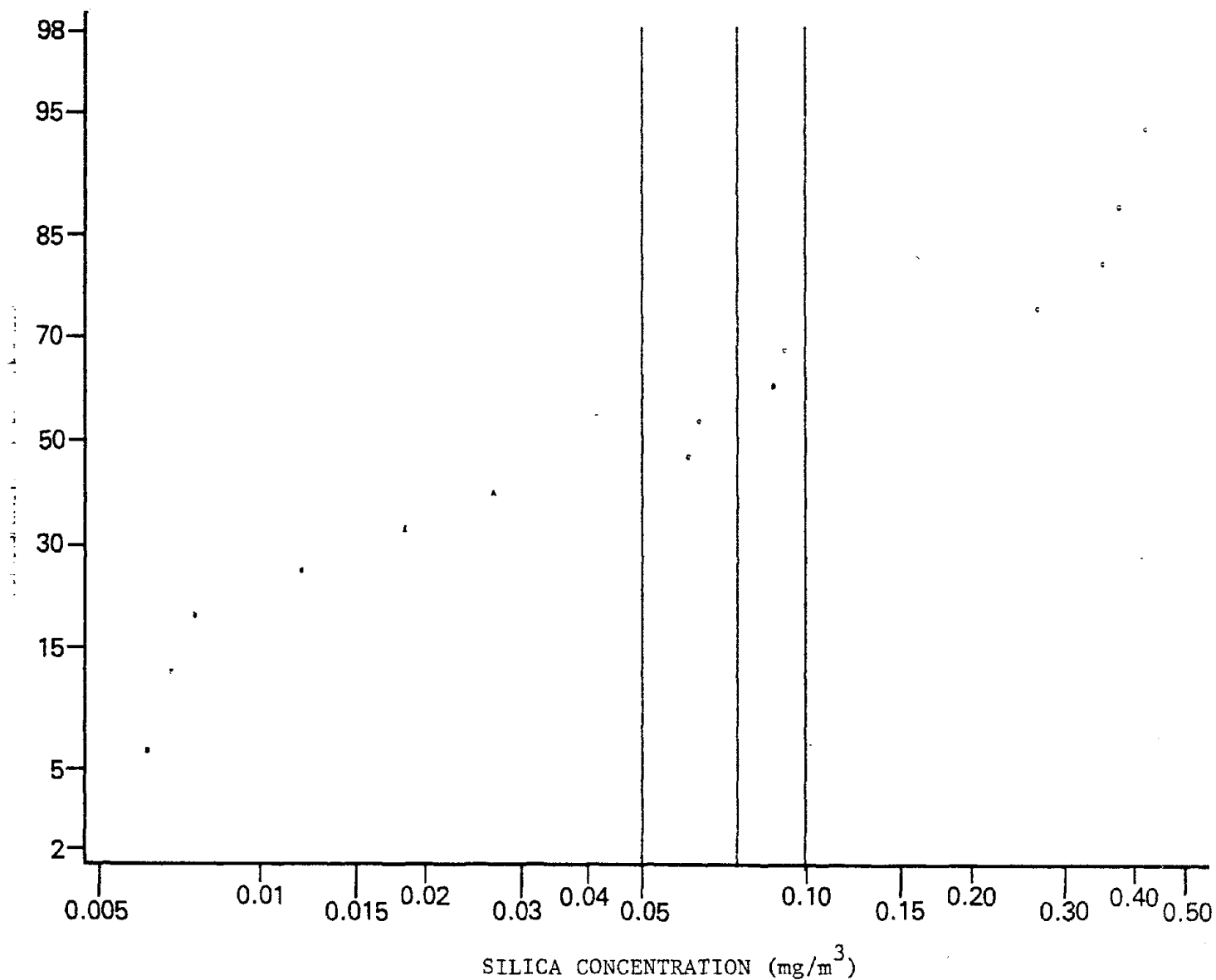
	<u>Surface</u>	<u>Underground</u>
No. samples	1	9
No. of mine ID's represented	1	2
No. of active sites in 1980	22	12
Percent of samples less than 0.05 mg/m ³	100	78
Percent of samples less than 0.075 mg/m ³	100	89
Percent of samples less than 0.1 mg/m ³	100	100

Figure A -65. Respirable quartz concentrations found in production operations in the other metals industry group.

Respirable quartz sample data (mg/m ³ silica)	Establishment (mine ID)
Surface locations	
0.0024	124 (rare earths)
0.0048	261 (aluminum ore)
0.0060	646 (mercury)
0.0073	646 (mercury)
0.0194	876 (manganese)
0.0284	124
0.0440	124
Underground locations	
0.0529	143 (tungsten)

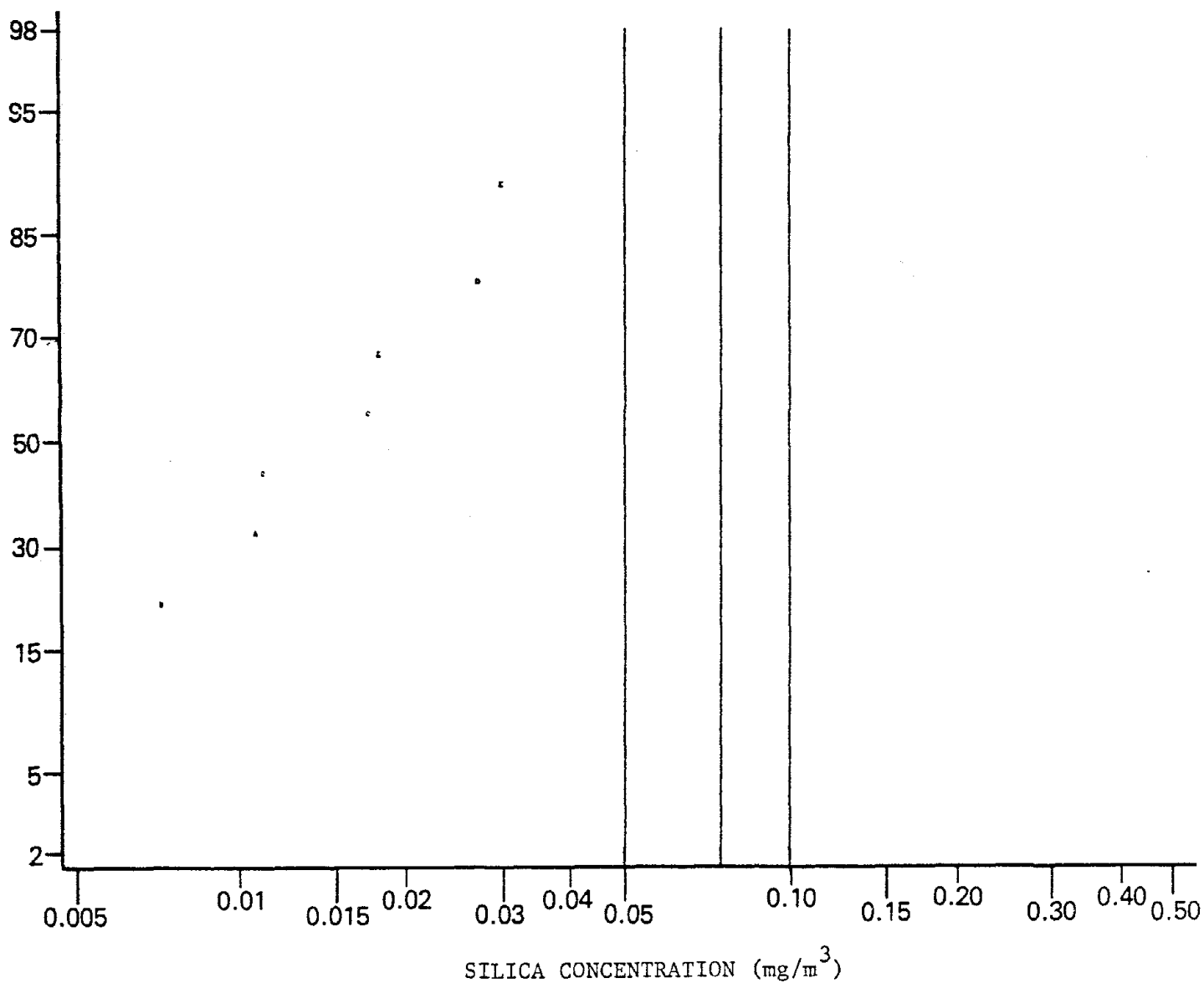
	<u>Surface</u>	<u>Underground</u>
No. samples	7	1
No. of mine ID's represented	4	1
No. of active sites in 1980	22	12
Percent of samples less than 0.05 mg/m ³	100	0
Percent of samples less than 0.075 mg/m ³	100	100
Percent of samples less than 0.1 mg/m ³	100	100

Figure A-66. Respirable quartz concentrations found in mobile transport operations in the other metals industry group.



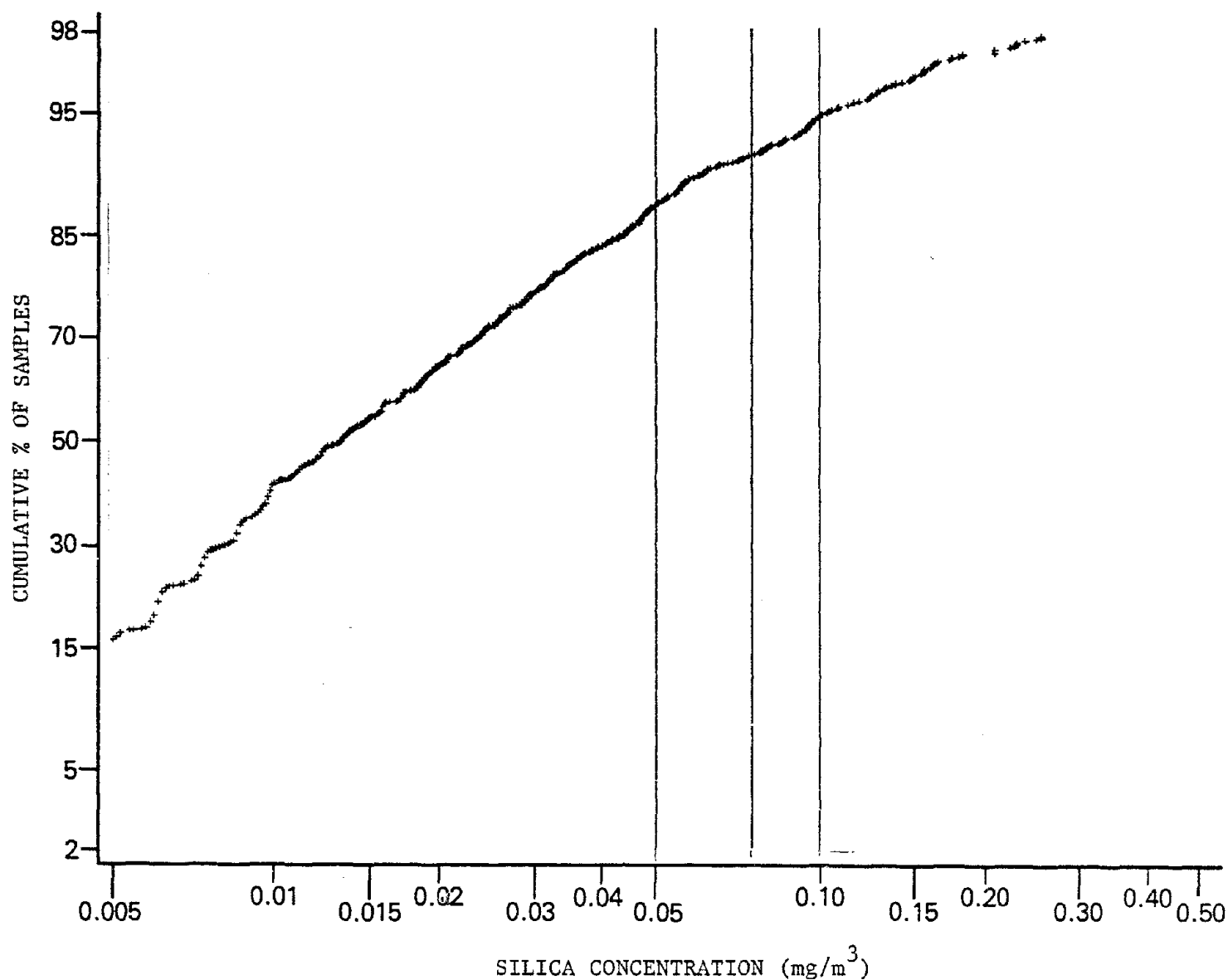
No. of samples: 15
 No. of mine ID's represented: 7
 No. of active sites in 1980: 58
 Percent of samples less than 0.05 mg/m³: 40
 Percent of samples less than 0.075 mg/m³: 53
 Percent of samples less than 0.1 mg/m³: 67

Figure A-67. Respirable quartz concentrations found in crushing, grinding, and sizing operations (surface and underground) in the other metals industry group.



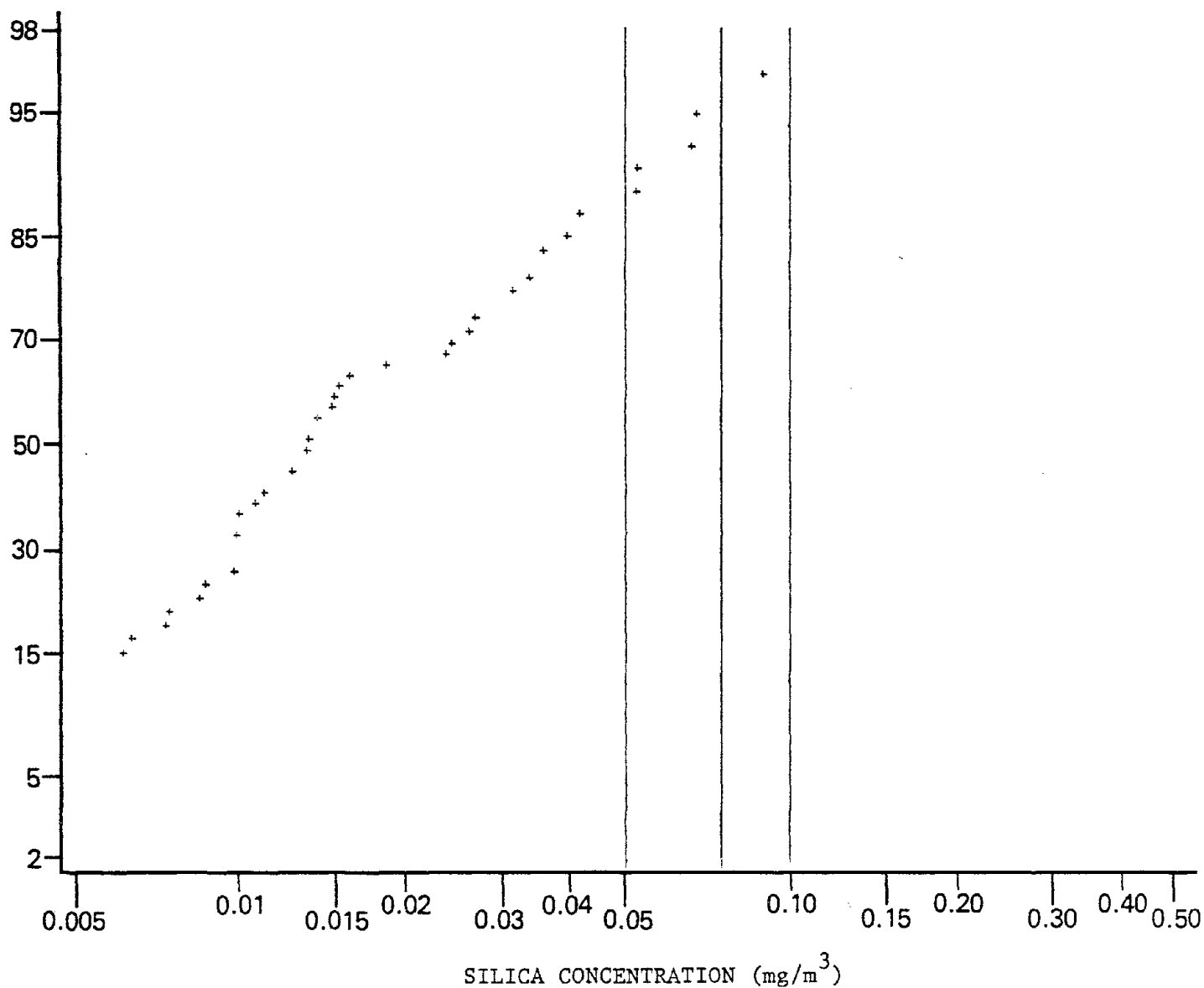
No. of samples: 9
 No. of mine ID's represented: 7
 No. of active sites in 1980: 58
 Percent of samples less than 0.05 mg/m³: 89
 Percent of samples less than 0.075 mg/m³: 100
 Percent of samples less than 0.1 mg/m³: 100

Figure A-68. Respirable quartz concentrations found in concentrating and finishing operations (surface and underground) in the other metals industry group.



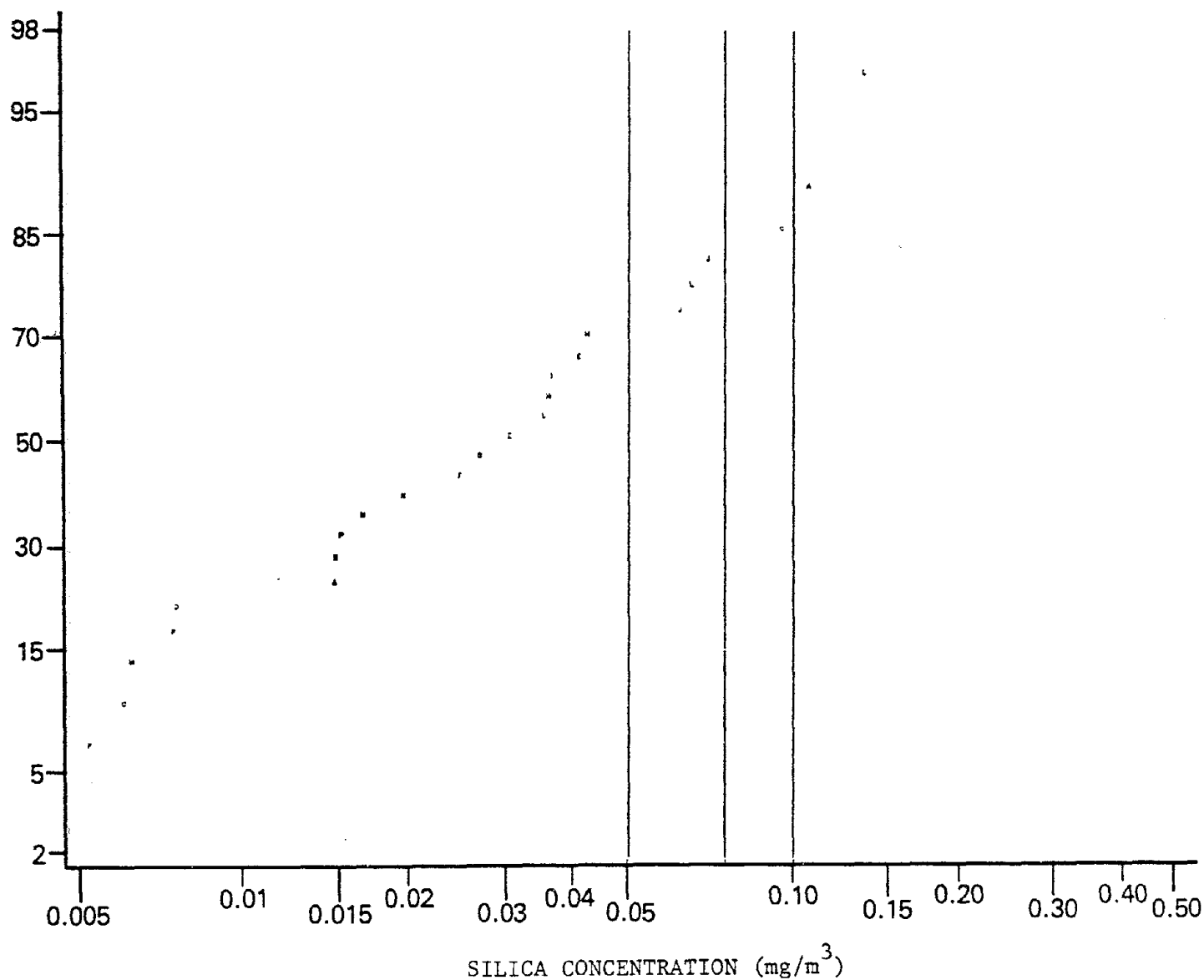
No. of samples: 1177
No. of mine ID's represented: 456
No. of active sites in 1980: 2,094
Percent of samples less than 0.05 mg/m³: 87
Percent of samples less than 0.075 mg/m³: 91
Percent of samples less than 0.1 mg/m³: 94

Figure A-69. Respirable quartz concentrations found in nonspecific surface operations in the limestone industry group.



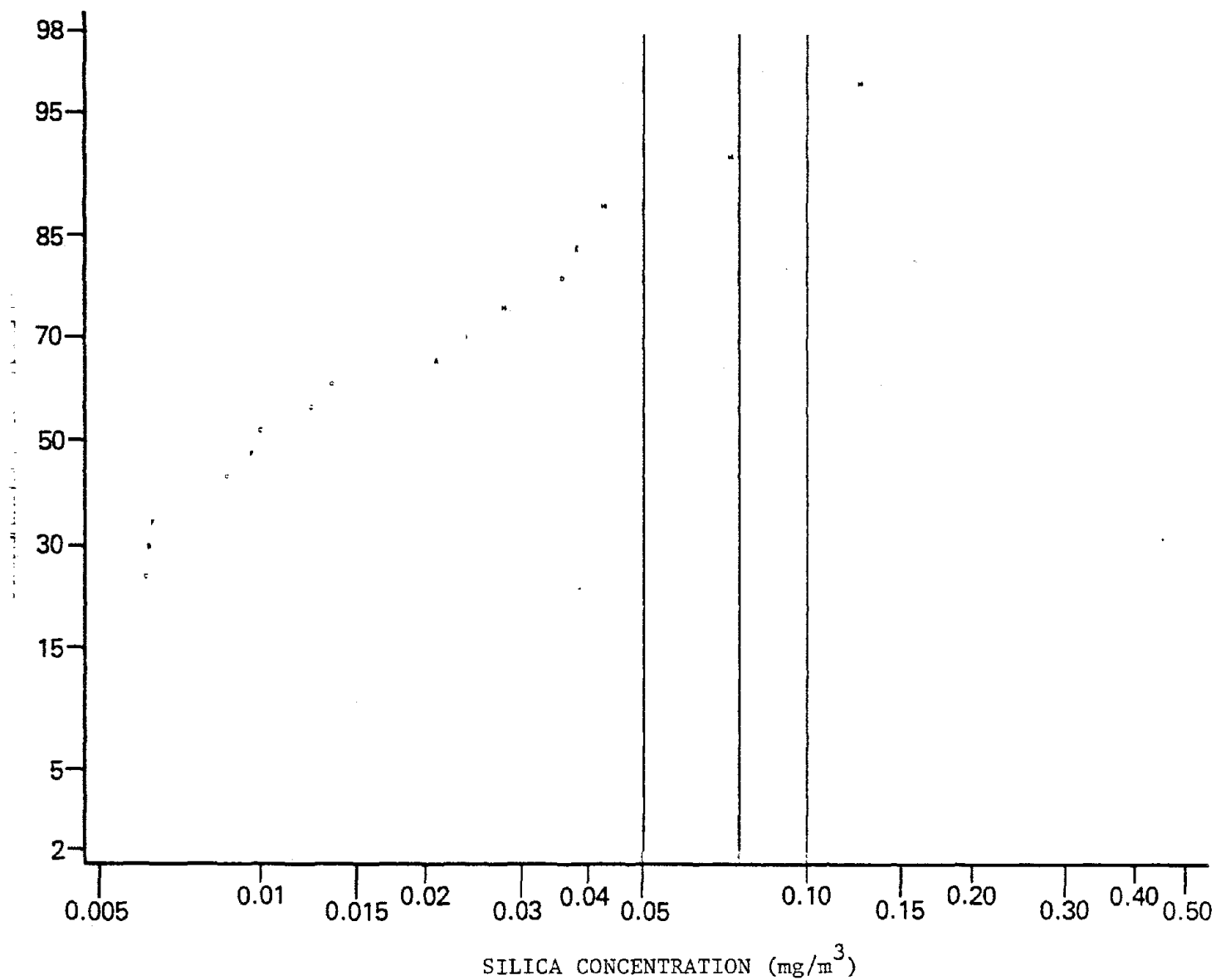
No. of samples: 51
 No. of mine ID's represented: 26
 No. of active sites in 1980: 104
 Percent of samples less than 0.05 mg/m³: 86
 Percent of samples less than 0.075 mg/m³: 94
 Percent of samples less than 0.1 mg/m³: 96

Figure A-70. Respirable quartz concentrations found in nonspecific underground operations in the limestone industry group.



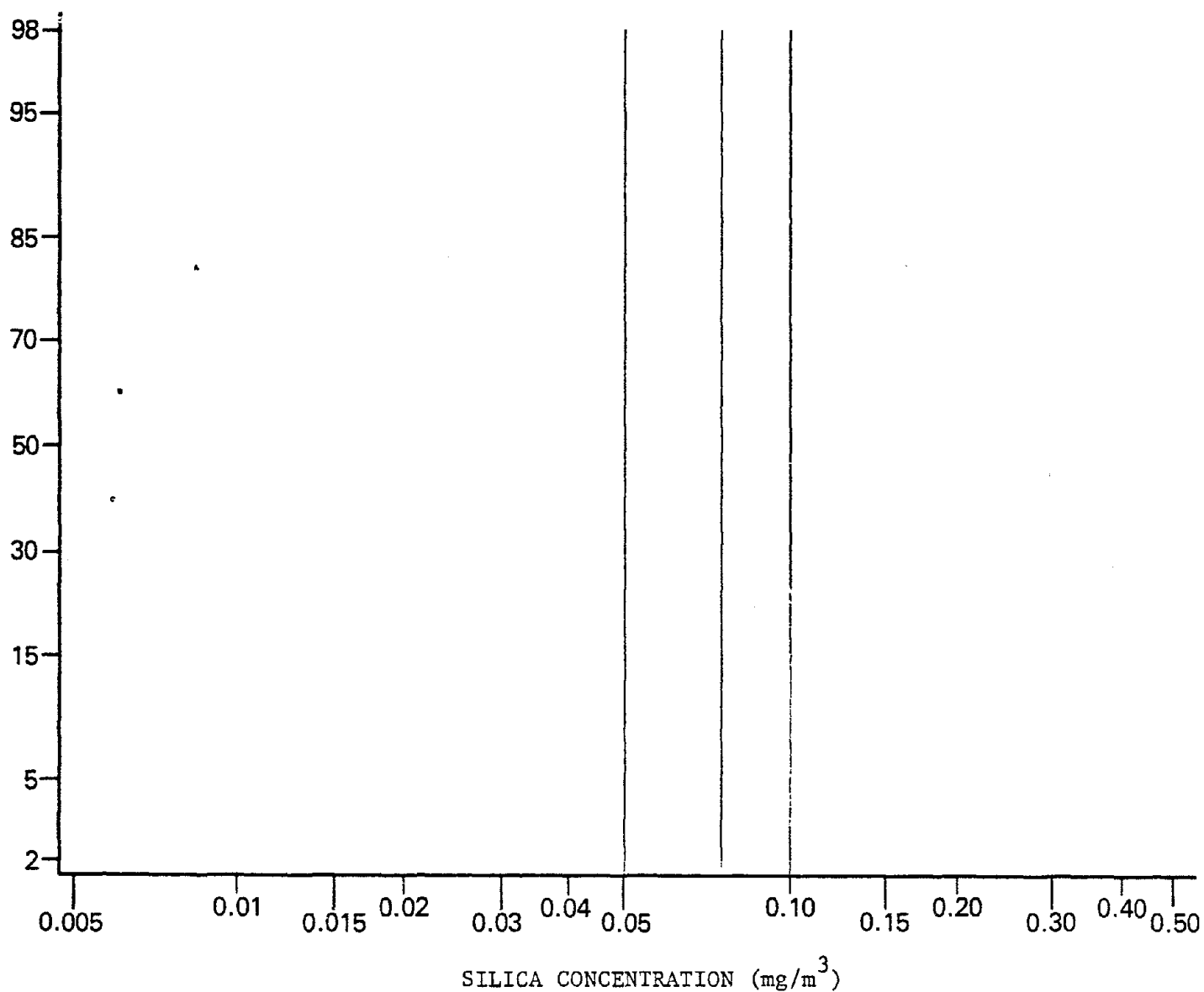
No. of samples: 27
 No. of mine ID's represented: 17
 No. of active sites in 1980: 104
 Percent of samples less than 0.05 mg/m³: 70
 Percent of samples less than 0.075 mg/m³: 81
 Percent of samples less than 0.1 mg/m³: 85

Figure A -71. Respirable quartz concentrations found in underground blasting operations in the limestone industry group.



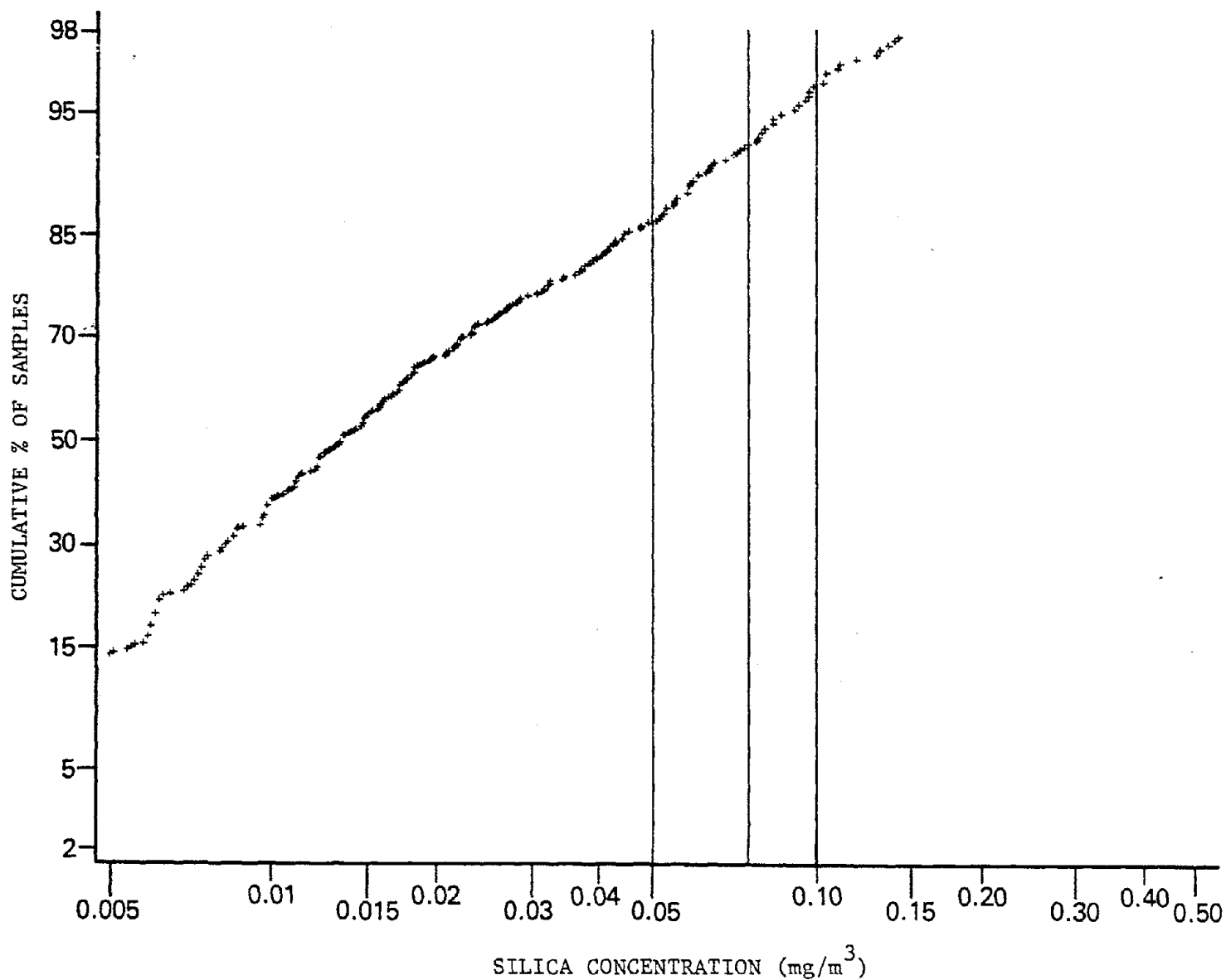
No. of samples: 23
No. of mine ID's represented: 9
No. of active sites in 1980: 1809
Percent of samples less than 0.05 mg/m³: 87
Percent of samples less than 0.075 mg/m³: 91
Percent of samples less than 0.1 mg/m³: 91

Figure A-72. Respirable quartz concentrations found in surface cutting and boring operations in the limestone industry group.



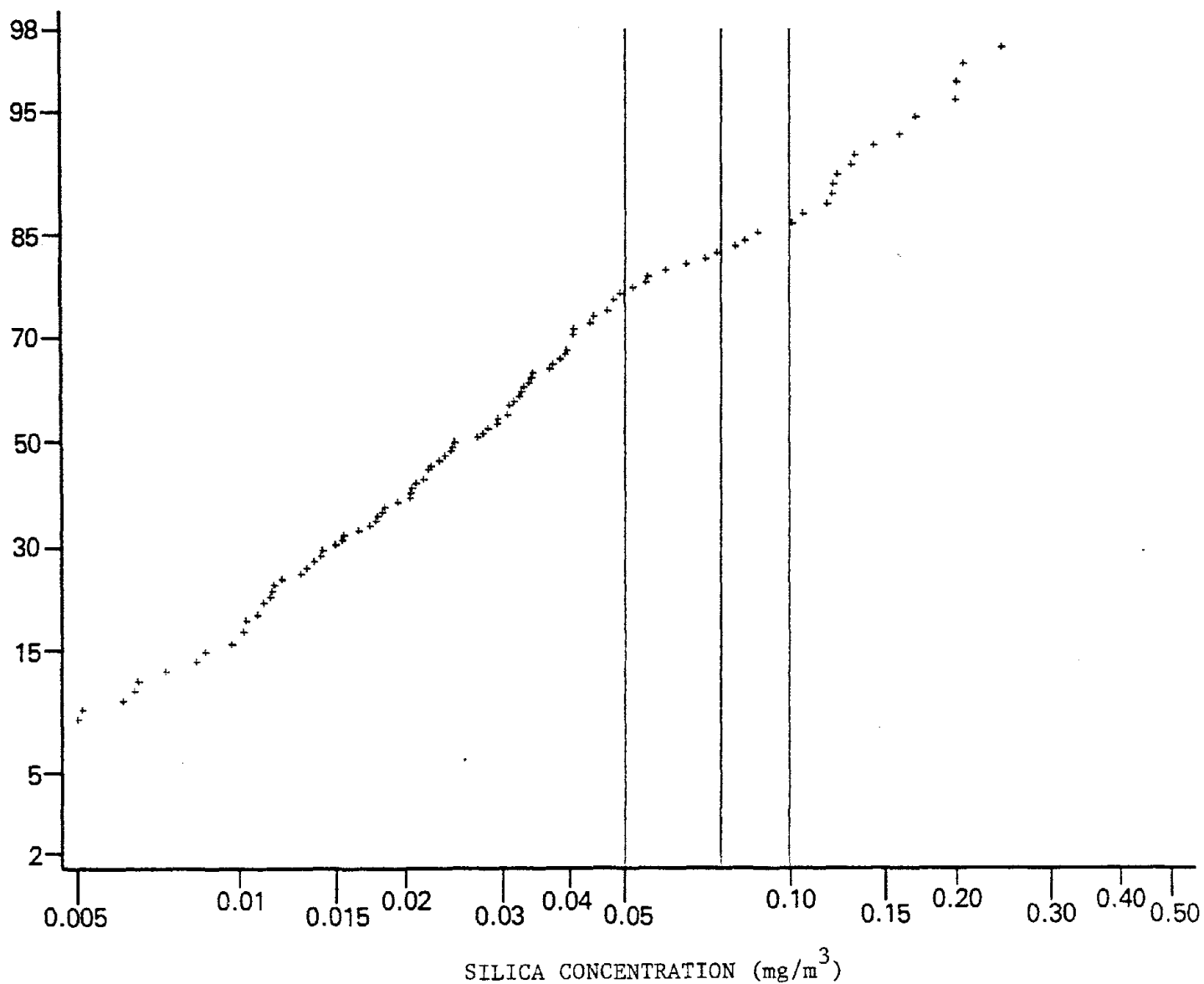
No. of samples: 5
 No. of mine ID's represented: 4
 No. of active sites in 1980: 104
 Percent of samples less than 0.05 mg/m³: 100
 Percent of samples less than 0.075 mg/m³: 100
 Percent of samples less than 0.1 mg/m³: 100

Figure A-73. Respirable quartz concentrations found
 in underground cutting and boring
 operations in the limestone industry
 group.



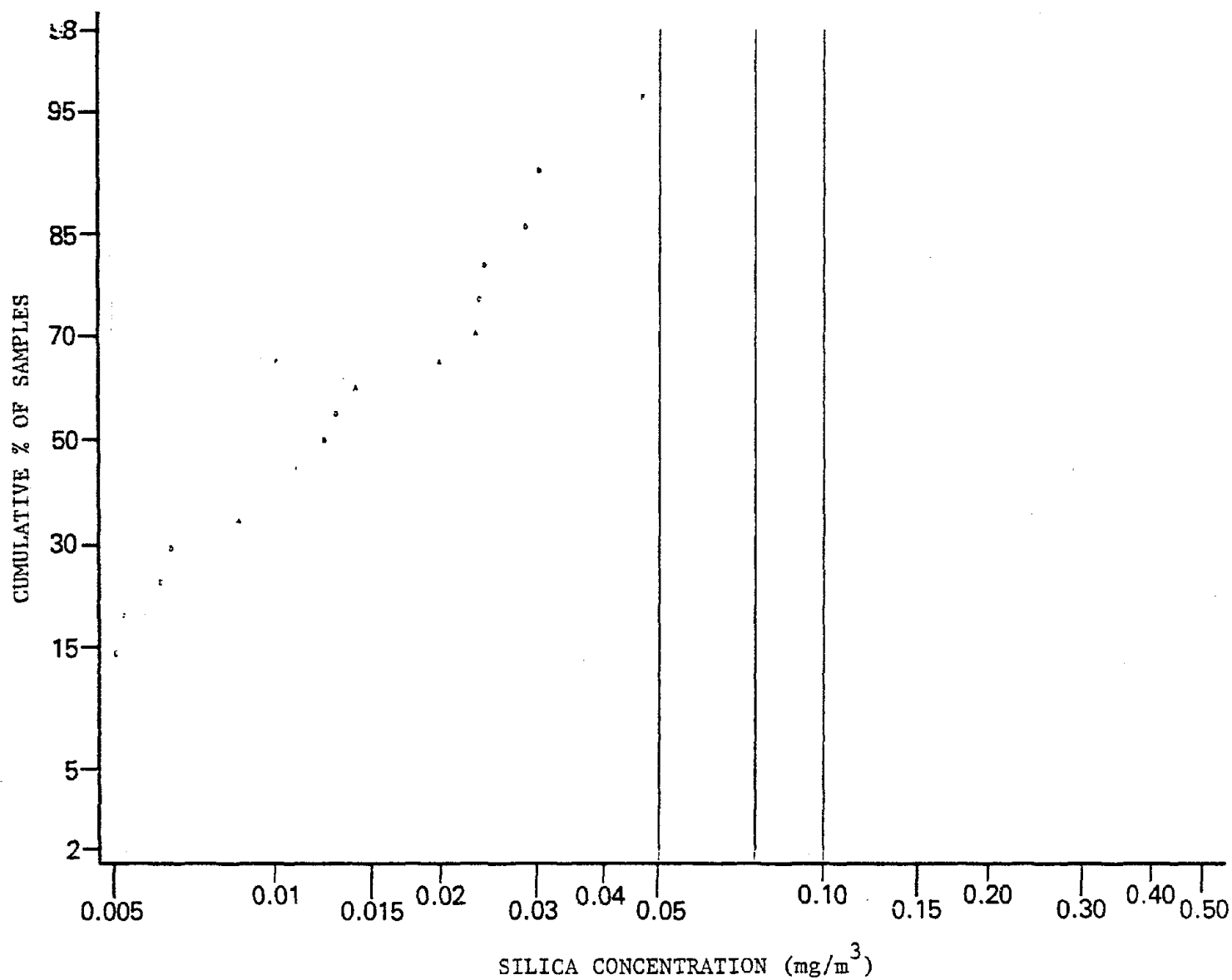
No. of samples: 443
 No. of mine ID's represented: 309
 No. of active sites in 1980: 1809
 Percent of samples less than 0.05 mg/m³: 85
 Percent of samples less than 0.075 mg/m³: 92
 Percent of samples less than 0.1 mg/m³: 95

Figure A-74. Respirable quartz concentrations found in surface drilling operations in the limestone industry group.



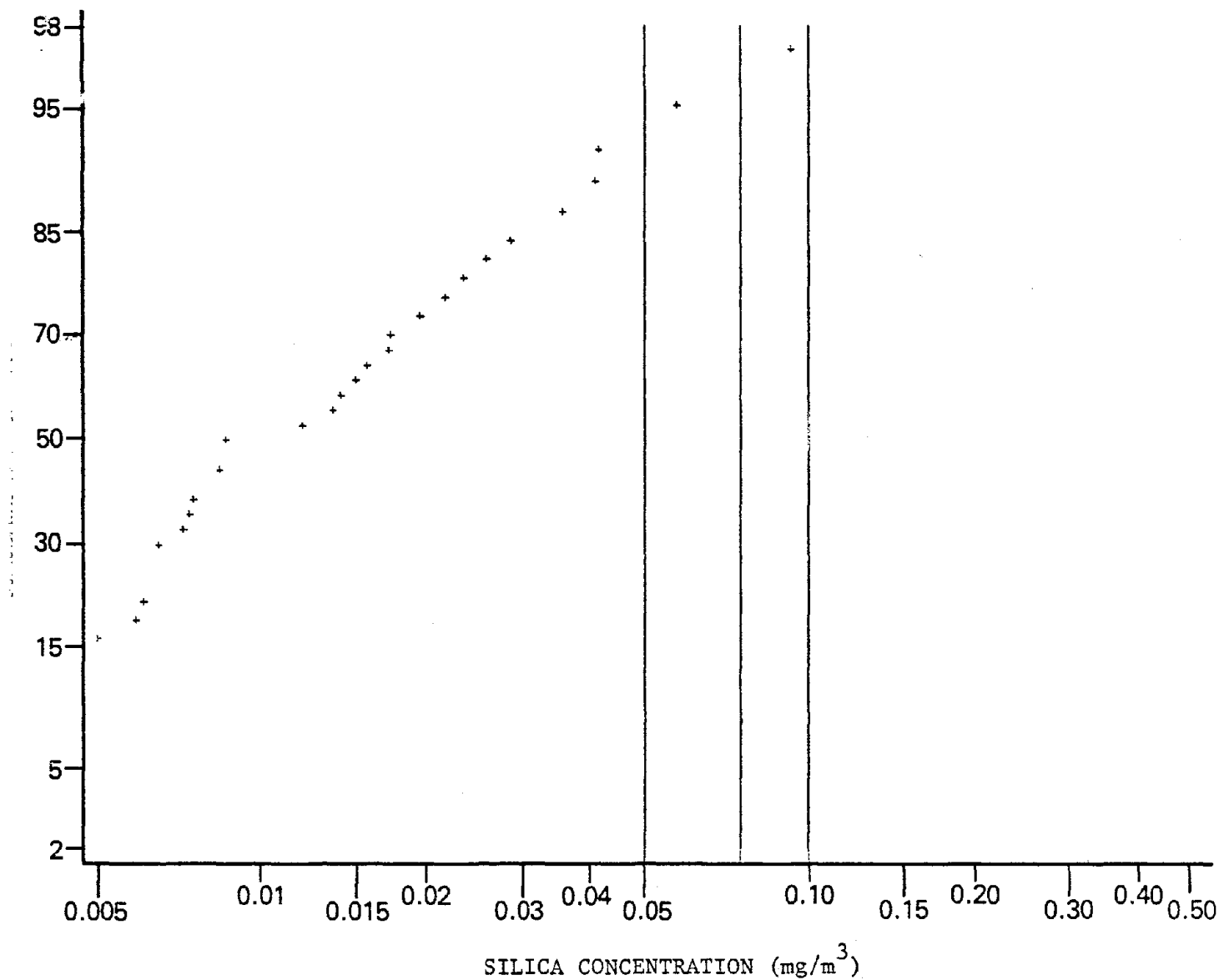
No. of samples: 116
No. of mine ID's represented: 50
No. of active sites in 1980: 104
Percent of samples less than 0.05 mg/m³: 76
Percent of samples less than 0.075 mg/m³: 82
Percent of samples less than 0.1 mg/m³: 84

Figure A-75. Respirable quartz concentrations found in underground drilling operations in the limestone industry group.



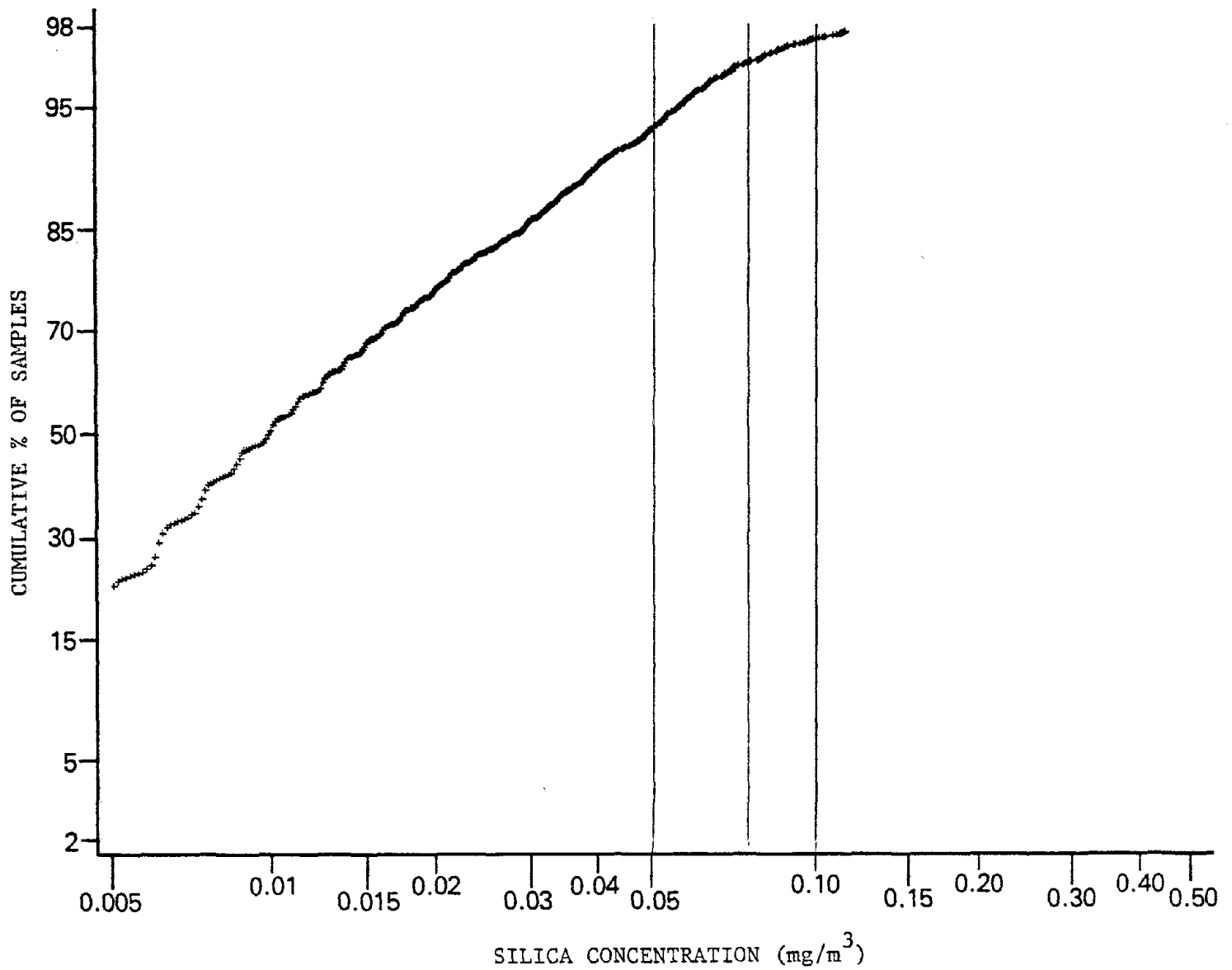
No. of samples: 20
 No. of mine ID's represented: 9
 No. of active sites in 1980: 1809
 Percent of samples less than 0.05 mg/m³: 95
 Percent of samples less than 0.075 mg/m³: 95
 Percent of samples less than 0.1 mg/m³: 100

Figure A-76. Respirable quartz concentrations found in surface haulageway maintenance operations in the limestone industry group.



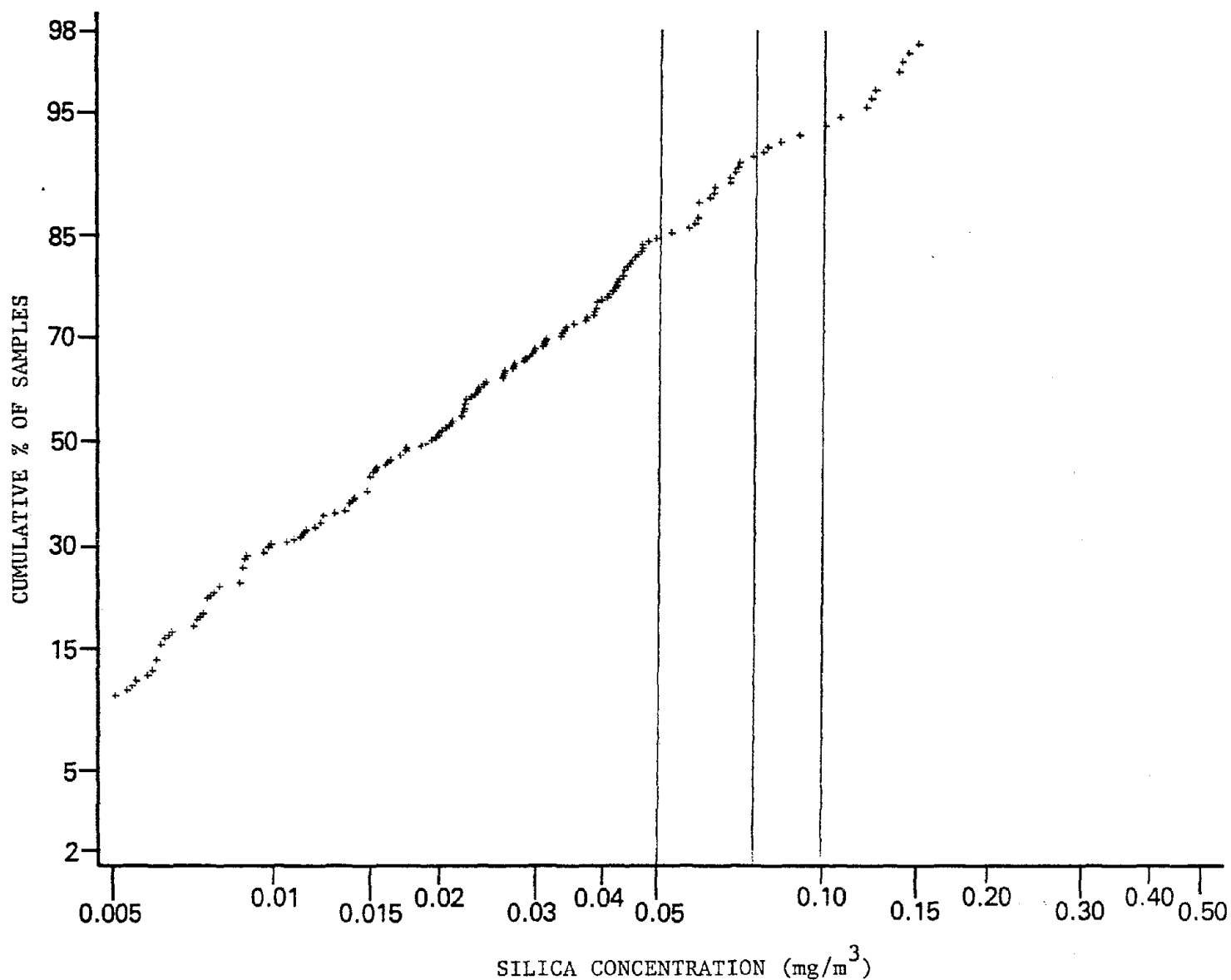
No. of samples: 36
 No. of mine ID's represented: 31
 No. of active sites in 1980: 1809
 Percent of samples less than 0.05 mg/m³: 92
 Percent of samples less than 0.075 mg/m³: 94
 Percent of samples less than 0.1 mg/m³: 97

Figure A-77. Respirable quartz concentrations found in surface production operations in the limestone industry group.



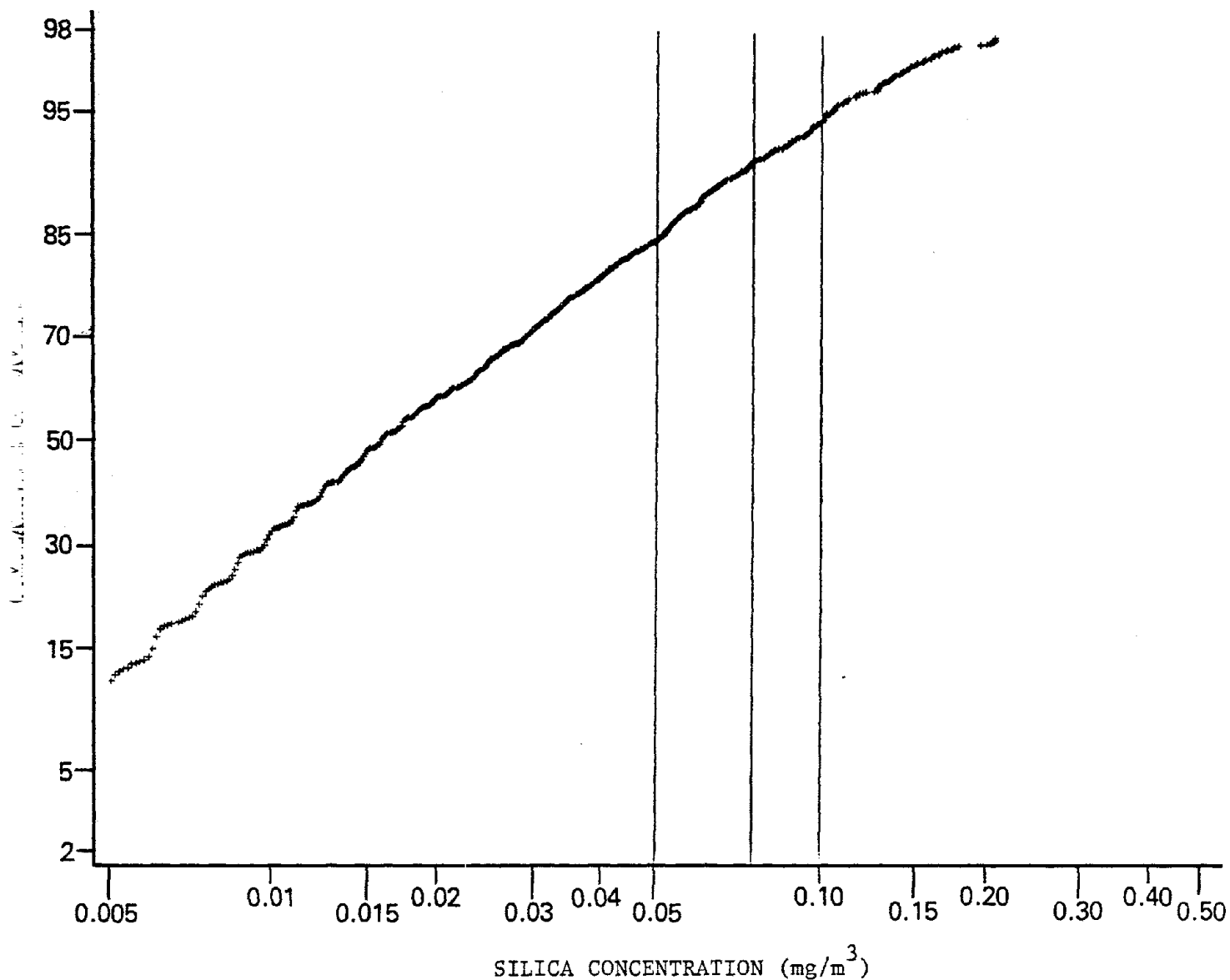
No. of samples: 3779
No. of mine ID's represented: 1045
No. of active sites in 1980: 1809
Percent of samples less than 0.05 mg/m³: 93
Percent of samples less than 0.075 mg/m³: 96
Percent of samples less than 0.1 mg/m³: 98

Figure A-78. Respirable quartz concentrations found in surface mobile transport operations in the limestone industry group.



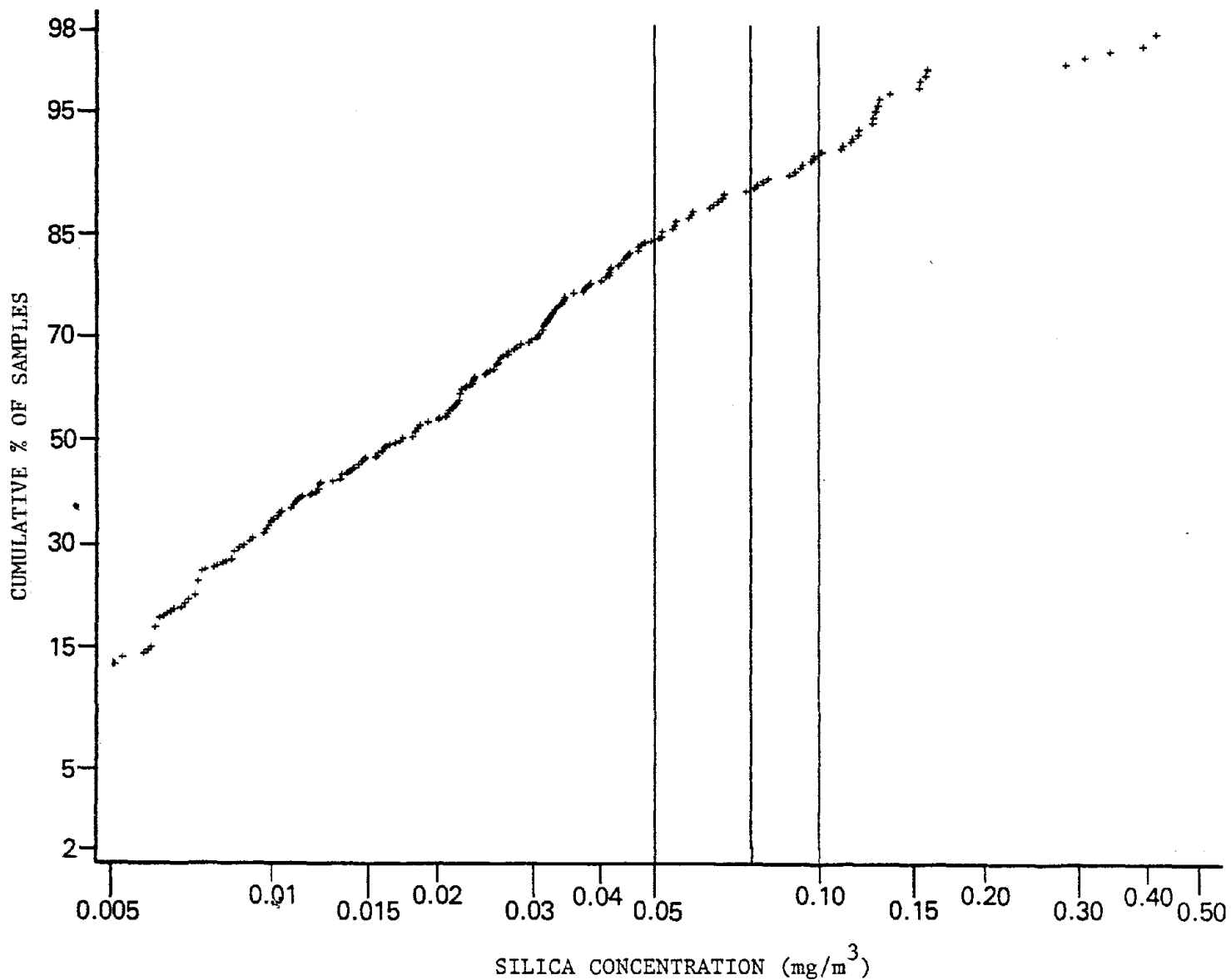
No. of samples: 221
 No. of mine ID's represented: 54
 No. of active sites in 1980: 104
 Percent of samples less than 0.05 mg/m³: 84
 Percent of samples less than 0.075 mg/m³: 91
 Percent of samples less than 0.1 mg/m³: 93

Figure A-79. Respirable quartz concentrations found in underground mobile transport operations in the limestone industry group.



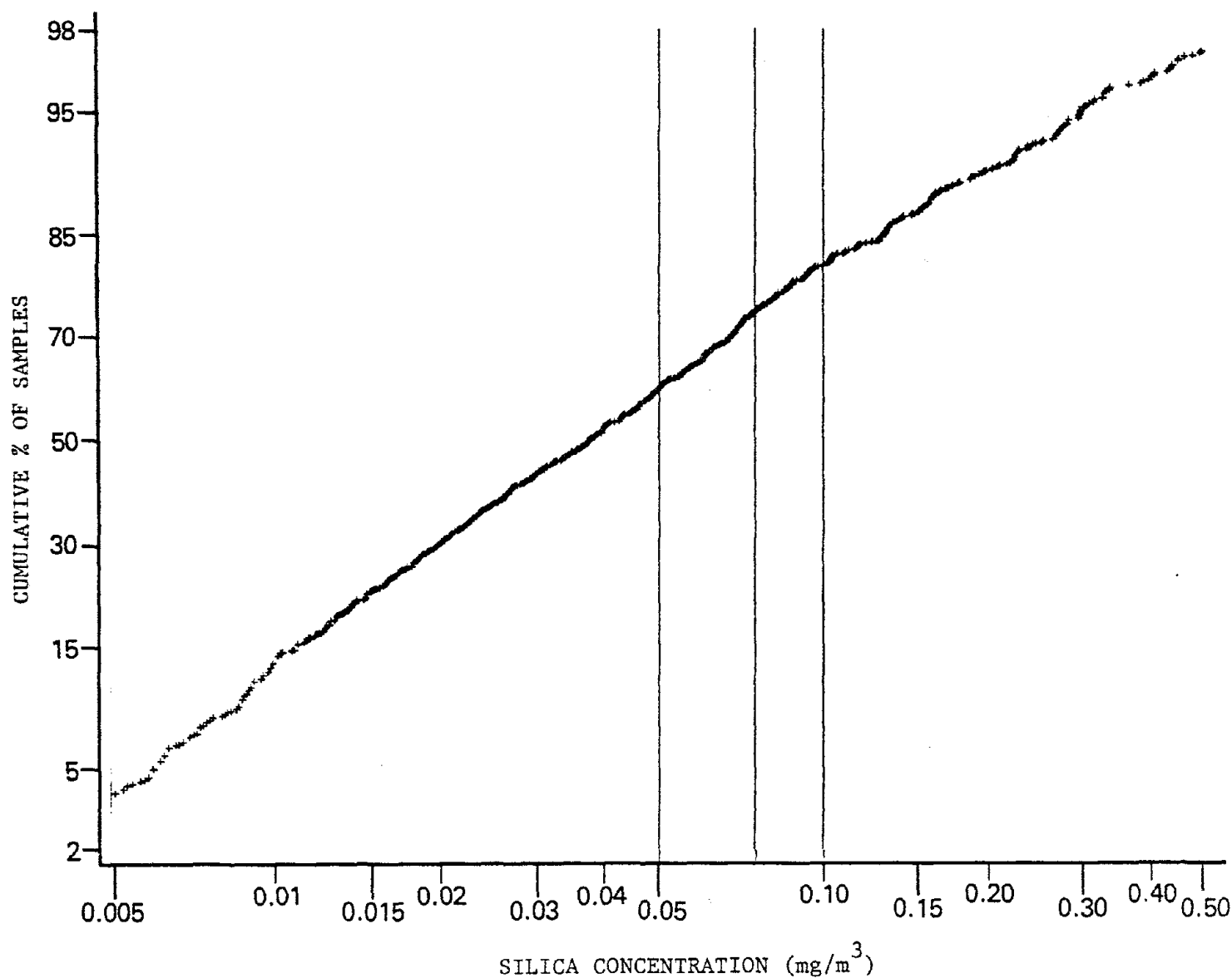
No. of samples: 2324
 No. of mine ID's represented: 933
 No. of active sites in 1980: 2094
 Percent of samples less than 0.05 mg/m³: 84
 Percent of samples less than 0.075 mg/m³: 91
 Percent of samples less than 0.1 mg/m³: 94

Figure A-80. Respirable quartz concentrations found in crushing, grinding, and sizing operations (surface and underground) in the limestone industry group.



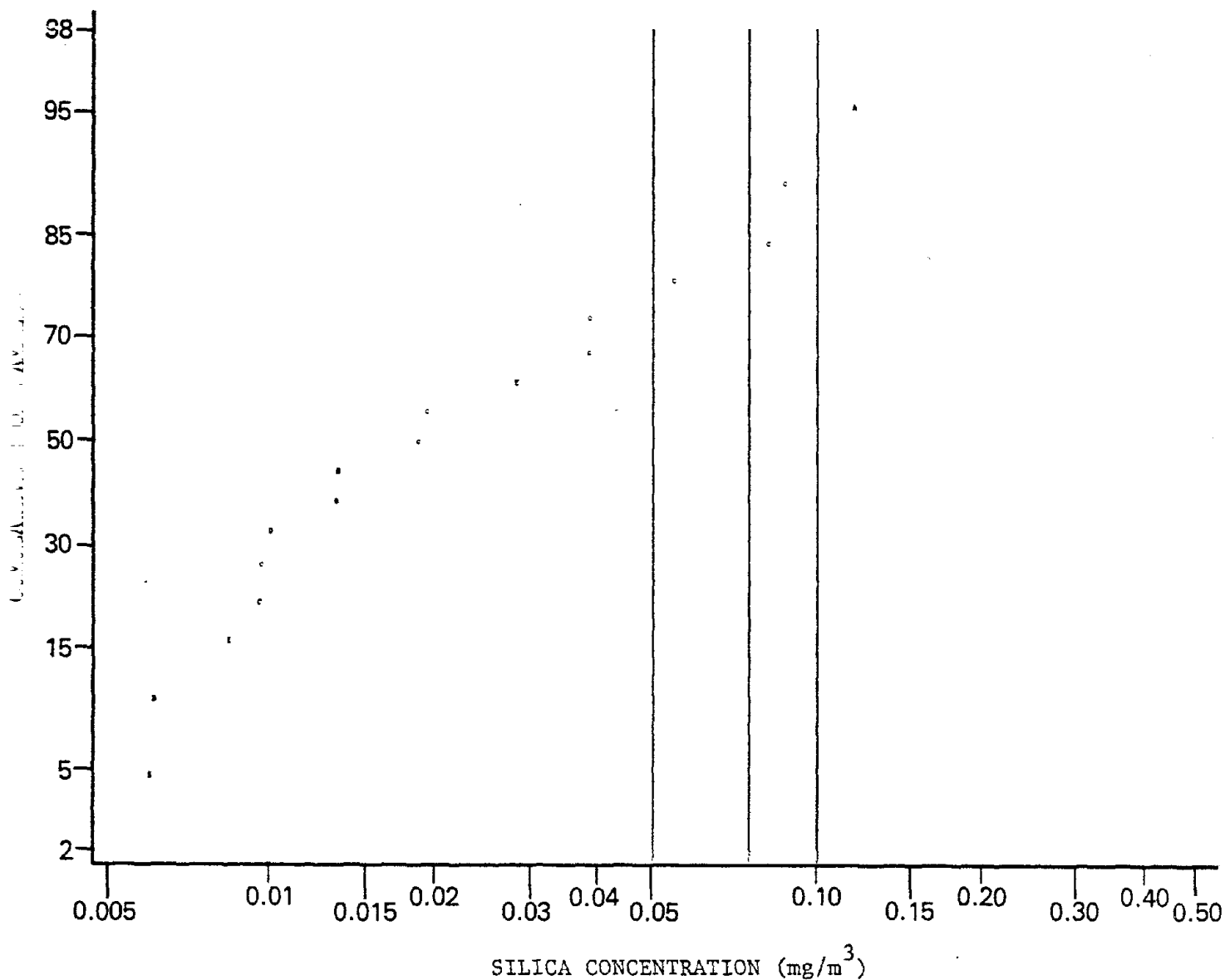
No. of samples: 339
 No. of mine ID's represented: 134
 No. of active sites in 1980: 2,094
 Percent of samples less than 0.05 mg/m³: 83
 Percent of samples less than 0.075 mg/m³: 88
 Percent of samples less than 0.1 mg/m³: 91

Figure A-81. Respirable quartz concentrations found in
 concentrating and finishing operations
 (surface and underground) in the limestone
 industry group.



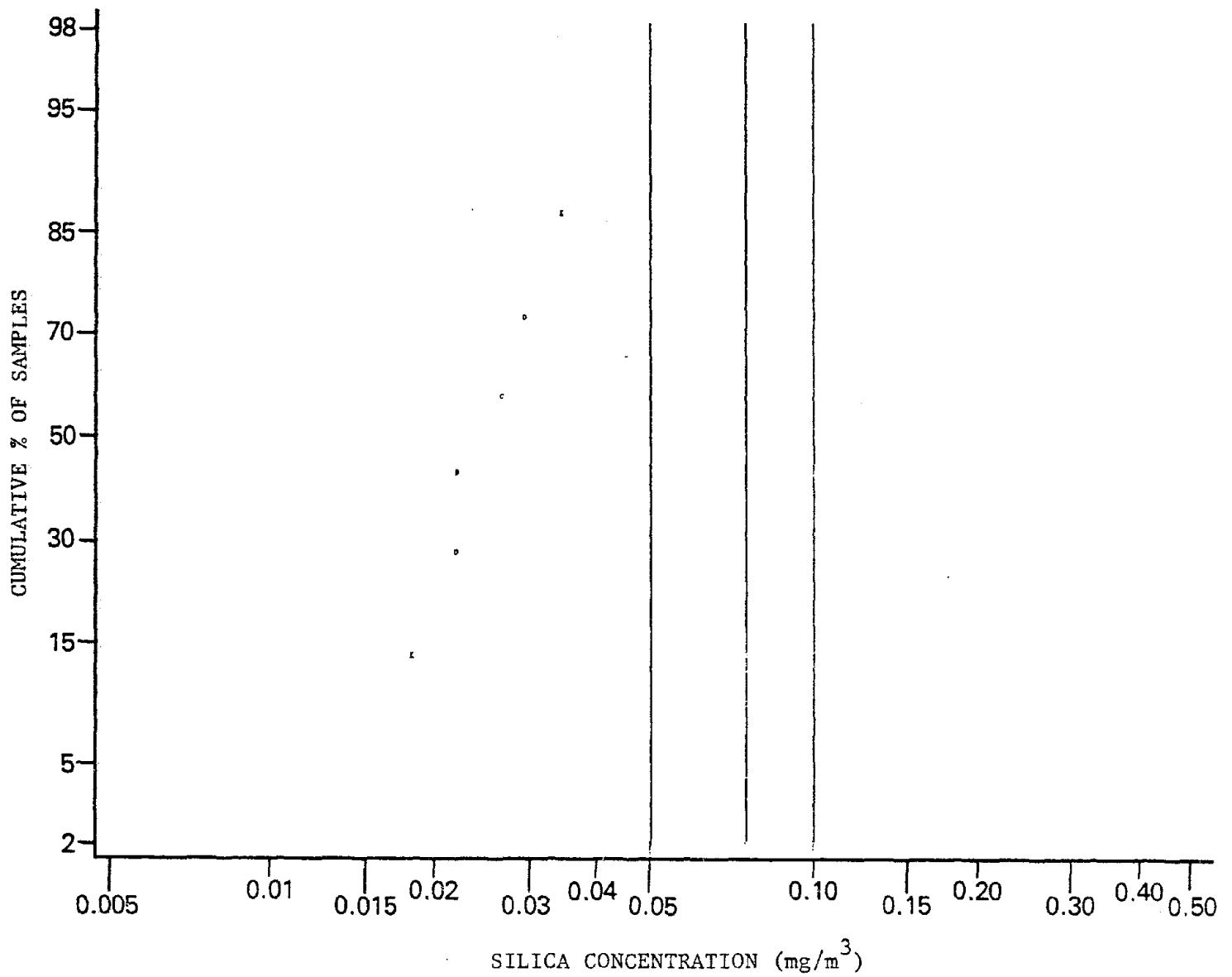
No. of samples: 1000
 No. of mine ID's represented: 301
 No. of active sites in 1980: 925
 Percent of samples less than 0.05 mg/m³: 60
 Percent of samples less than 0.075 mg/m³: 73
 Percent of samples less than 0.1 mg/m³: 80

Figure A-82. Respirable quartz concentrations found in nonspecific surface operations in the other stone industry group.



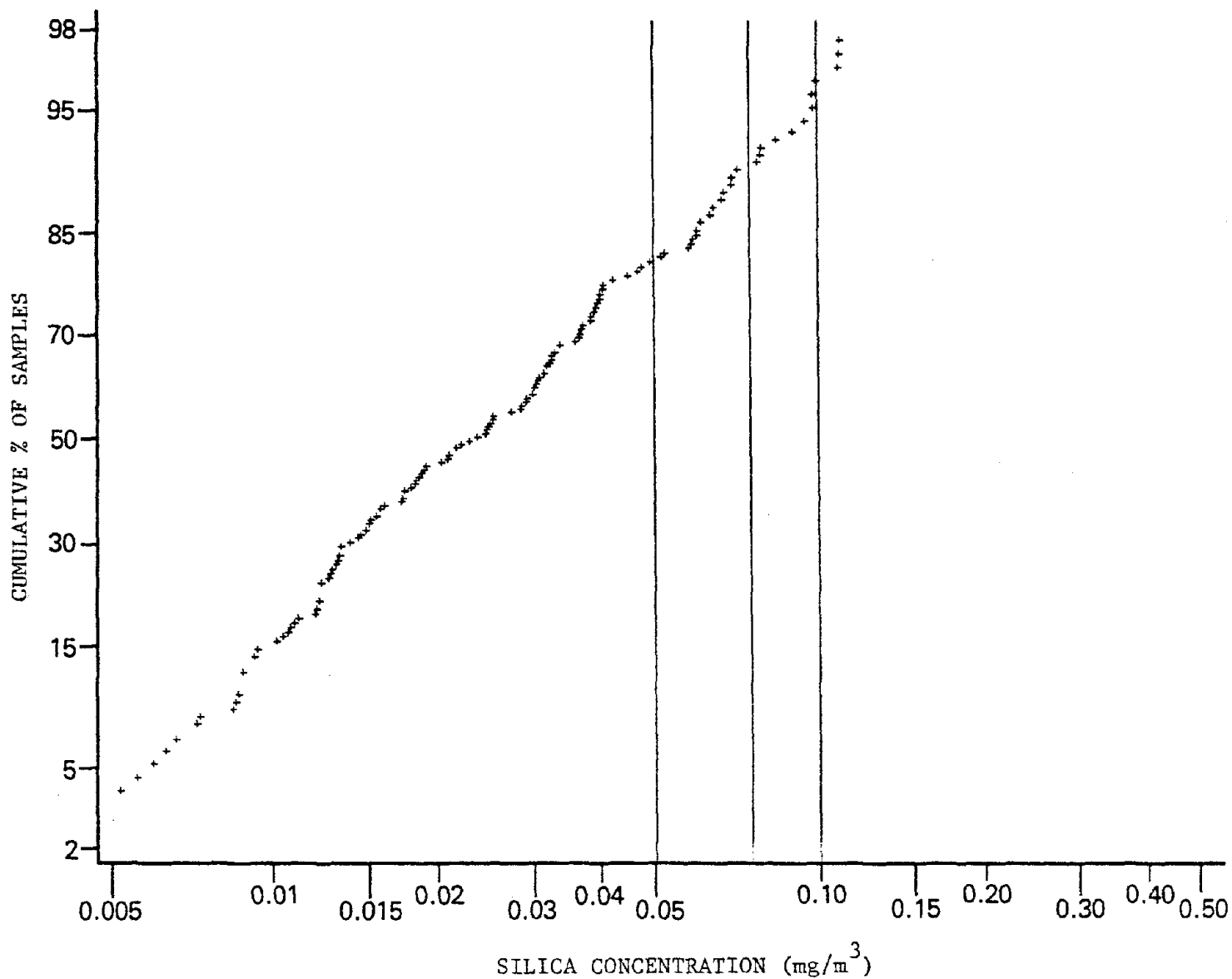
No. of samples: 18
 No. of mine ID's represented: 5
 No. of active sites in 1980: 15
 Percent of samples less than 0.05 mg/m³: 72
 Percent of samples less than 0.075 mg/m³: 78
 Percent of samples less than 0.1 mg/m³: 89

Figure A-83. Respirable quartz concentrations found in nonspecific underground operations in the other stone industry group.



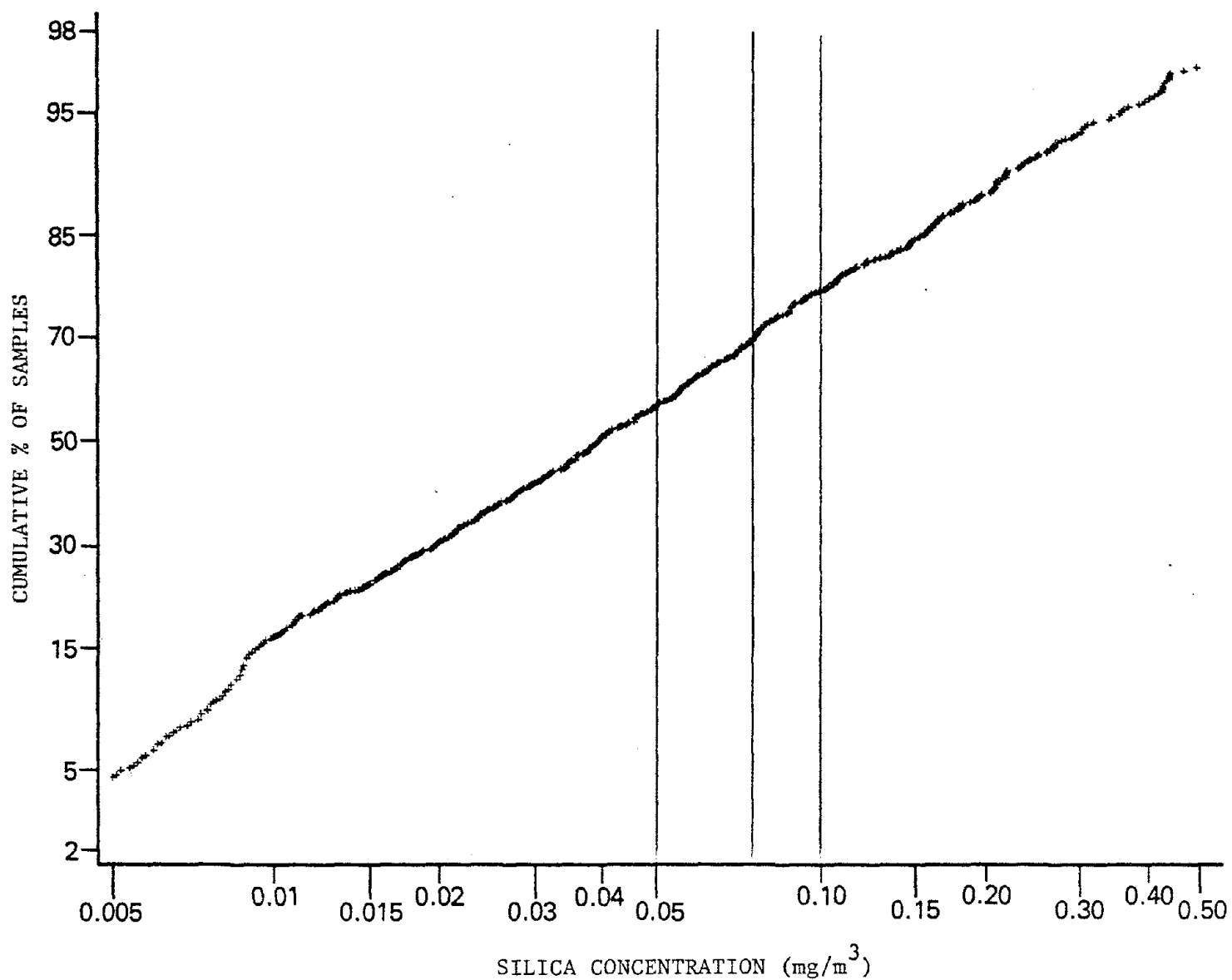
No. of samples: 7
 No. of mine ID's represented: 5
 No. of active sites in 1980: 925
 Percent of samples less than 0.05 mg/m³: 86
 Percent of samples less than 0.075 mg/m³: 100
 Percent of samples less than 0.1 mg/m³: 100

Figure A-84. Respirable quartz concentrations found
 in blasting operations (surface and
 underground) in the other stone industry
 group.



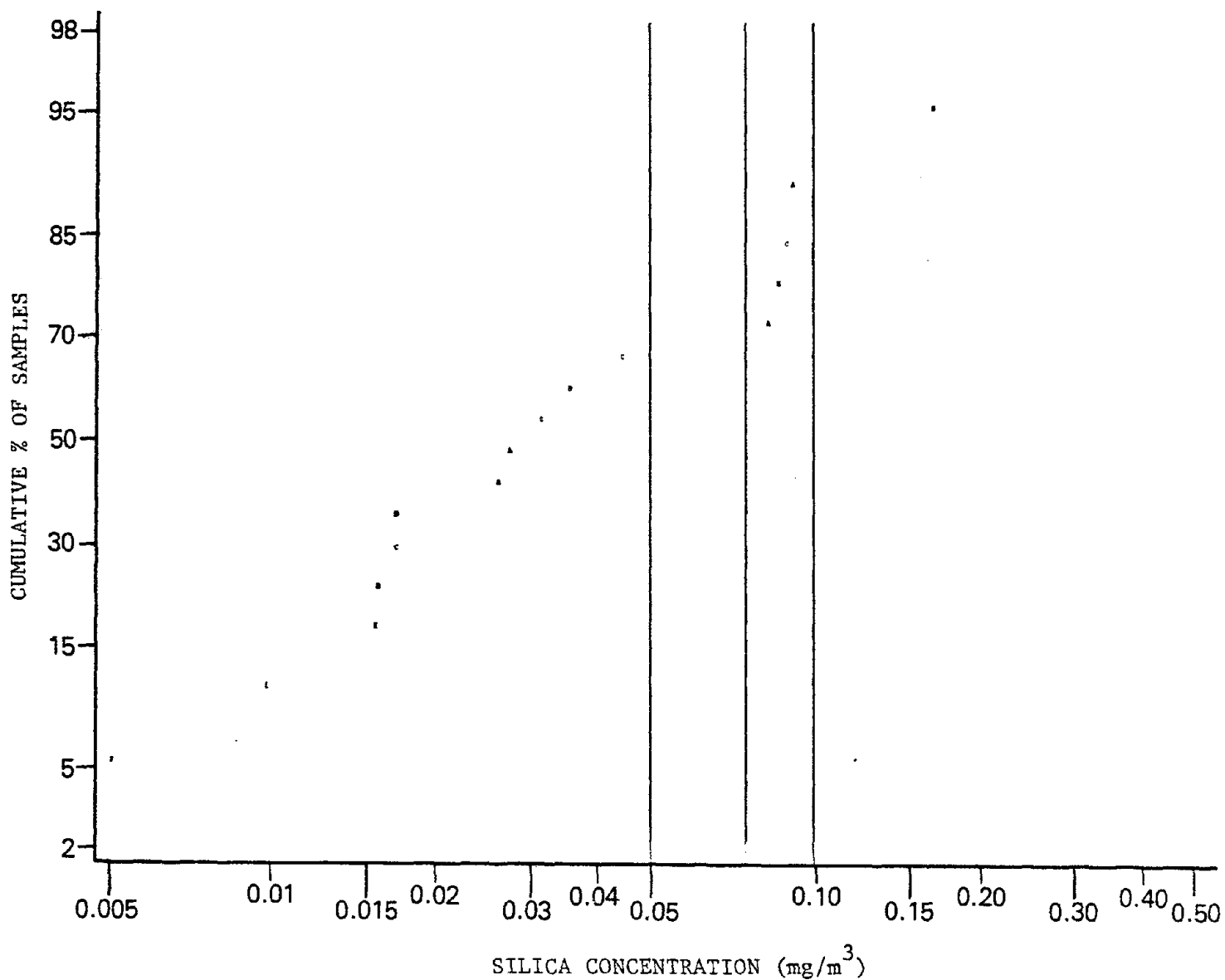
No. of samples: 151
 No. of mine ID's represented: 41
 No. of active sites in 1980: 832
 Percent of samples less than 0.05 mg/m³: 79
 Percent of samples less than 0.075 mg/m³: 89
 Percent of samples less than 0.1 mg/m³: 95

Figure A-85. Respirable quartz concentrations found in surface cutting and boring operations in the other stone industry group.



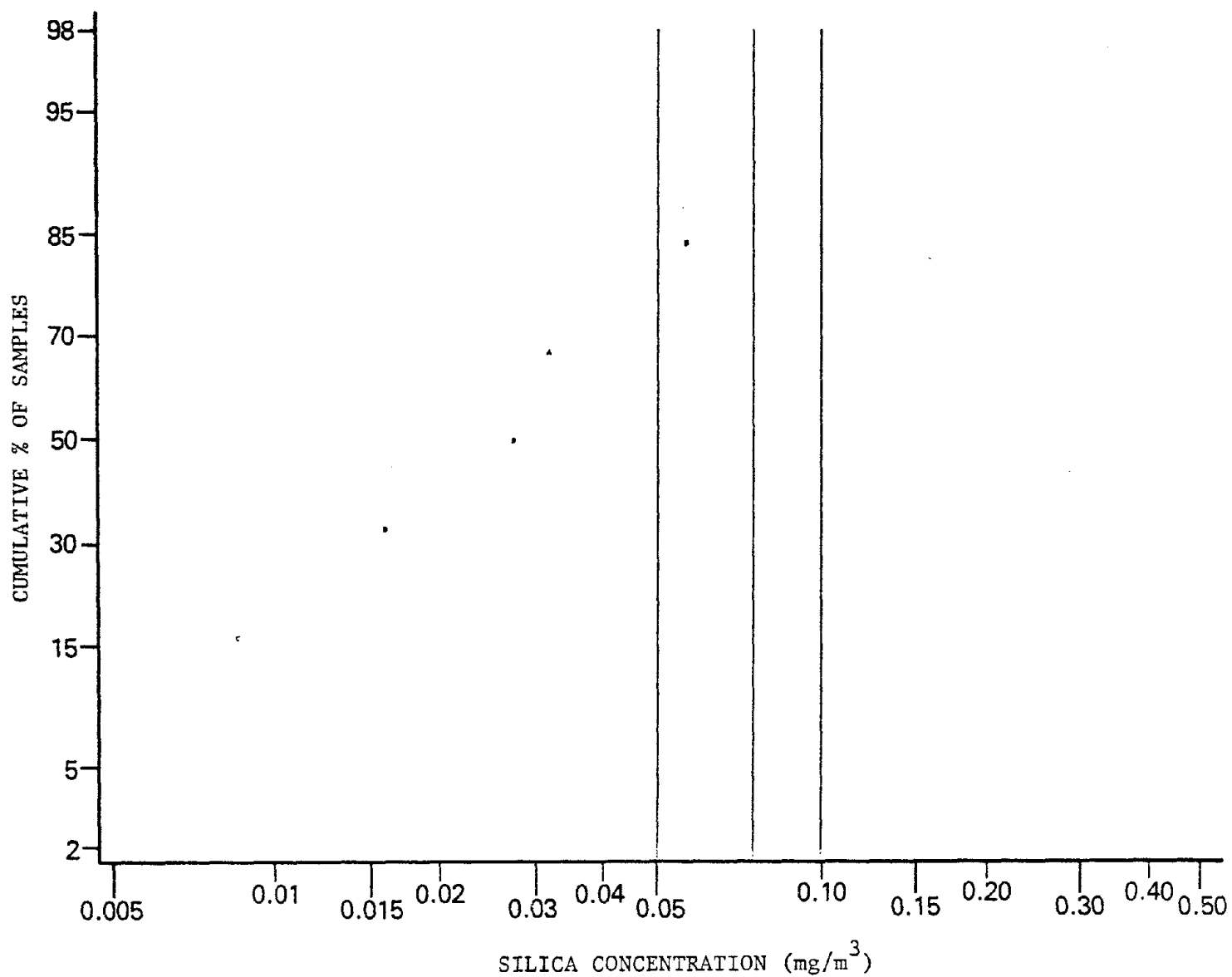
No. of samples: 796
No. of mine ID's represented: 220
No. of active sites in 1980: 832
Percent of samples less than 0.05 mg/m³: 57
Percent of samples less than 0.075 mg/m³: 69
Percent of samples less than 0.1 mg/m³: 76

Figure A-86. Respirable quartz concentrations found in surface drilling operations in the other stone industry group.



No. of samples: 17
 No. of mine ID's represented: 6
 No. of active sites in 1980: 15
 Percent of samples less than 0.05 mg/m³: 65
 Percent of samples less than 0.075 mg/m³: 65
 Percent of samples less than 0.1 mg/m³: 88

Figure A-87. Respirable quartz concentrations found in underground drilling operations in the other stone industry group.



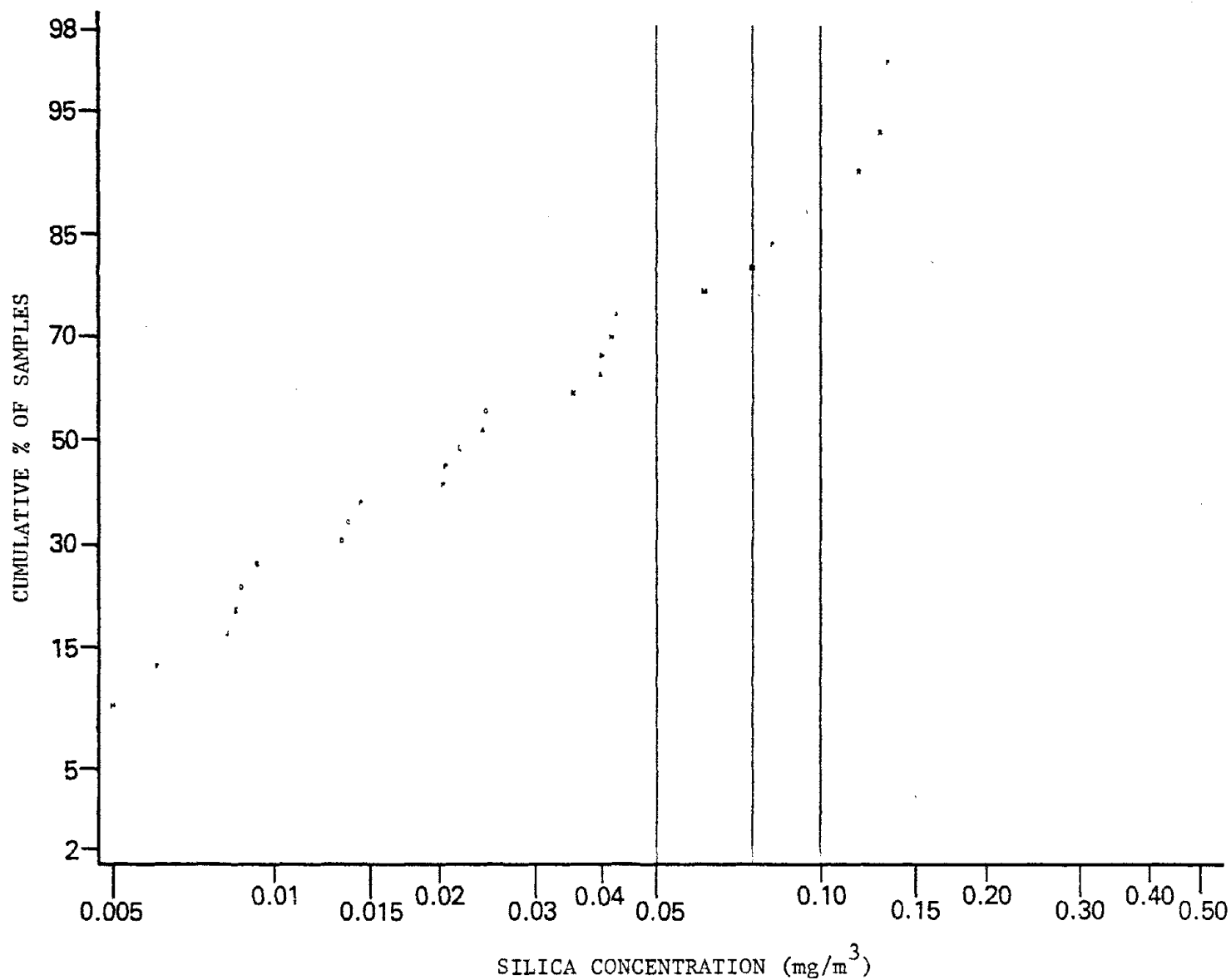
No. of samples: 6
 No. of mine ID's represented: 3
 No. of active sites in 1980: 832
 Percent of samples less than 0.05 mg/m³: 67
 Percent of samples less than 0.075 mg/m³: 83
 Percent of samples less than 0.1 mg/m³: 83

Figure A-88. Respirable quartz concentrations found in surface haulage maintenance operations in the other stone industry group.

Respirable quartz sample data (mg/m ³ silica)	Establishment (mine ID)
0.0669	598
0.0910	598
0.1788	598

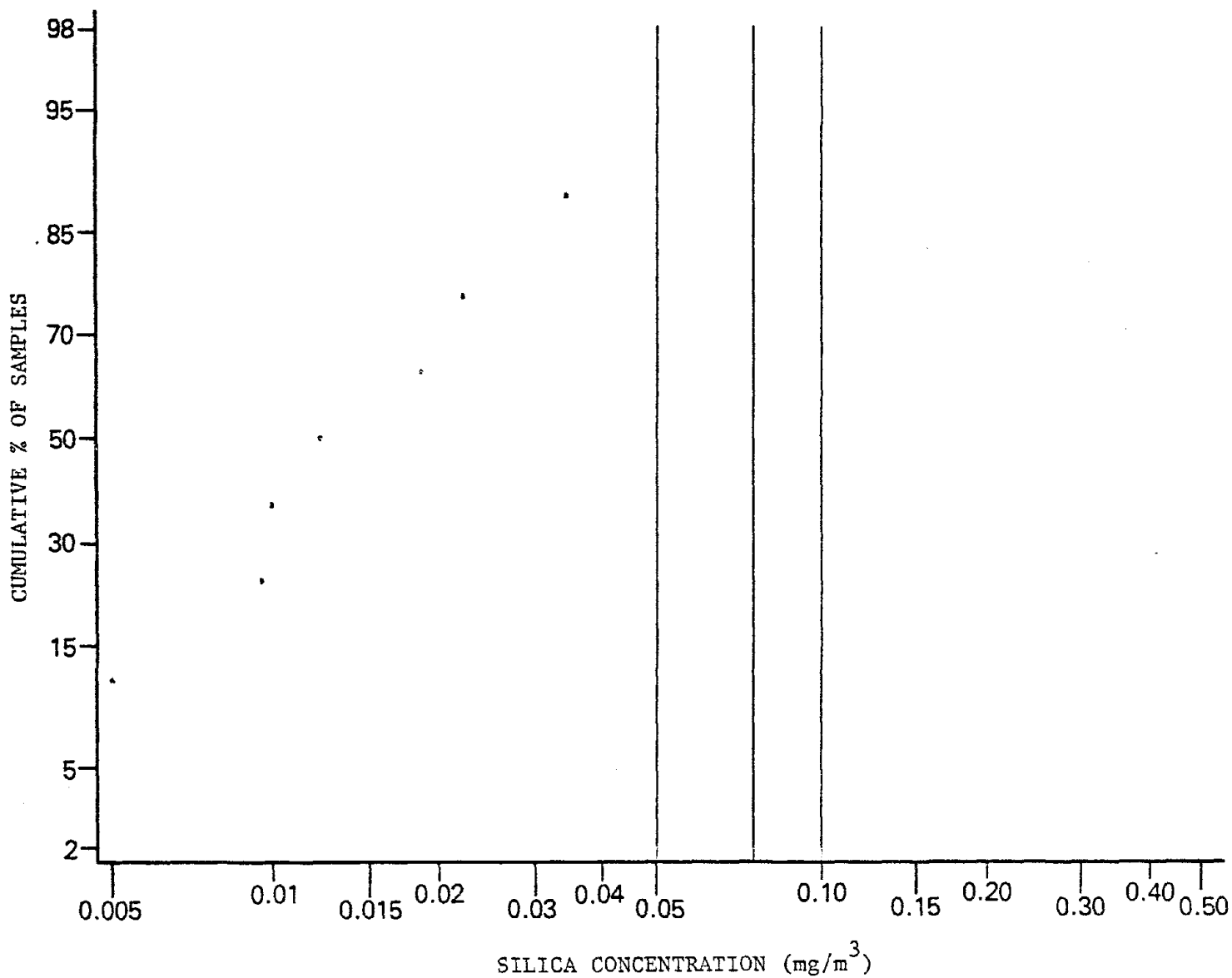
No. of samples: 3
 No. of mine ID's represented: 1
 No. of active sites in 1980: 15
 Percent of samples less than 0.05 mg/m³: 0
 Percent of samples less than 0.075 mg/m³: 33
 Percent of samples less than 0.1 mg/m³: 67

Figure A-89. Respirable quartz concentrations found in underground haulageway maintenance operations in the other stone industry group.



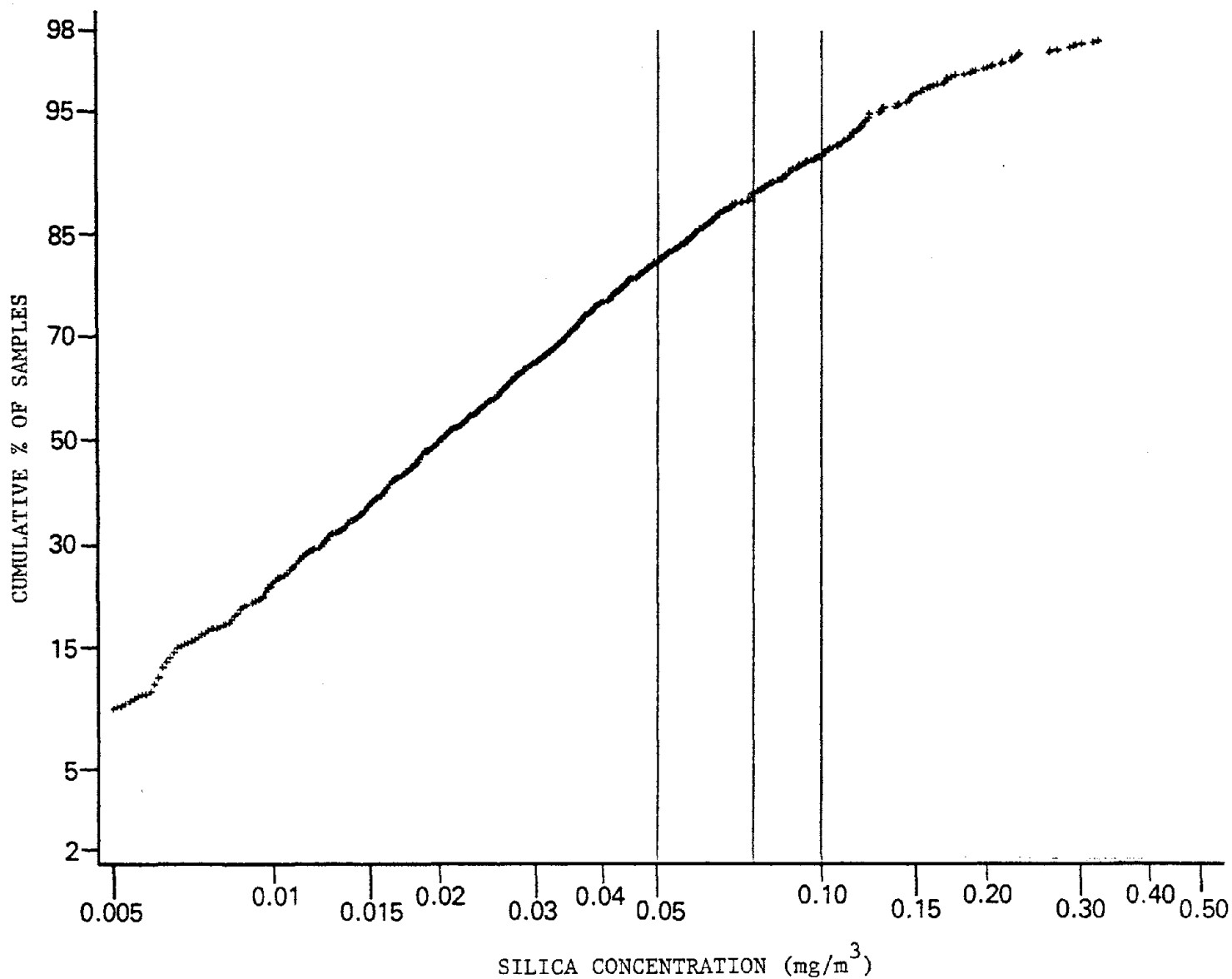
No. of samples: 29
 No. of mine ID's represented: 18
 No. of active sites in 1980: 832
 Percent of samples less than 0.05 mg/m³: 72
 Percent of samples less than 0.075 mg/m³: 79
 Percent of samples less than 0.1 mg/m³: 86

Figure A-90. Respirable quartz concentrations found in surface production operations in the other stone industry group.



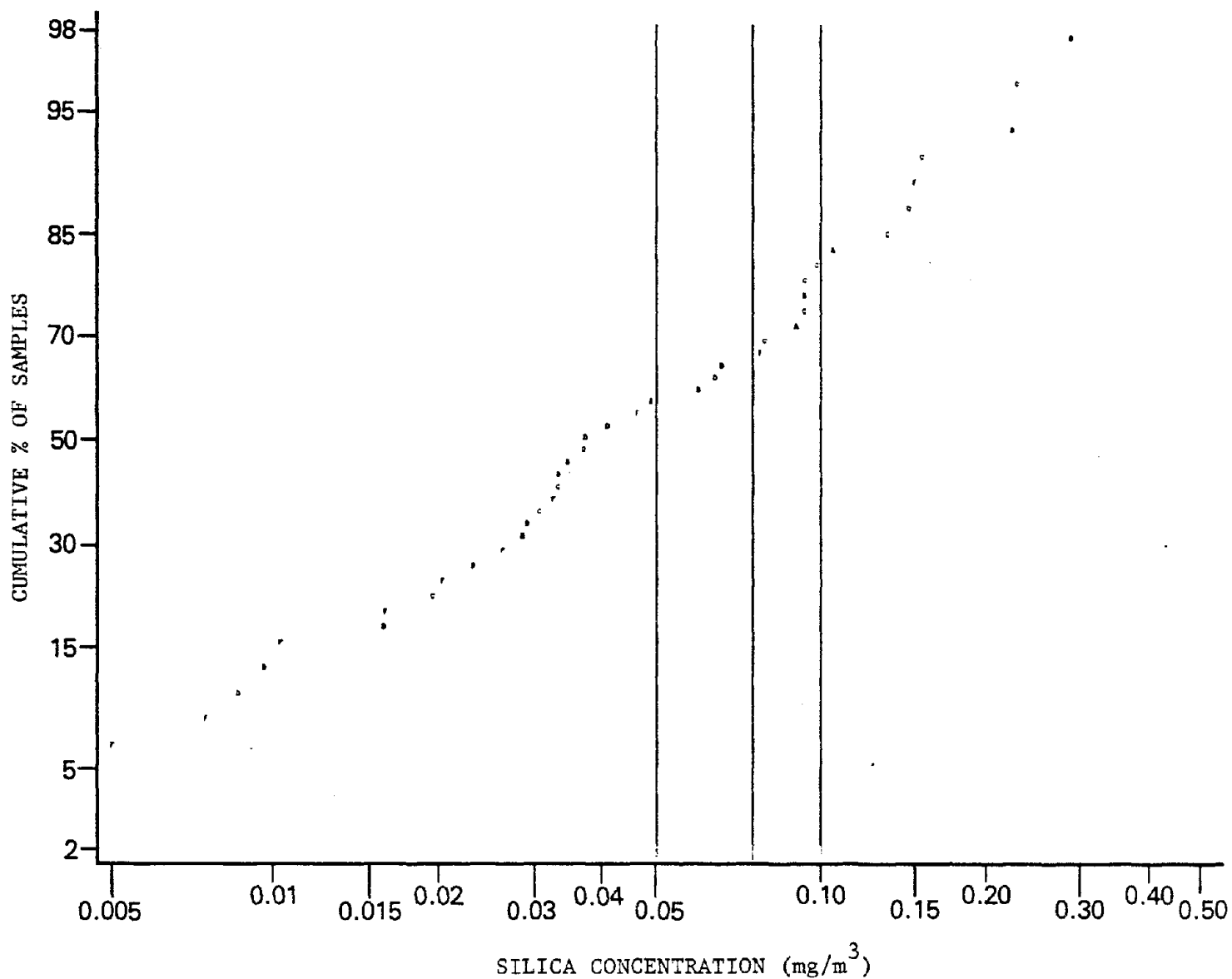
No. of samples: 8
No. of mine ID's represented: 3
No. of active sites in 1980: 15
Percent of samples less than 0.05 mg/m³: 100
Percent of samples less than 0.075 mg/m³: 100
Percent of samples less than 0.1 mg/m³: 100

Figure A-91. Respirable quartz concentrations found in underground production operations in the other stone industry group.



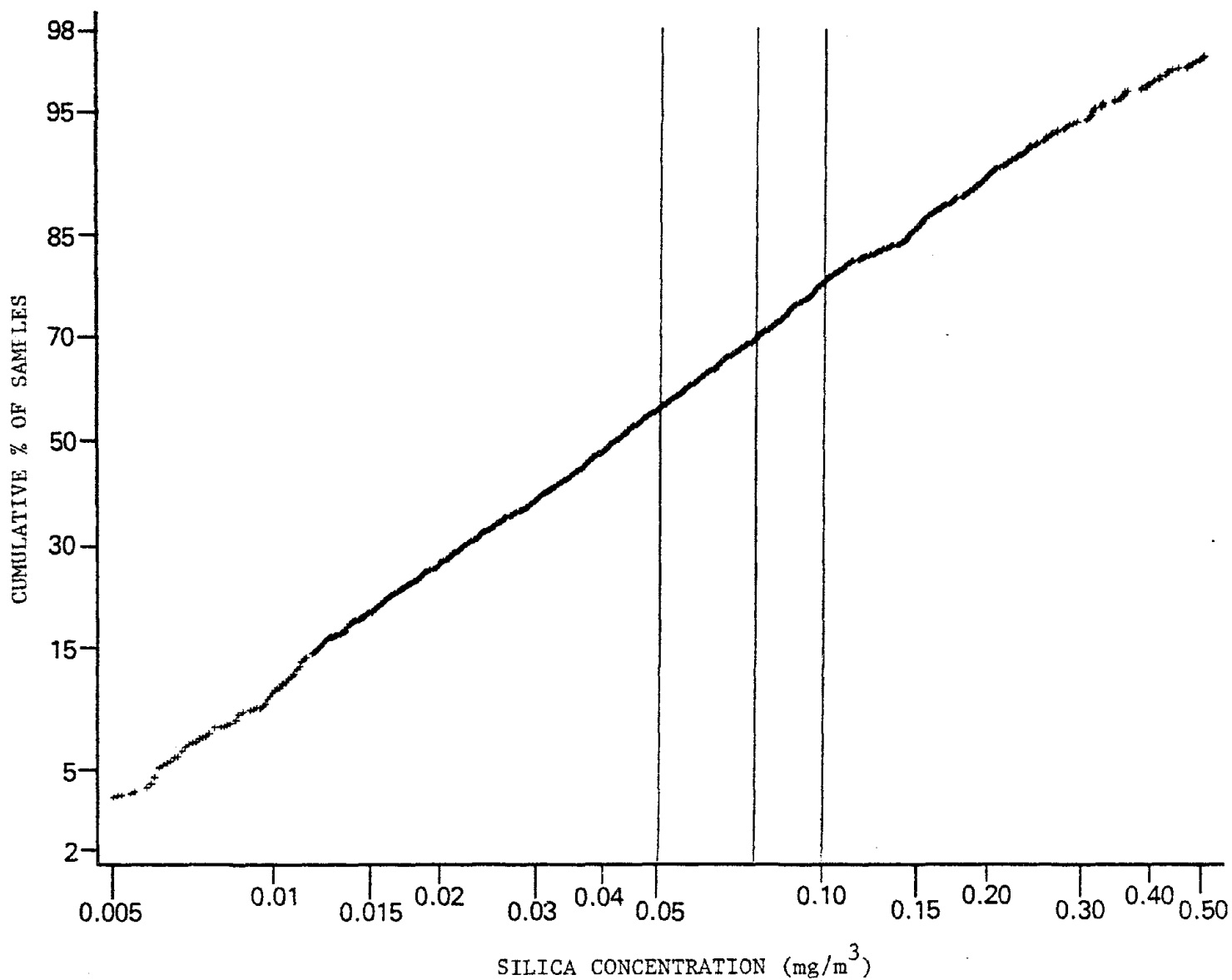
No. of samples: 1554
No. of mine ID's represented: 370
No. of active sites in 1980: 832
Percent of samples less than 0.05 mg/m³: 81
Percent of samples less than 0.075 mg/m³: 88
Percent of samples less than 0.1 mg/m³: 92

Figure A-92. Respirable quartz concentrations found in surface mobile transport operations in the other stone industry group.



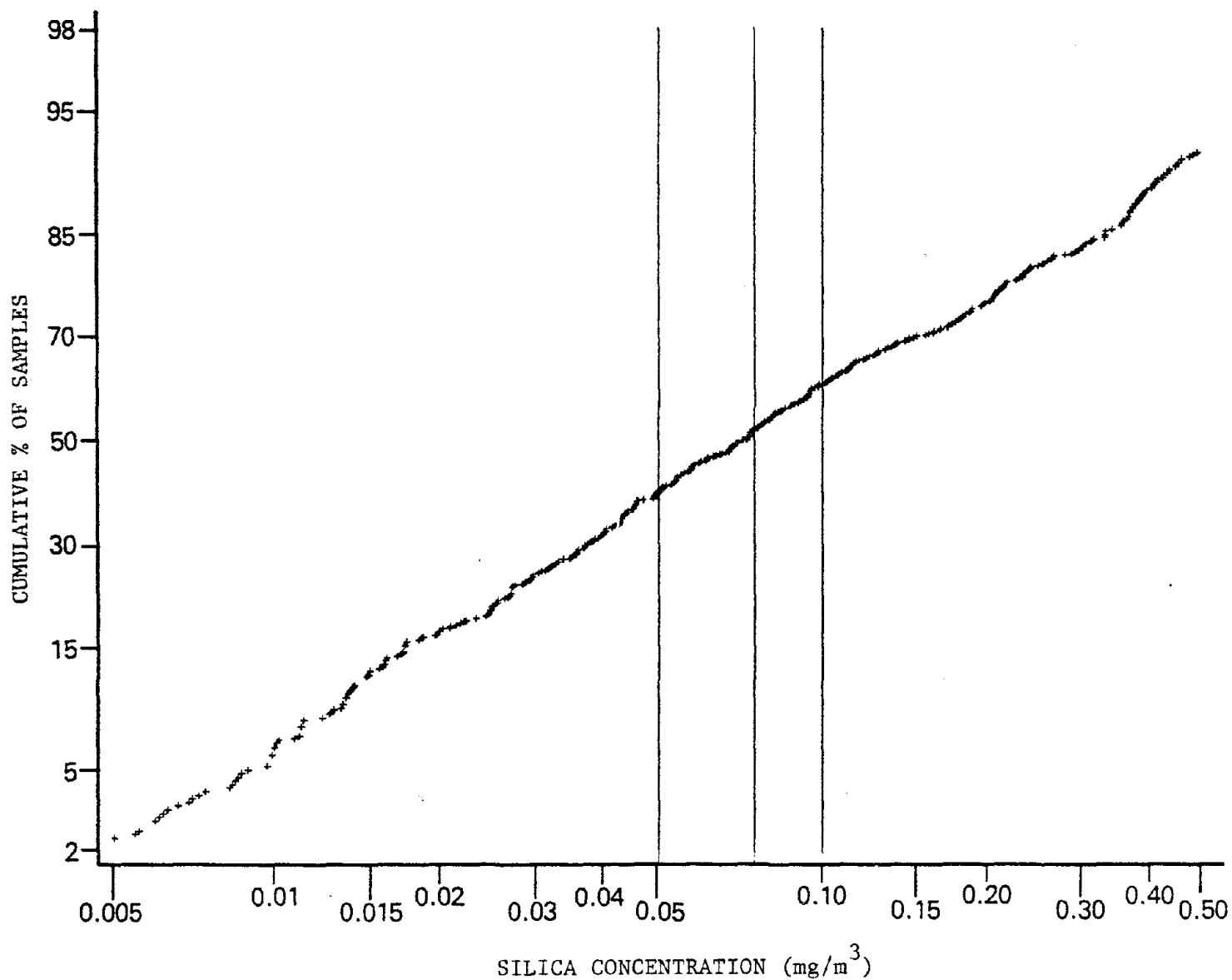
No. of samples: 44
 No. of mine ID's represented: 6
 No. of active sites in 1980: 15
 Percent of samples less than 0.05 mg/m³: 57
 Percent of samples less than 0.075 mg/m³: 64
 Percent of samples less than 0.1 mg/m³: 80

Figure A-93. Respirable quartz concentrations found in underground mobile transport operations in the other stone industry group.



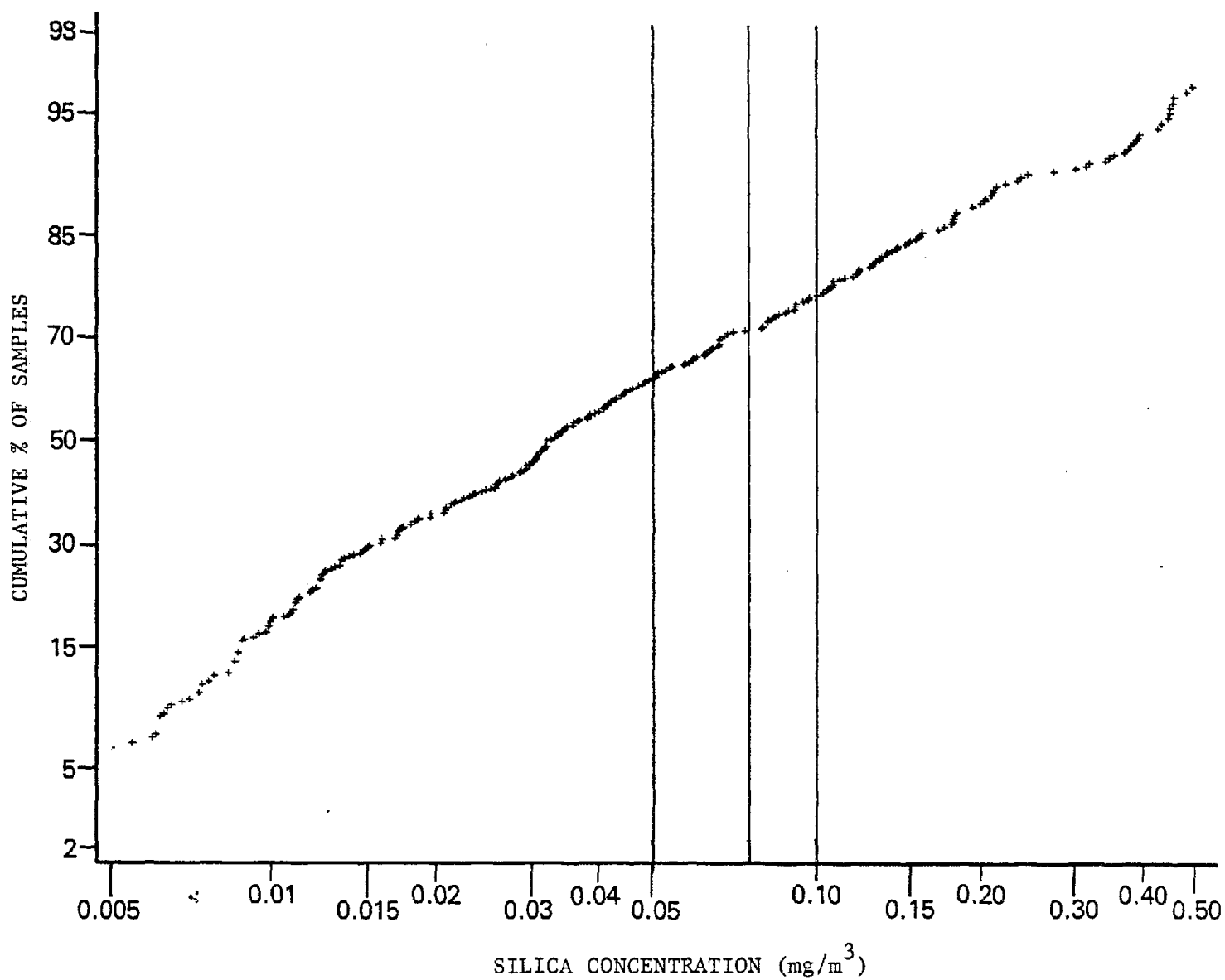
No. of samples: 1513
No. of mine ID's represented: 385
No. of active sites in 1980: 925
Percent of samples less than 0.05 mg/m³: 56
Percent of samples less than 0.075 mg/m³: 70
Percent of samples less than 0.1 mg/m³: 78

Figure A-94. Respirable quartz concentrations found in crushing, grinding, and sizing operations (surface and underground) in the other stone industry group.



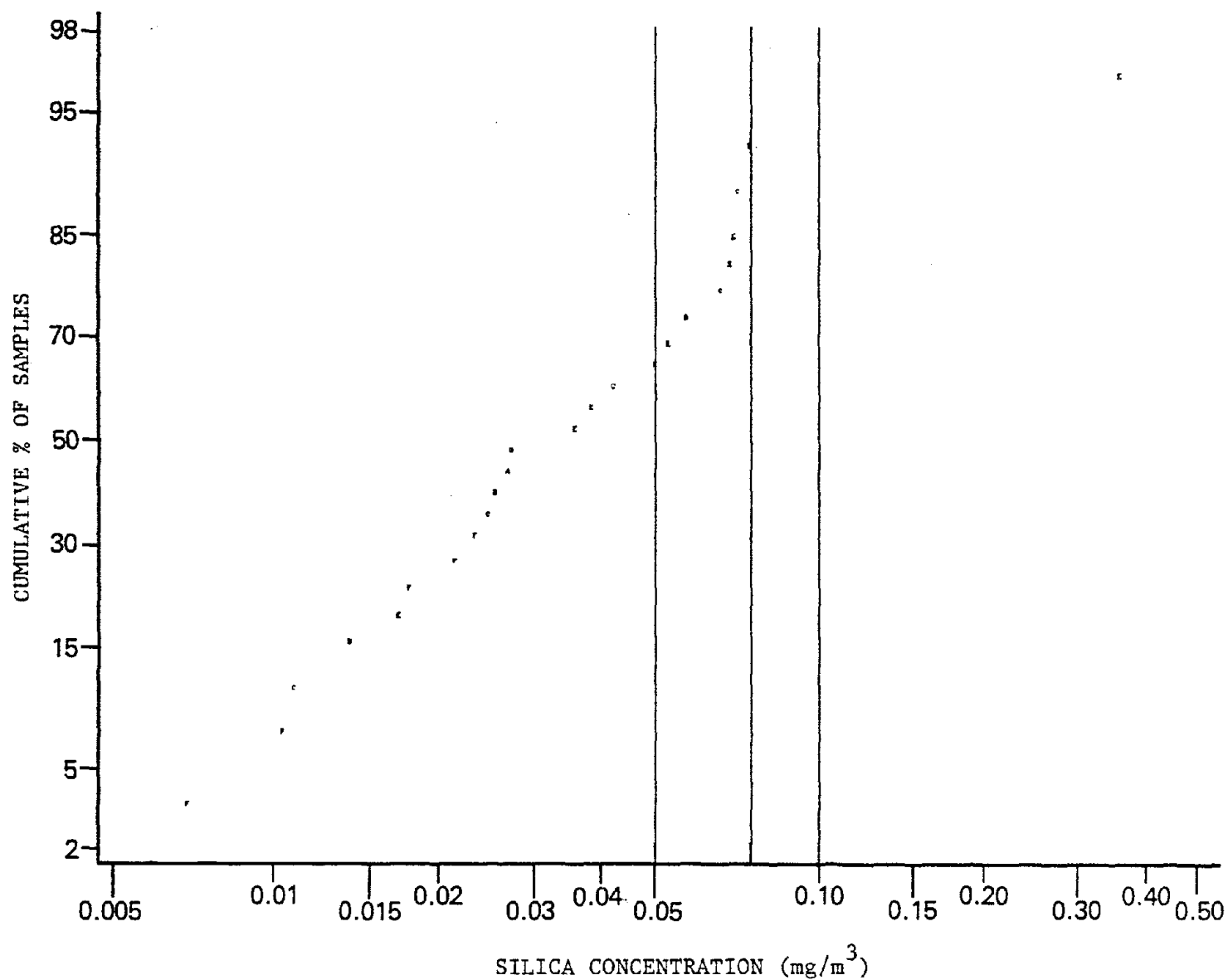
No. of samples: 549
 No. of mine ID's represented: 66
 No. of active sites in 1980: 925
 Percent of samples less than 0.05 mg/m³: 40
 Percent of samples less than 0.075 mg/m³: 52
 Percent of samples less than 0.1 mg/m³: 61

Figure A-95. Respirable quartz concentrations found in concentrating and finishing operations (surface and underground) in the other stone industry group.



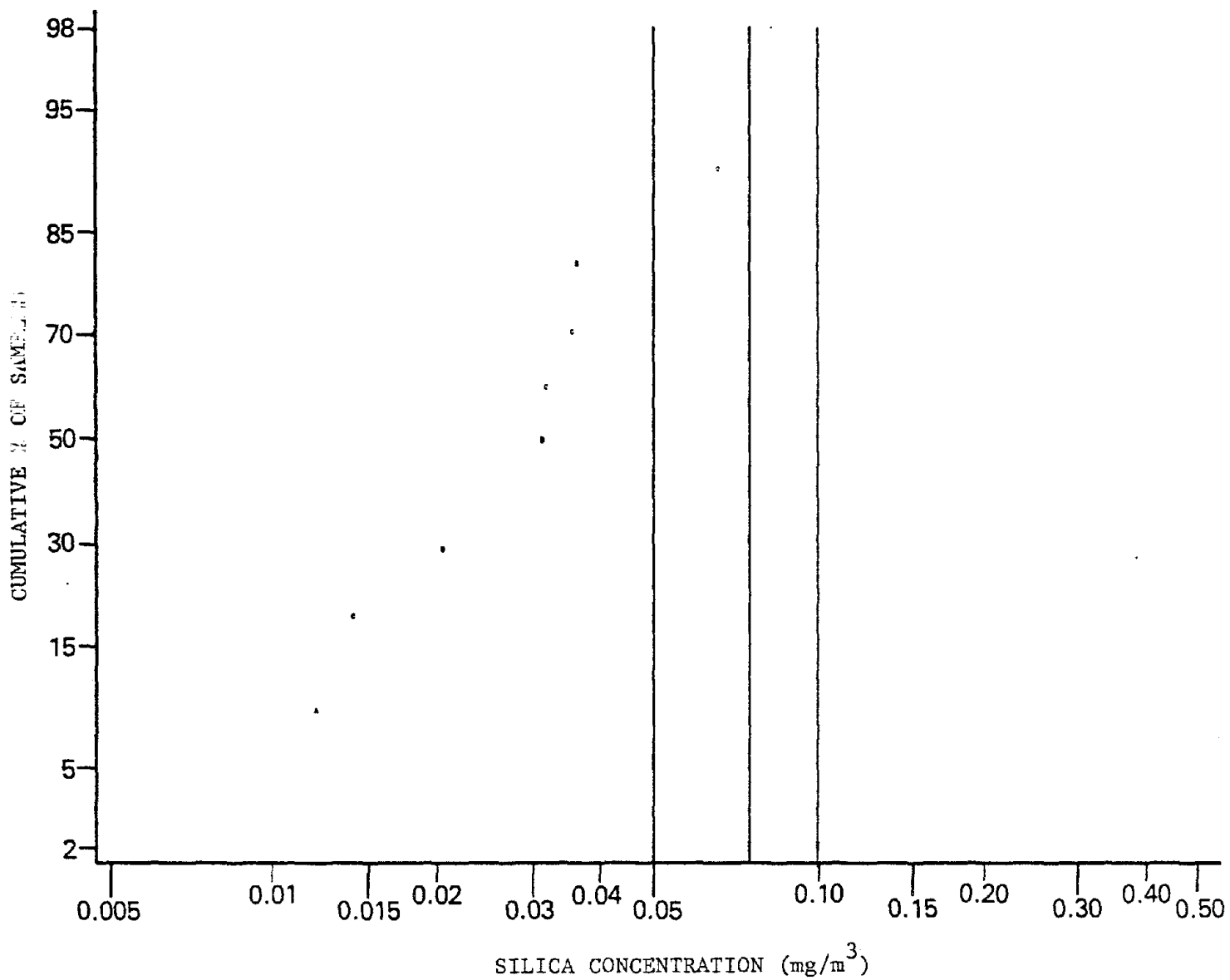
No. of samples: 386
 No. of mine ID's represented: 92
 No. of active sites in 1980: 507
 Percent of samples less than 0.05 mg/m³: 61
 Percent of samples less than 0.075 mg/m³: 70
 Percent of samples less than 0.1 mg/m³: 75

Figure A-96. Respirable quartz concentrations found in nonspecific surface operations in the clay and shale industry group.



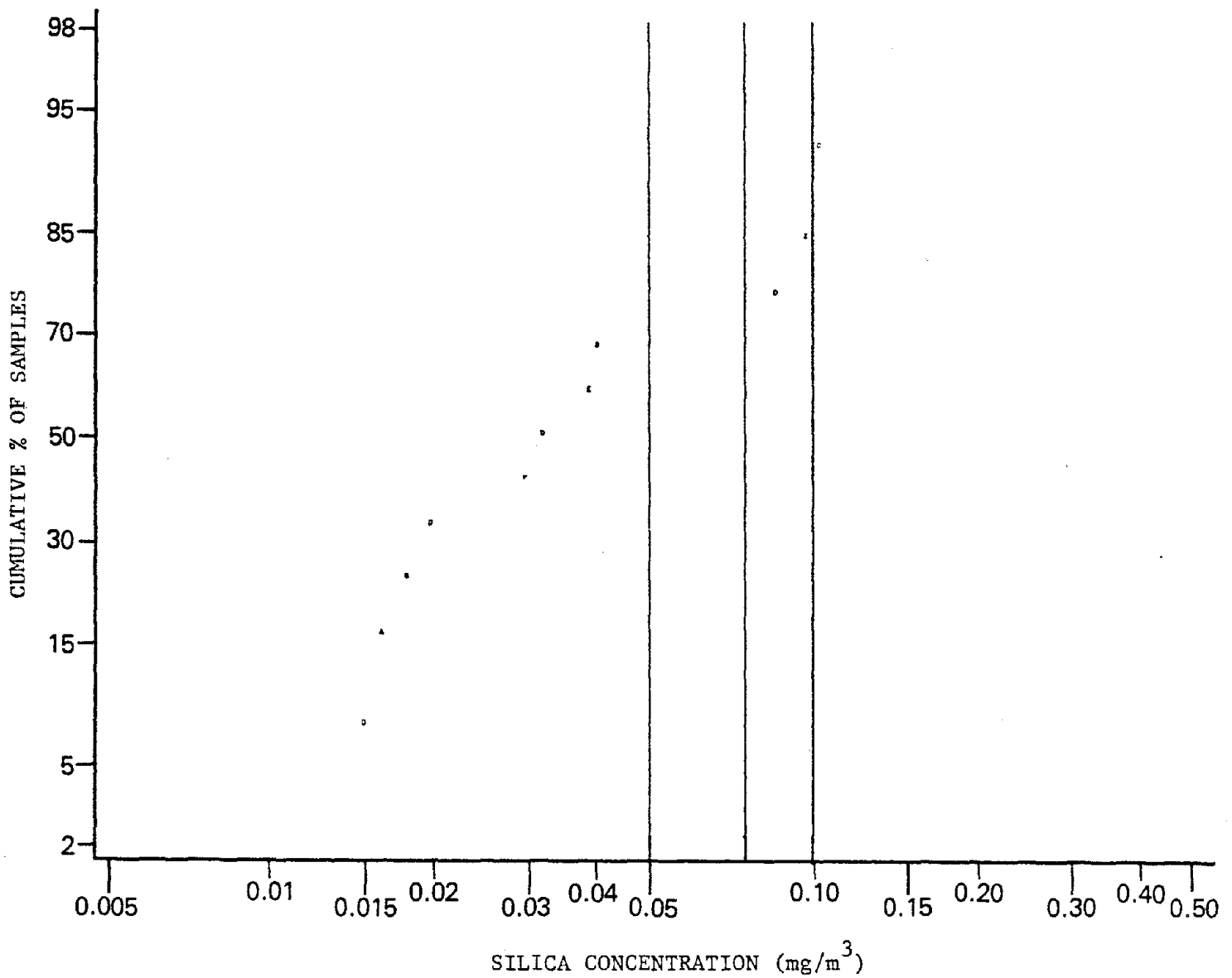
No. of samples: 25
 No. of mine ID's represented: 6
 No. of active sites in 1980: 14
 Percent of samples less than 0.05 mg/m³: 64
 Percent of samples less than 0.075 mg/m³: 92
 Percent of samples less than 0.1 mg/m³: 92

Figure A-97. Respirable quartz concentrations found in nonspecific underground operations in the clay and shale industry group.



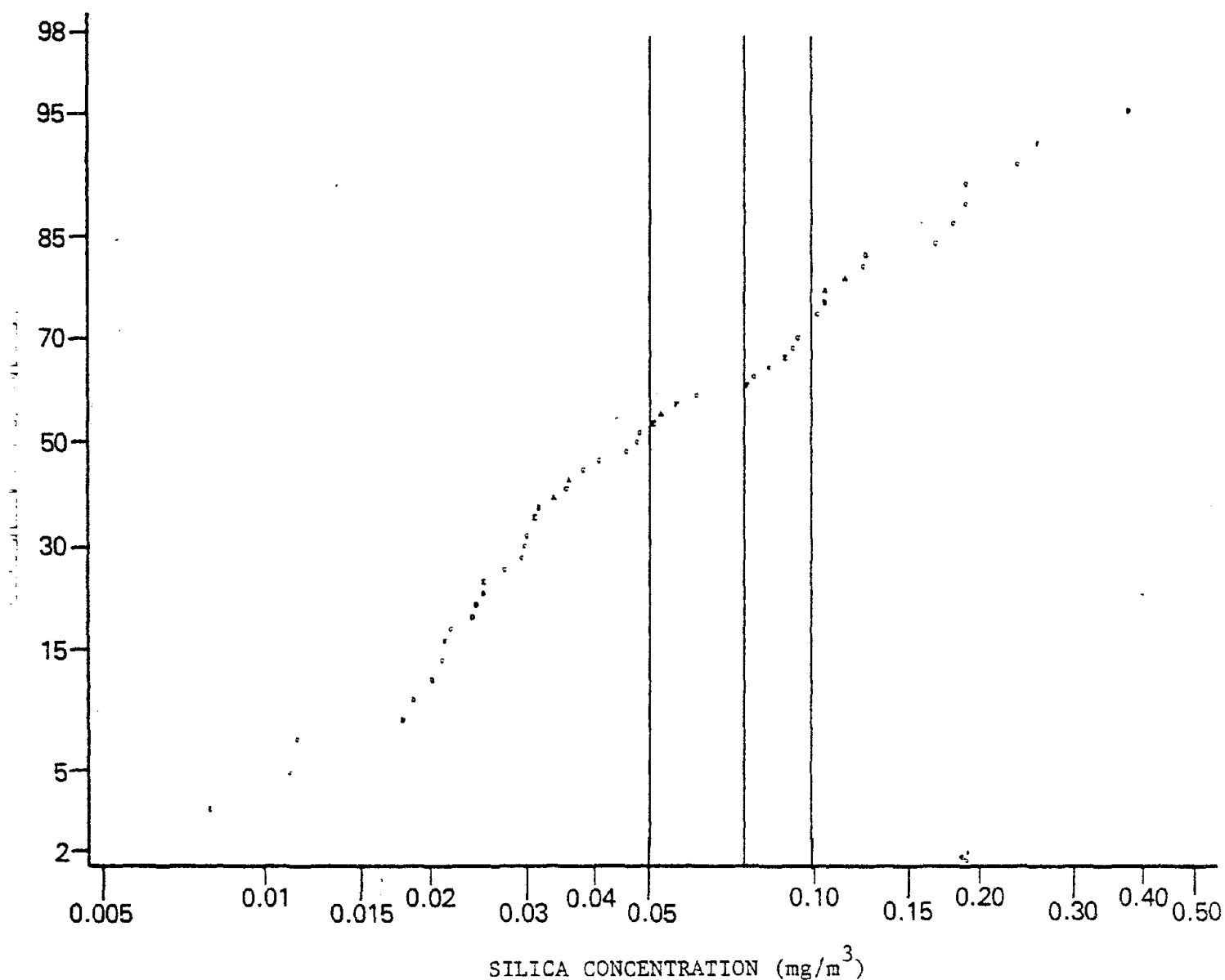
No. of samples: 10
 No. of mine ID's represented: 3
 No. of active sites in 1980: 507
 Percent of samples less than 0.05 mg/m³: 80
 Percent of samples less than 0.075 mg/m³: 90
 Percent of samples less than 0.1 mg/m³: 90

Figure A-98. Respirable quartz concentrations
 found in blasting operations
 (surface and underground) in the
 clay and shale industry group.



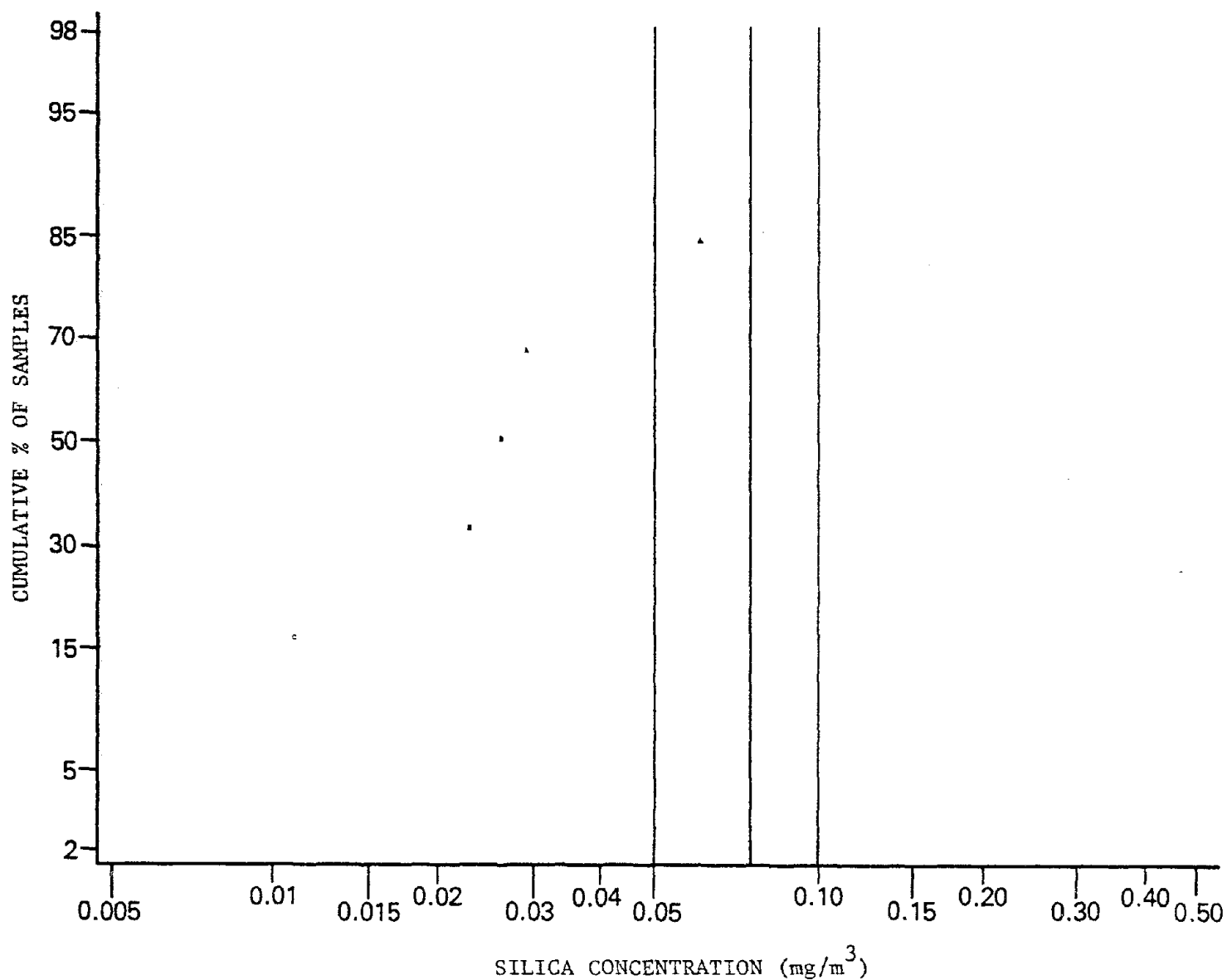
No. of samples: 12
 No. of mine ID's represented: 7
 No. of active sites in 1980: 421
 Percent of samples less than 0.05 mg/m³: 67
 Percent of samples less than 0.075 mg/m³: 67
 Percent of samples less than 0.1 mg/m³: 83

Figure A-99. Respirable quartz concentrations
 found in surface drilling operations
 in the clay and shale industry group.



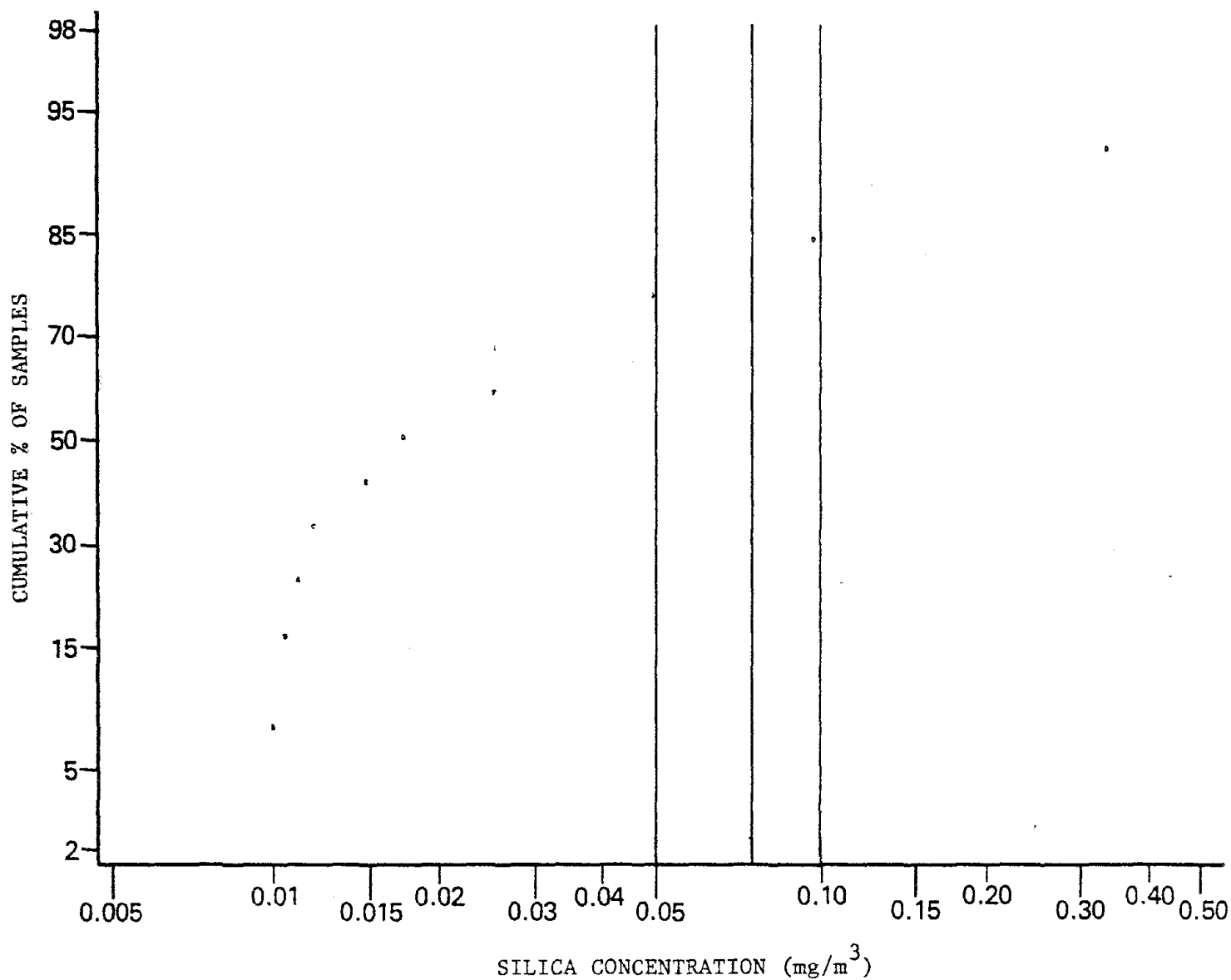
No. of samples: 56
 No. of mine ID's represented: 7
 No. of active sites in 1980: 14
 Percent of samples less than $0.05 \text{ mg}/\text{m}^3$: 52
 Percent of samples less than $0.075 \text{ mg}/\text{m}^3$: 59
 Percent of samples less than $0.1 \text{ mg}/\text{m}^3$: 70

Figure A-100. Respirable quartz concentrations found in underground drilling operations in the clay and shale industry group.



No. of samples: 6
No. of mine ID's represented: 3
No. of active sites in 1980: 14
Percent of samples less than 0.05 mg/m³: 67
Percent of samples less than 0.075 mg/m³: 83
Percent of samples less than 0.1 mg/m³: 100

Figure A-101. Respirable quartz concentrations found in underground haulageway maintenance operations in the clay and shale industry group.



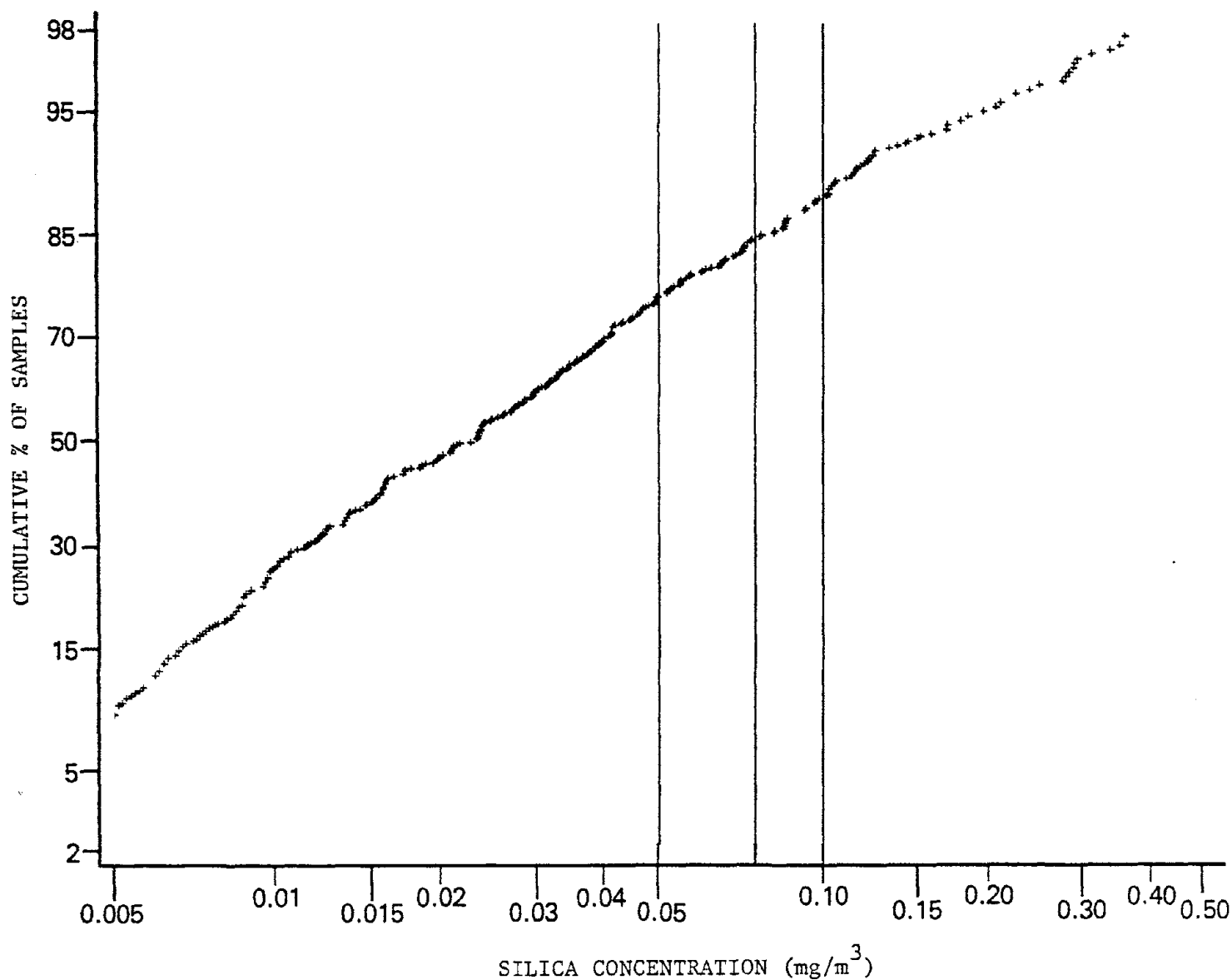
No. of samples: 12
No. of mine ID's represented: 9
No. of active sites in 1980: 421
Percent of samples less than 0.05 mg/m³: 75
Percent of samples less than 0.075 mg/m³: 75
Percent of samples less than 0.1 mg/m³: 83

Figure A-102. Respirable quartz concentrations found in surface production operations in the clay and shale industry group.

Respirable quartz sample data (mg/m ³ silica)	Establishment
0.0073	168
0.0241	616
0.0794	616
0.2328	616

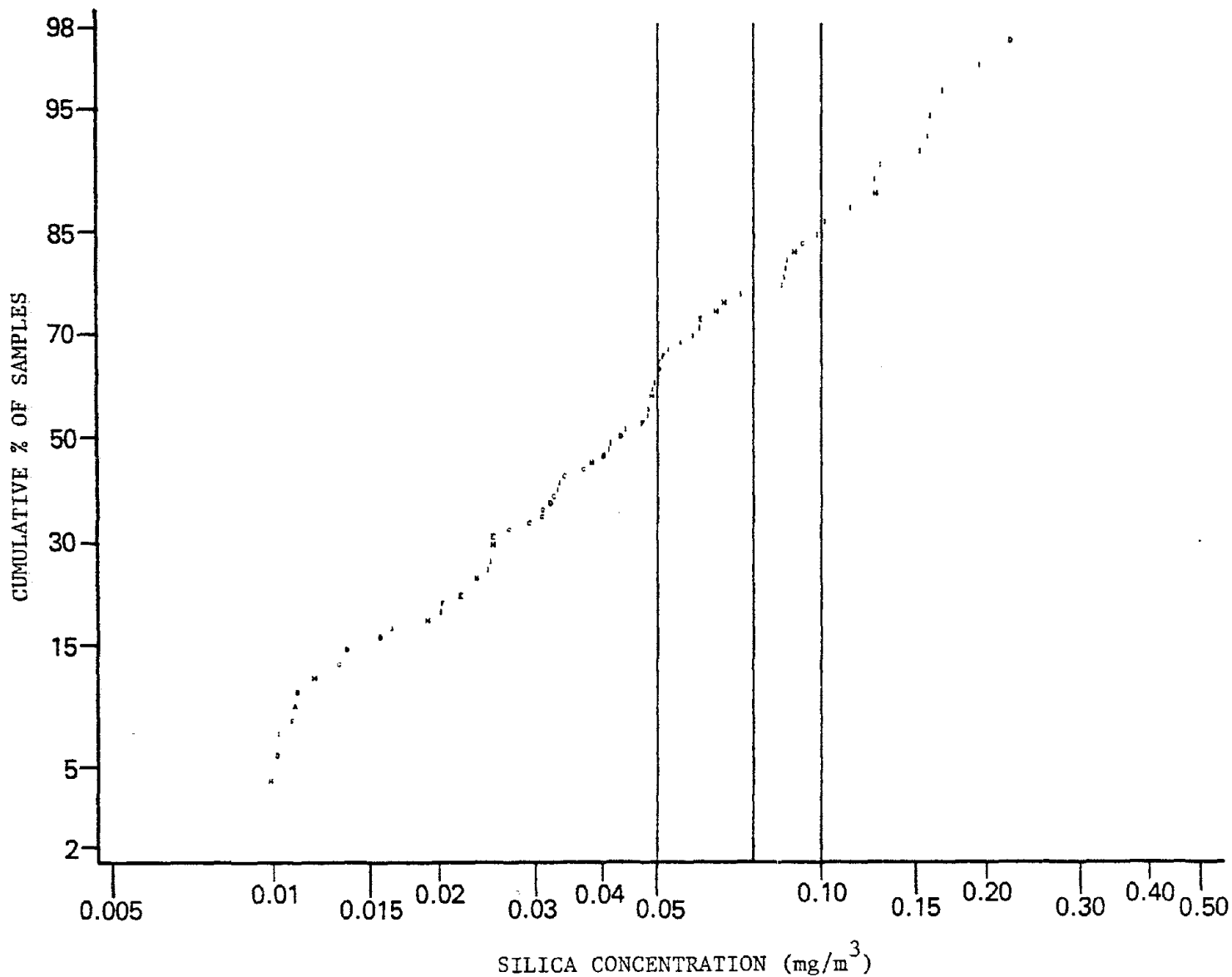
No. of samples: 4
 No. of mine ID's represented: 2
 No. of active sites in 1980: 14
 Percent of samples less than 0.05 mg/m³: 50
 Percent of samples less than 0.075 mg/m³: 50
 Percent of samples less than 0.1 mg/m³: 75

Figure A-103. Respirable quartz concentrations found in underground production operations in the clay and shale industry group.



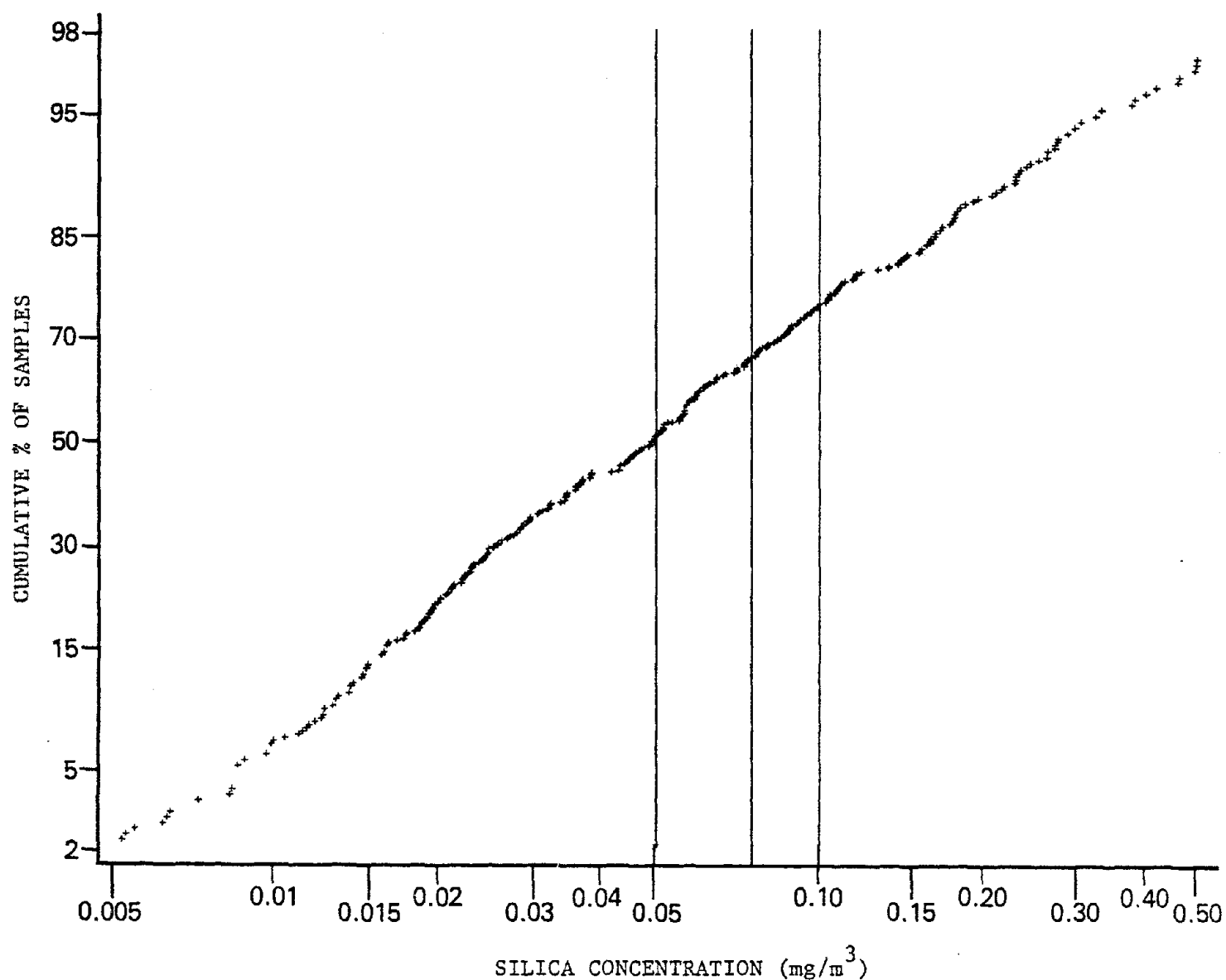
No. of samples: 454
 No. of mine ID's represented: 163
 No. of active sites in 1980: 421
 Percent of samples less than 0.05 mg/m³: 75
 Percent of samples less than 0.075 mg/m³: 83
 Percent of samples less than 0.1 mg/m³: 87

Figure A-104. Respirable quartz concentrations found in surface mobile transport operations in the clay and shale industry group.



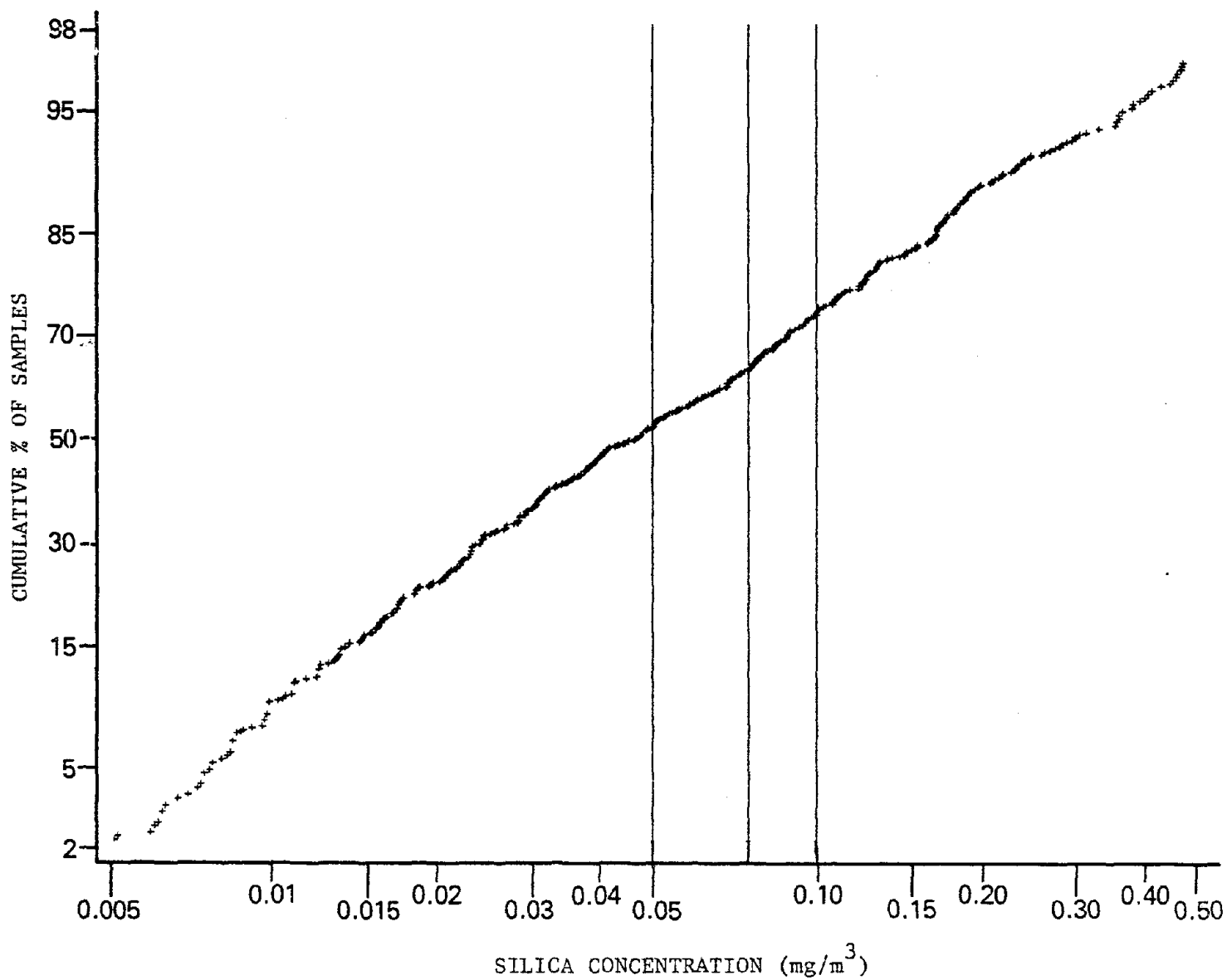
No. of samples: 80
 No. of mine ID's represented: 10
 No. of active sites in 1980: 14
 Percent of samples less than 0.05 mg/m³: 60
 Percent of samples less than 0.075 mg/m³: 75
 Percent of samples less than 0.1 mg/m³: 84

Figure A-105. Respirable quartz concentrations
 found in underground mobile
 transport operations in the
 clay and shale industry group.



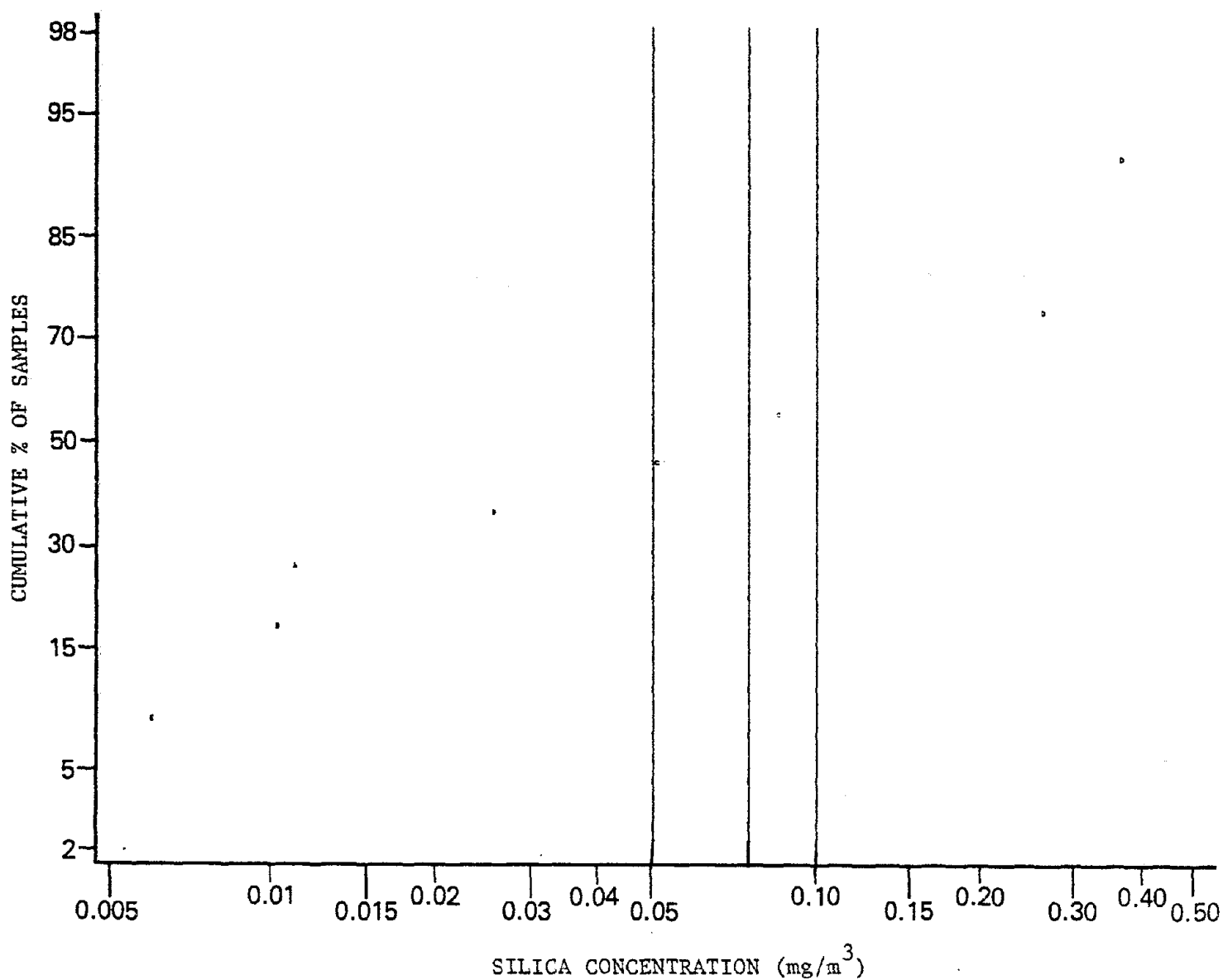
No. of samples: 353
 No. of mine ID's represented: 147
 No. of active sites in 1980: 507
 Percent of samples less than 0.05 mg/m³: 51
 Percent of samples less than 0.075 mg/m³: 66
 Percent of samples less than 0.1 mg/m³: 74

Figure A-106. Respirable quartz concentrations found in crushing, grinding, and sizing operations (surface and underground) in the clay and shale industry group.



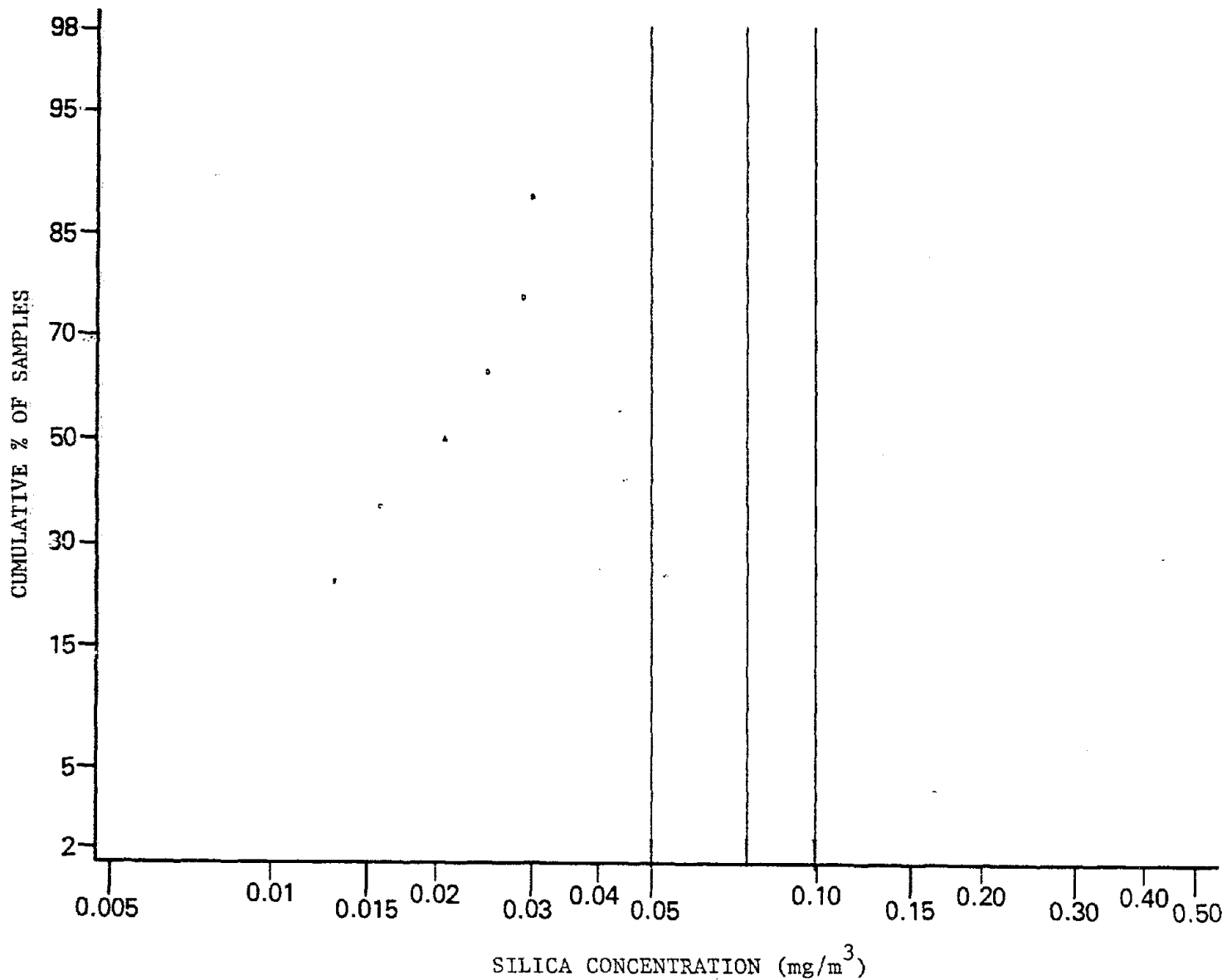
No. of samples: 573
 No. of mine ID's represented: 89
 No. of active sites in 1980: 507
 Percent of samples less than 0.05 mg/m³: 52
 Percent of samples less than 0.075 mg/m³: 63
 Percent of samples less than 0.1 mg/m³: 72

Figure A-107. Respirable quartz concentrations found in concentrating and finishing operations (surface and underground) in the clay and shale industry group.



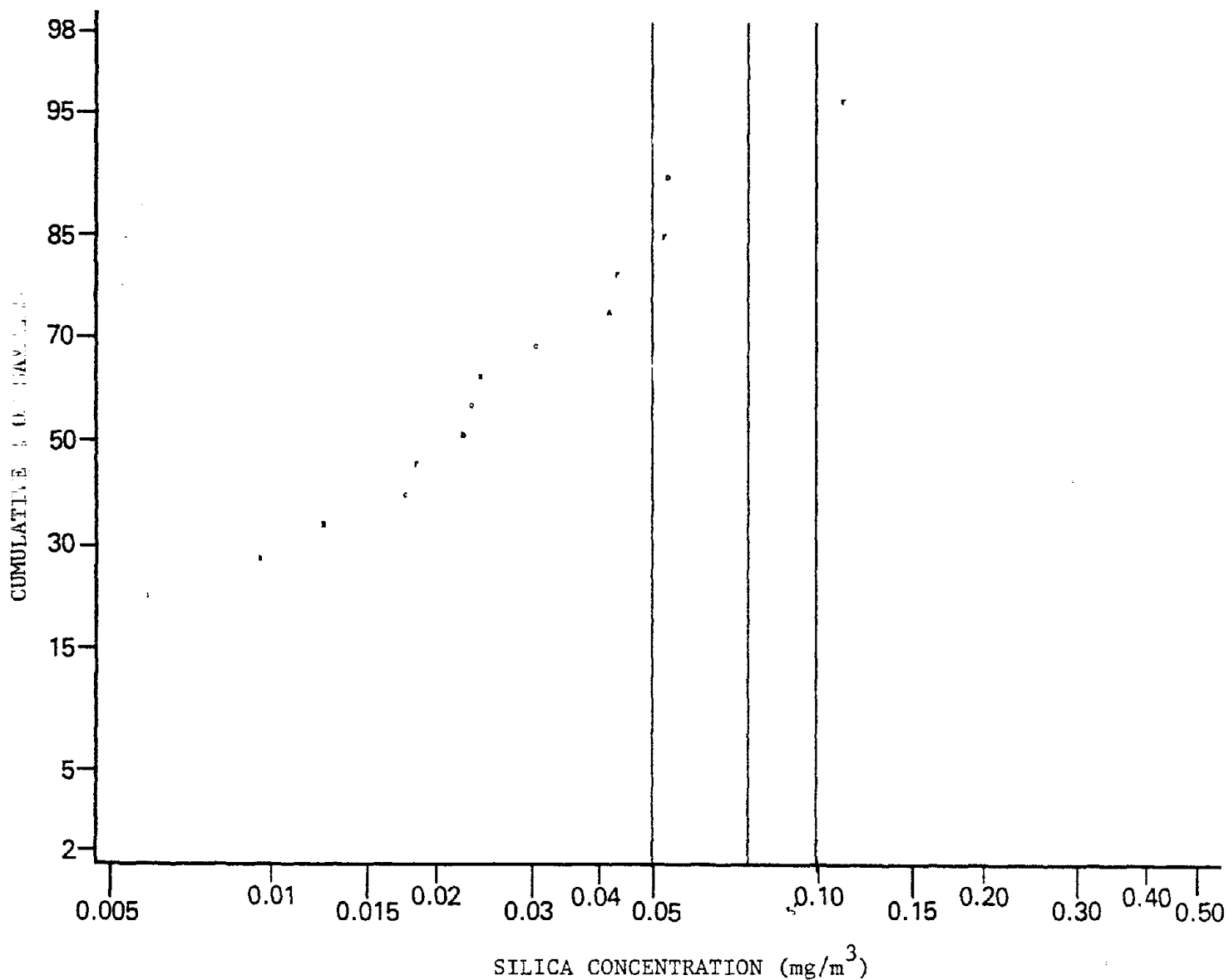
No. of samples: 11
 No. of mine ID's represented: 5
 No. of active sites in 1980: 49
 Percent of samples less than 0.05 mg/m³: 36
 Percent of samples less than 0.075 mg/m³: 45
 Percent of samples less than 0.1 mg/m³: 55

Figure A-108. Respirable quartz concentrations found in nonspecific surface operations in the talc, etc. industry group.



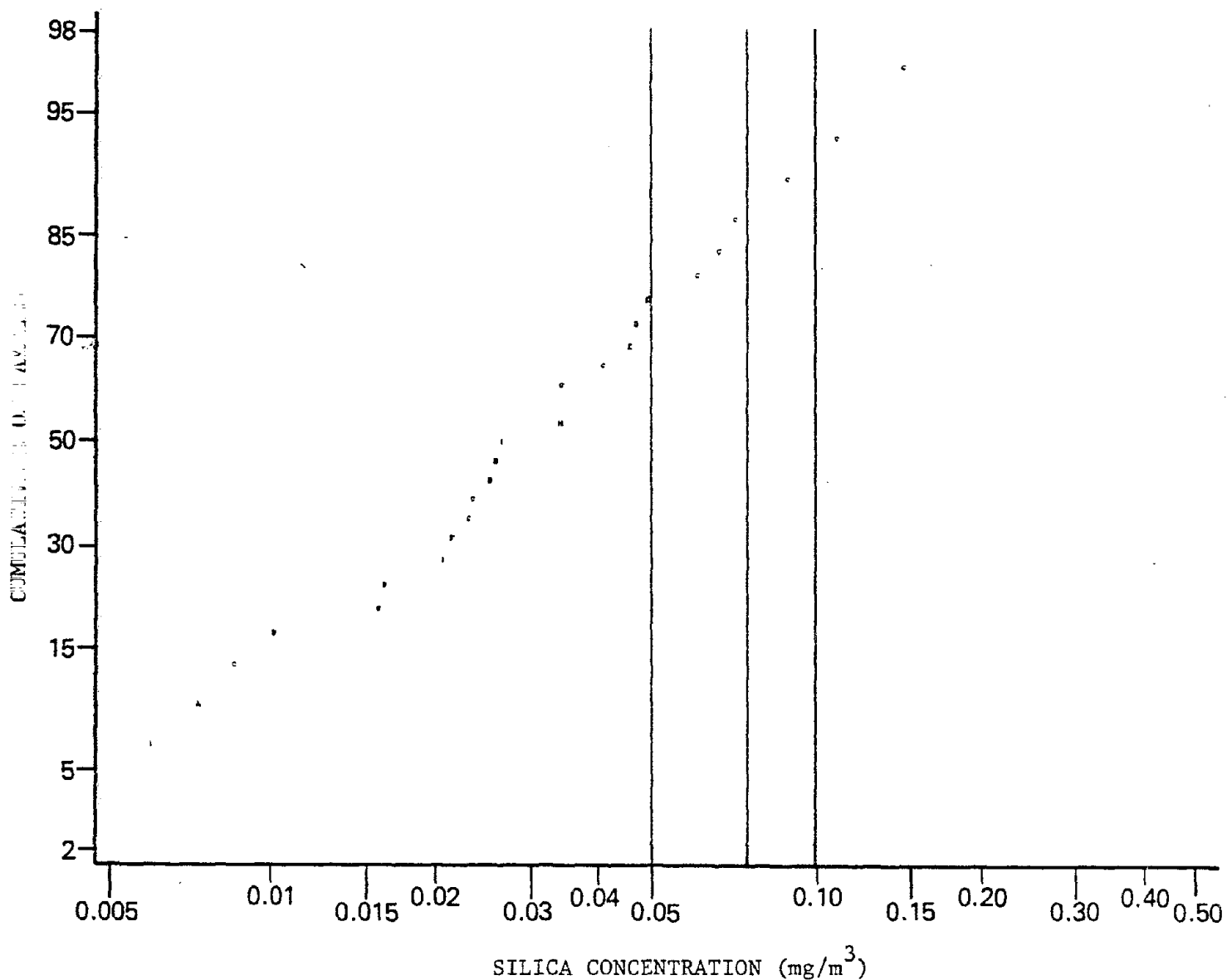
No. of samples: 8
 No. of mine ID's represented: 6
 No. of active sites in 1980: 25
 Percent of samples less than 0.05 mg/m³: 88
 Percent of samples less than 0.075 mg/m³: 88
 Percent of samples less than 0.1 mg/m³: 100

Figure A-109. Respirable quartz concentrations
 found in surface mobile transport
 operations in the talc, etc.
 industry group.



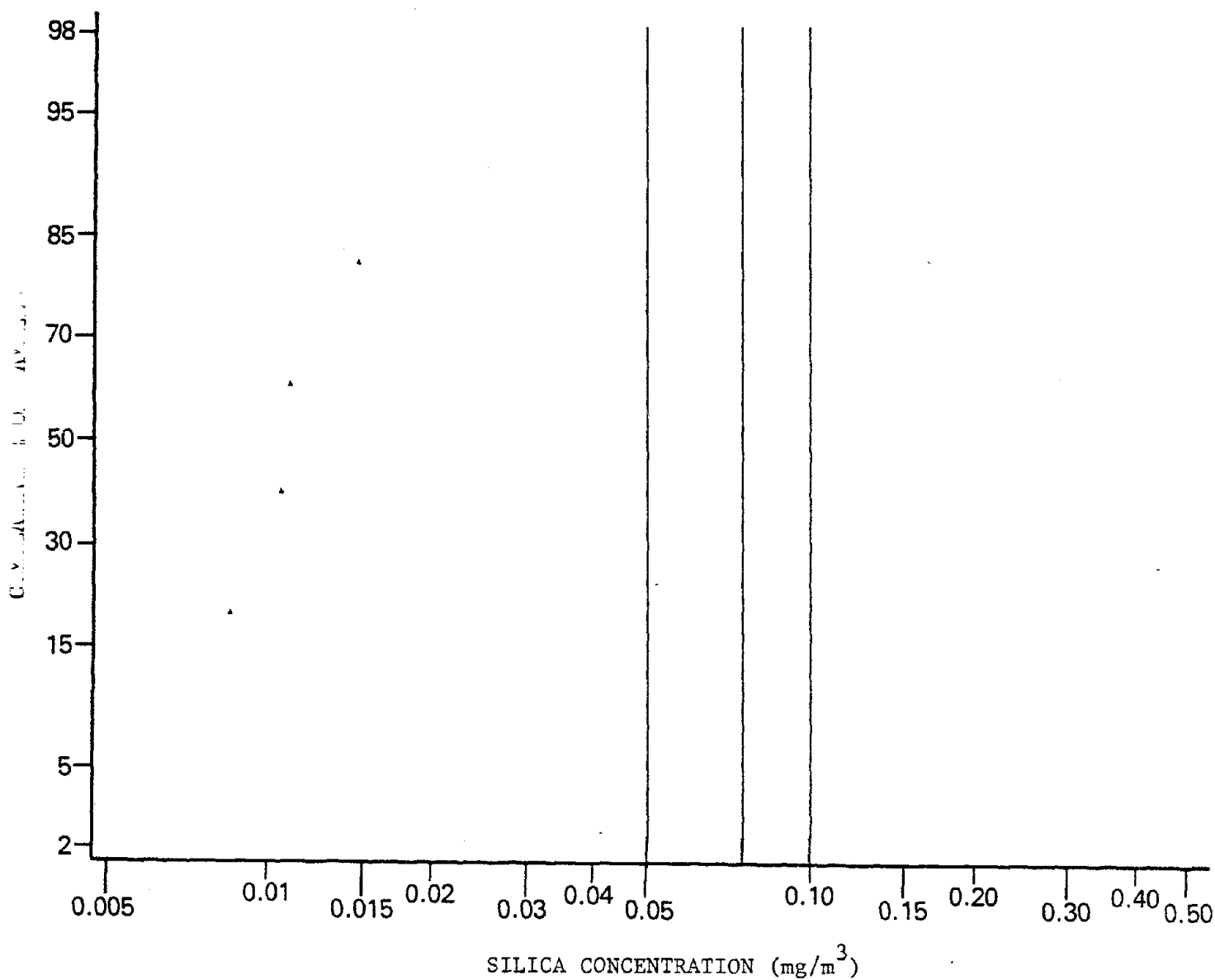
No. of samples: 18
 No. of mine ID's represented: 9
 No. of active sites in 1980: 49
 Percent of samples less than 0.05 mg/m³: 78
 Percent of samples less than 0.075 mg/m³: 89
 Percent of samples less than 0.1 mg/m³: 89

Figure A-110. Respirable quartz concentrations found in crushing, grinding, and sizing operations (surface and underground) in the talc, etc. industry group.



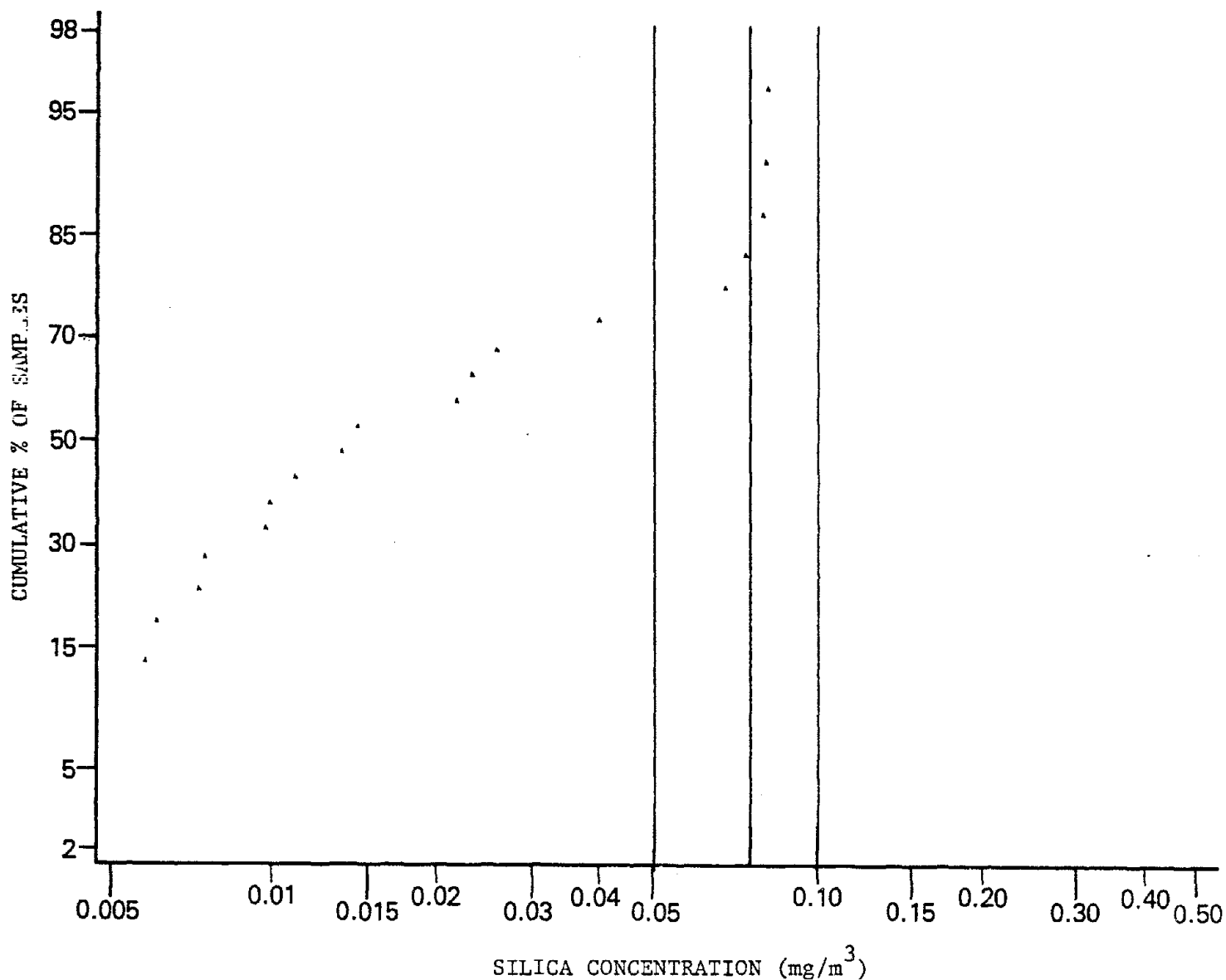
No. of samples: 28
 No. of mine ID's represented: 9
 No. of active sites in 1980: 49
 Percent of samples less than 0.05 mg/m³: 75
 Percent of samples less than 0.075 mg/m³: 86
 Percent of samples less than 0.1 mg/m³: 89

Figure A-111. Respirable quartz concentrations found in concentrating and finishing operations (surface and underground) in the talc, etc.. industry group.



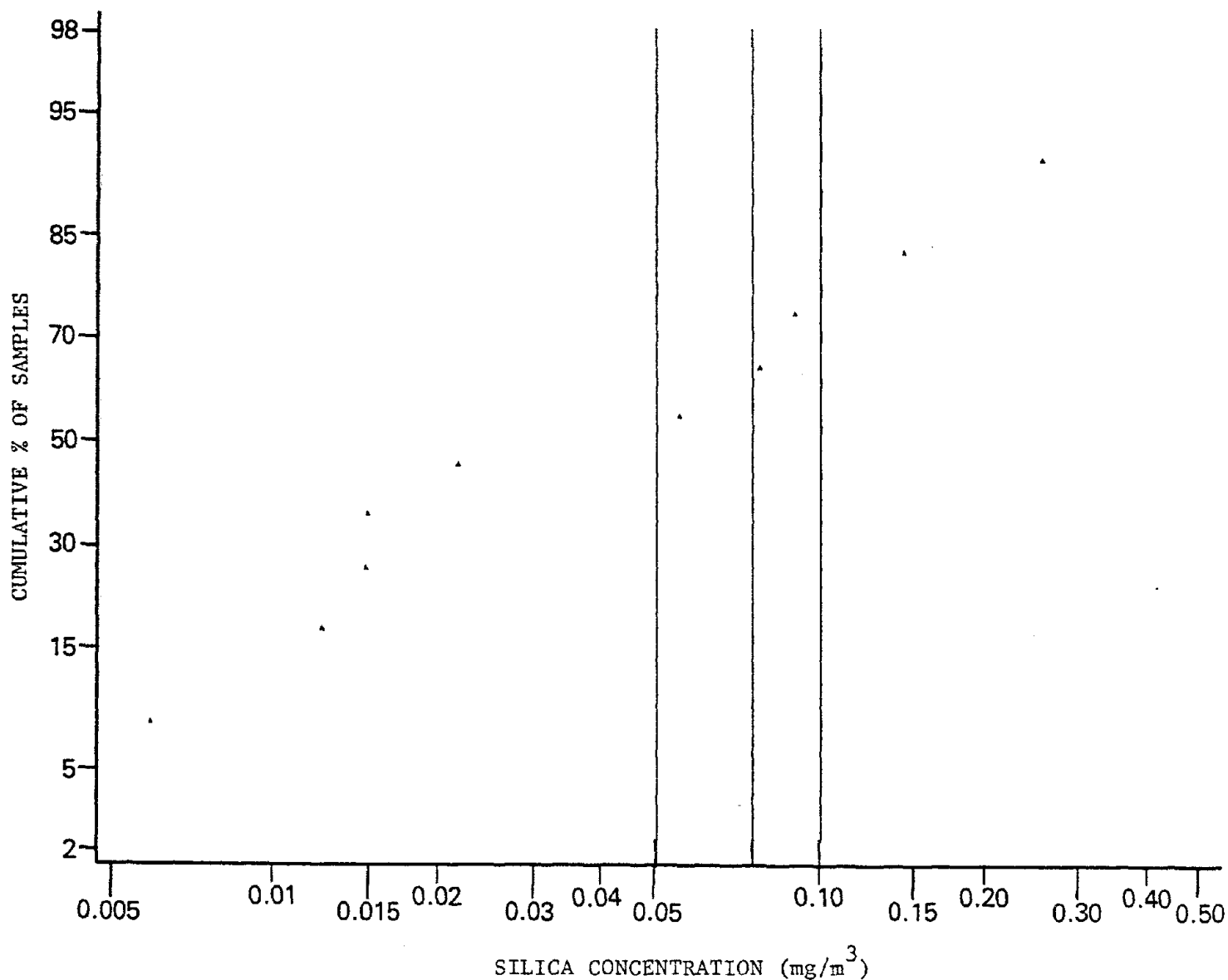
No. of samples: 5
 No. of mine ID's represented: 1
 No. of active sites in 1980: 11
 Percent of samples less than 0.05 mg/m³: 100
 Percent of samples less than 0.075 mg/m³: 100
 Percent of samples less than 0.1 mg/m³: 100

Figure A-112. Respirable quartz concentrations found in nonspecific underground operations in the oil shale industry group.



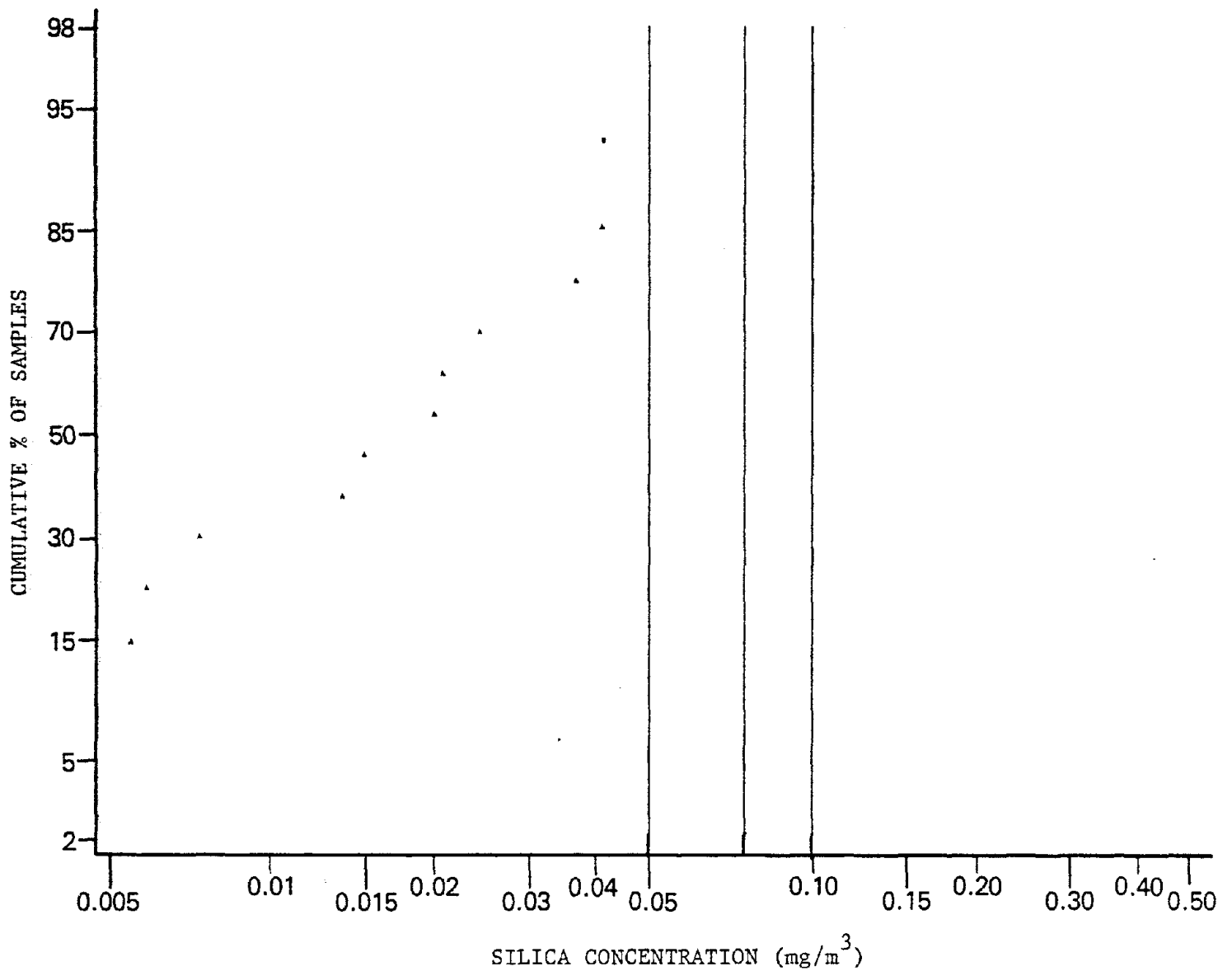
No. of samples: 21
 No. of mine ID's represented: 1
 No. of active sites in 1980: 11
 Percent of samples less than 0.05 mg/m³: 71
 Percent of samples less than 0.075 mg/m³: 81
 Percent of samples less than 0.1 mg/m³: 100

Figure A-113. Respirable quartz concentrations found in underground drilling operations in the oil shale industry group.



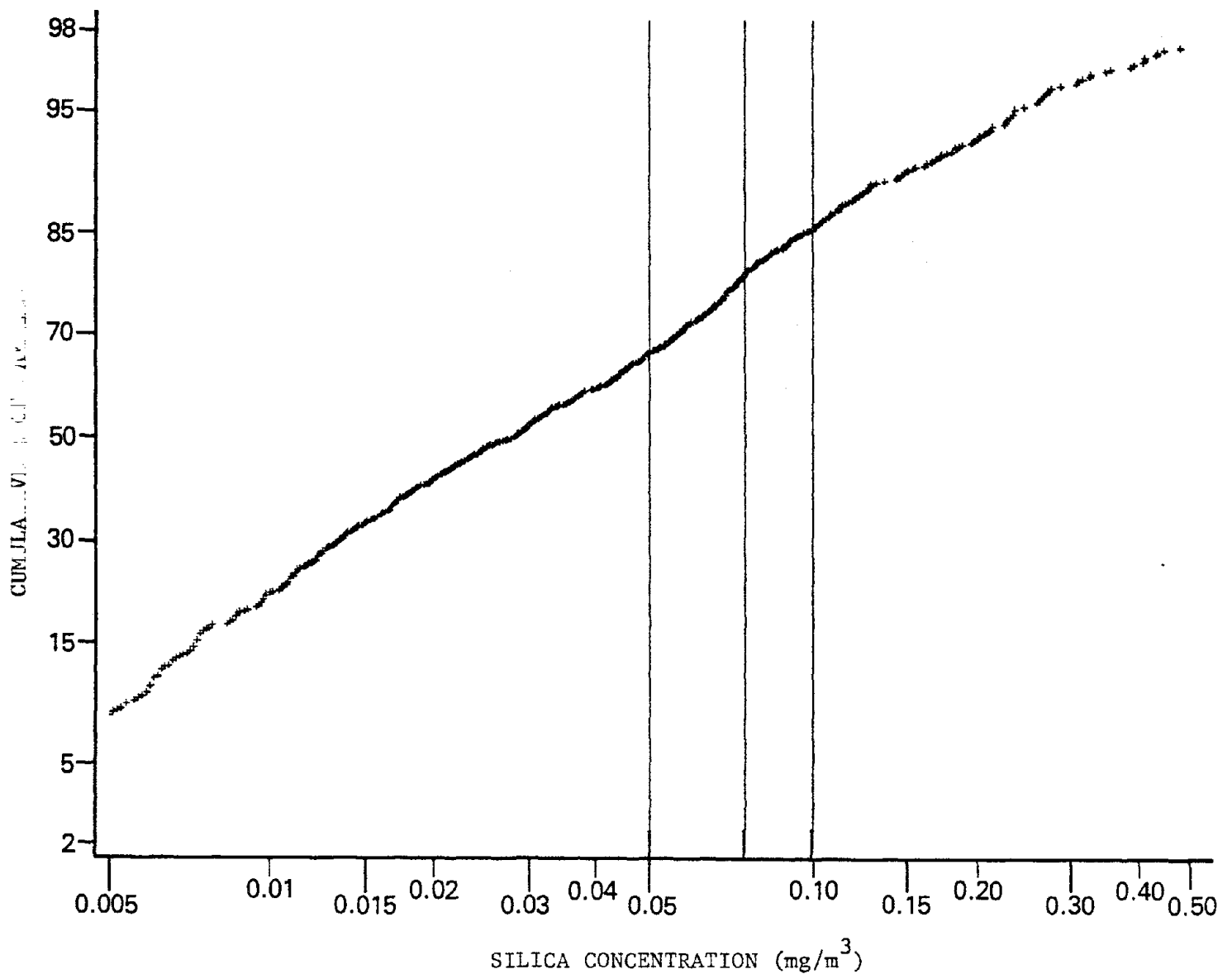
No. of samples: 11
 No. of mine ID's represented: 1
 No. of active sites in 1980: 0
 Percent of samples less than 0.05 mg/m³: 45
 Percent of samples less than 0.075 mg/m³: 55
 Percent of samples less than 0.1 mg/m³: 73

Figure A-114. Respirable quartz concentrations
 found in surface mobile
 transport operations in the
 oil shale industry group.



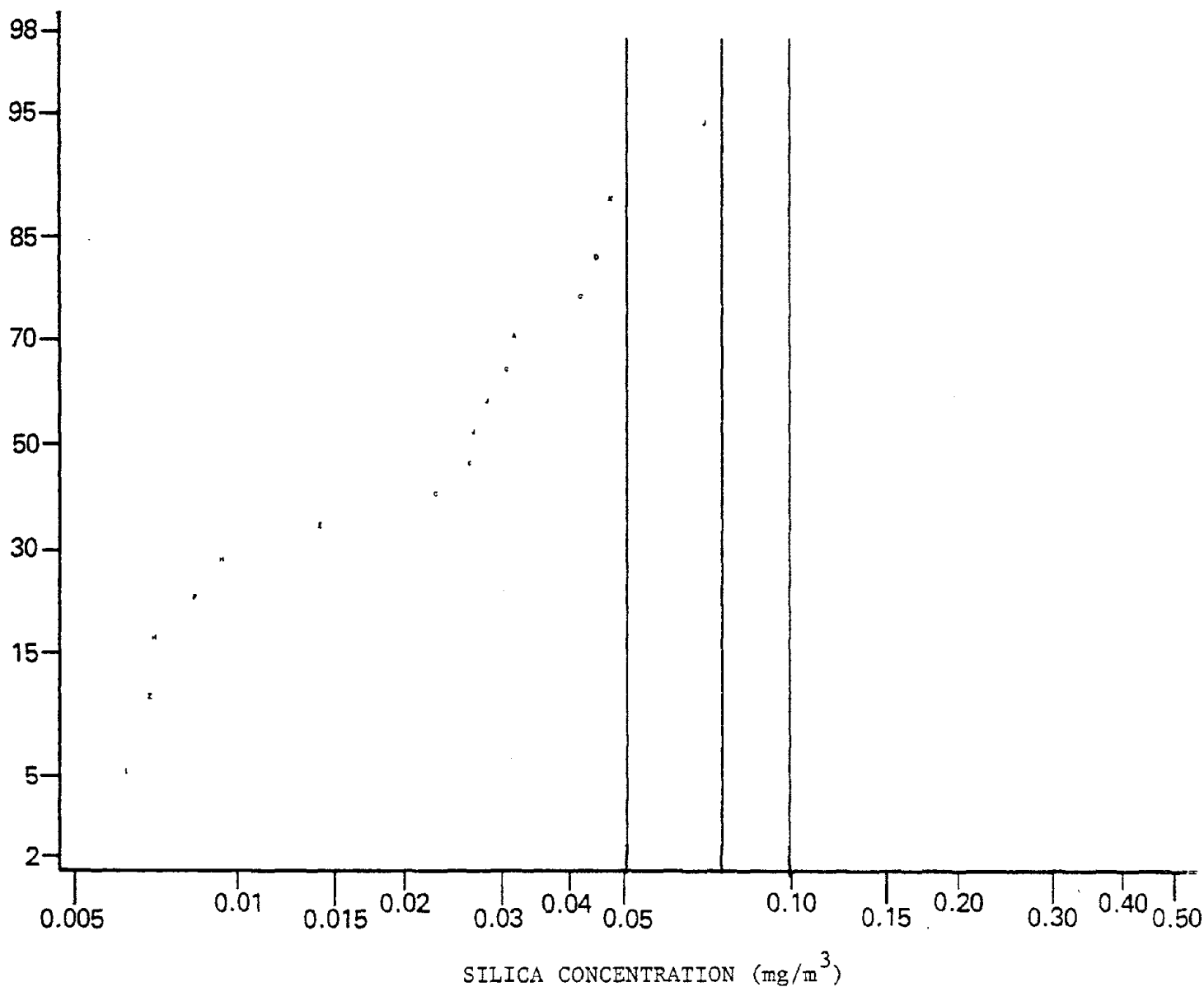
No. of samples: 13
 No. of mine ID's represented: 2
 No. of active sites in 1980: 11
 Percent of samples less than 0.05 mg/m³: 92
 Percent of samples less than 0.075 mg/m³: 92
 Percent of samples less than 0.1 mg/m³: 92

Figure A-115. Respirable quartz concentrations
 found in underground mobile transport
 operations in the oil shale industry
 group.



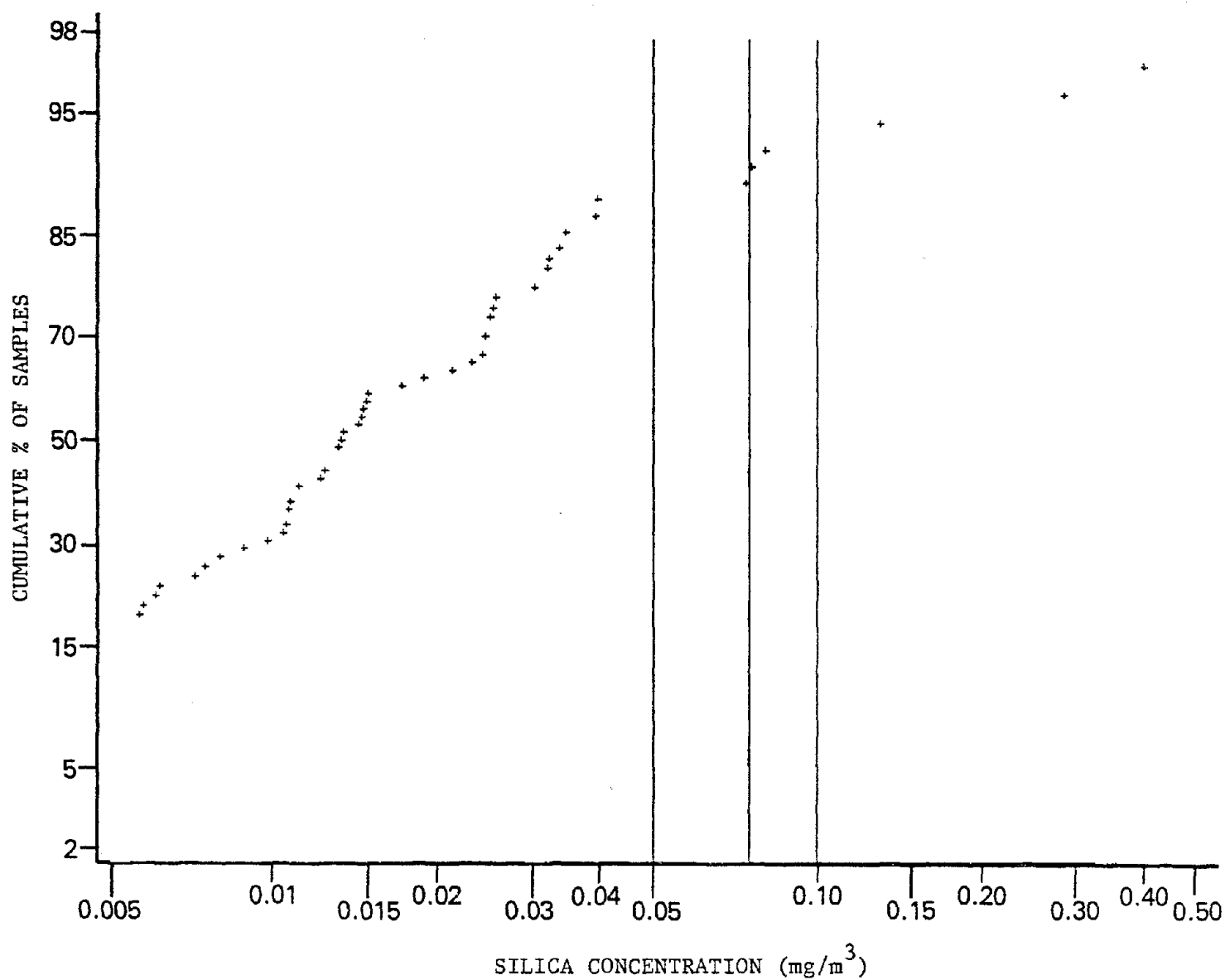
No. of samples: 836
 No. of mine ID's represented: 392
 No. of active sites in 1980: 3,453
 Percent of samples less than 0.05 mg/m³: 65
 Percent of samples less than 0.075 mg/m³: 77
 Percent of samples less than 0.1 mg/m³: 84

Figure A-116. Respirable quartz concentrations found in nonspecific surface operations in the sand and gravel industry group.



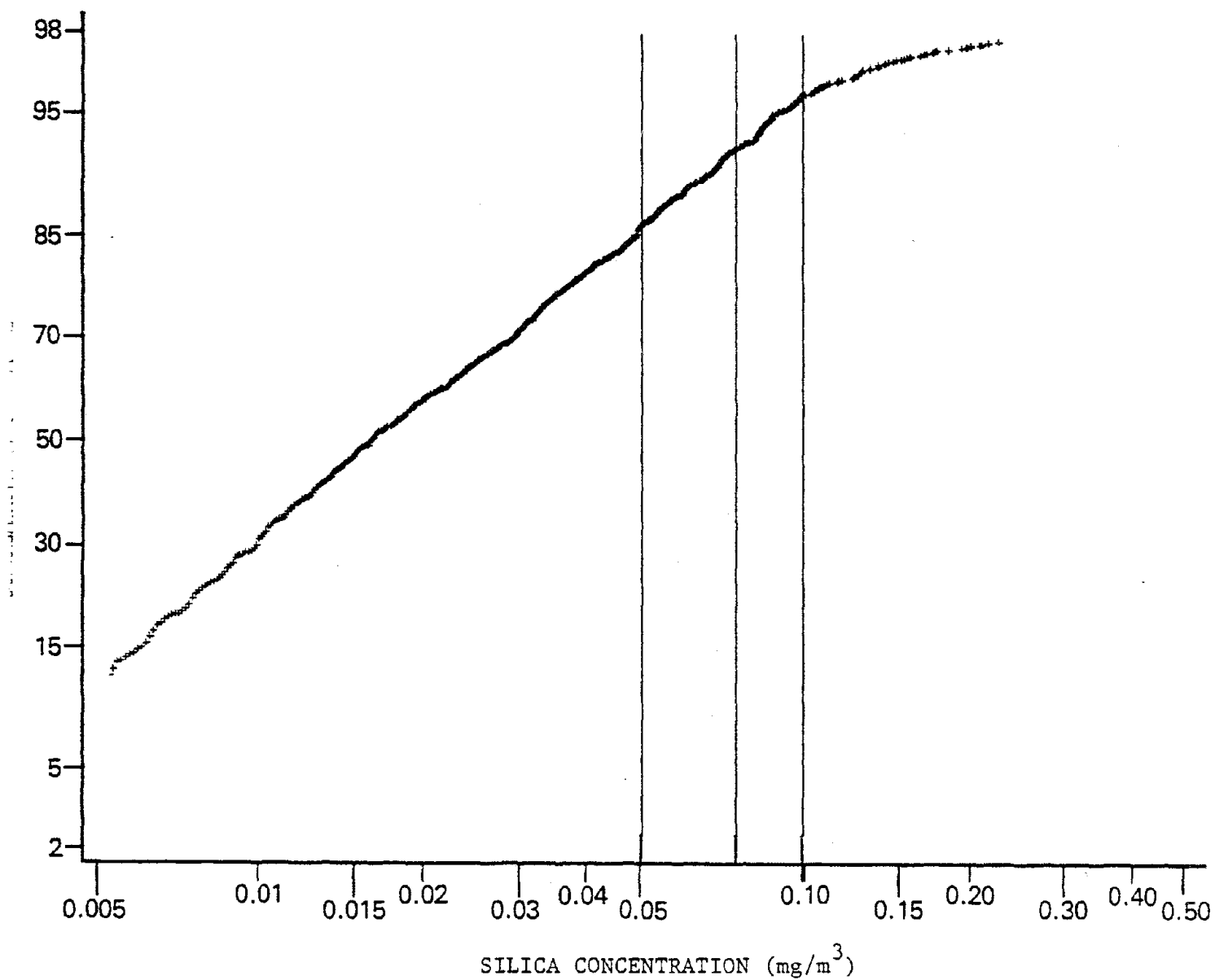
No. of samples: 17
 No. of mine ID's represented: 11
 No. of active sites in 1980: 3,351
 Percent of samples less than 0.05 mg/m³: 88
 Percent of samples less than 0.075 mg/m³: 94
 Percent of samples less than 0.1 mg/m³: 94

Figure A-117. Respirable quartz concentrations found in surface drilling operations in the sand and gravel industry group.



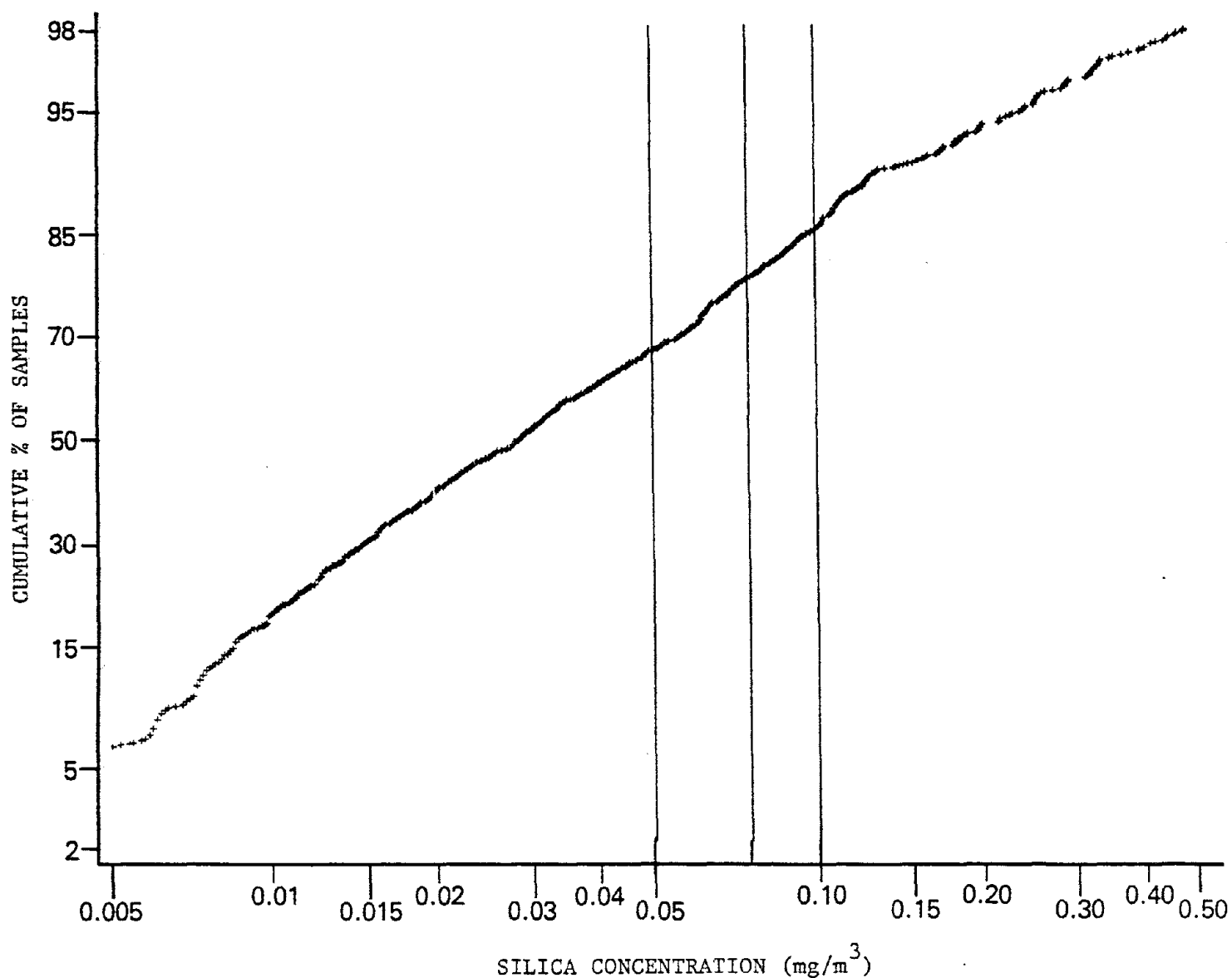
No. of samples: 69
 No. of mine ID's represented: 44
 No. of active sites in 1980: 3,351
 Percent of samples less than 0.05 mg/m³: 88
 Percent of samples less than 0.075 mg/m³: 90
 Percent of samples less than 0.1 mg/m³: 93

Figure A-118. Respirable quartz concentrations found in surface production operations in the sand and gravel industry group.



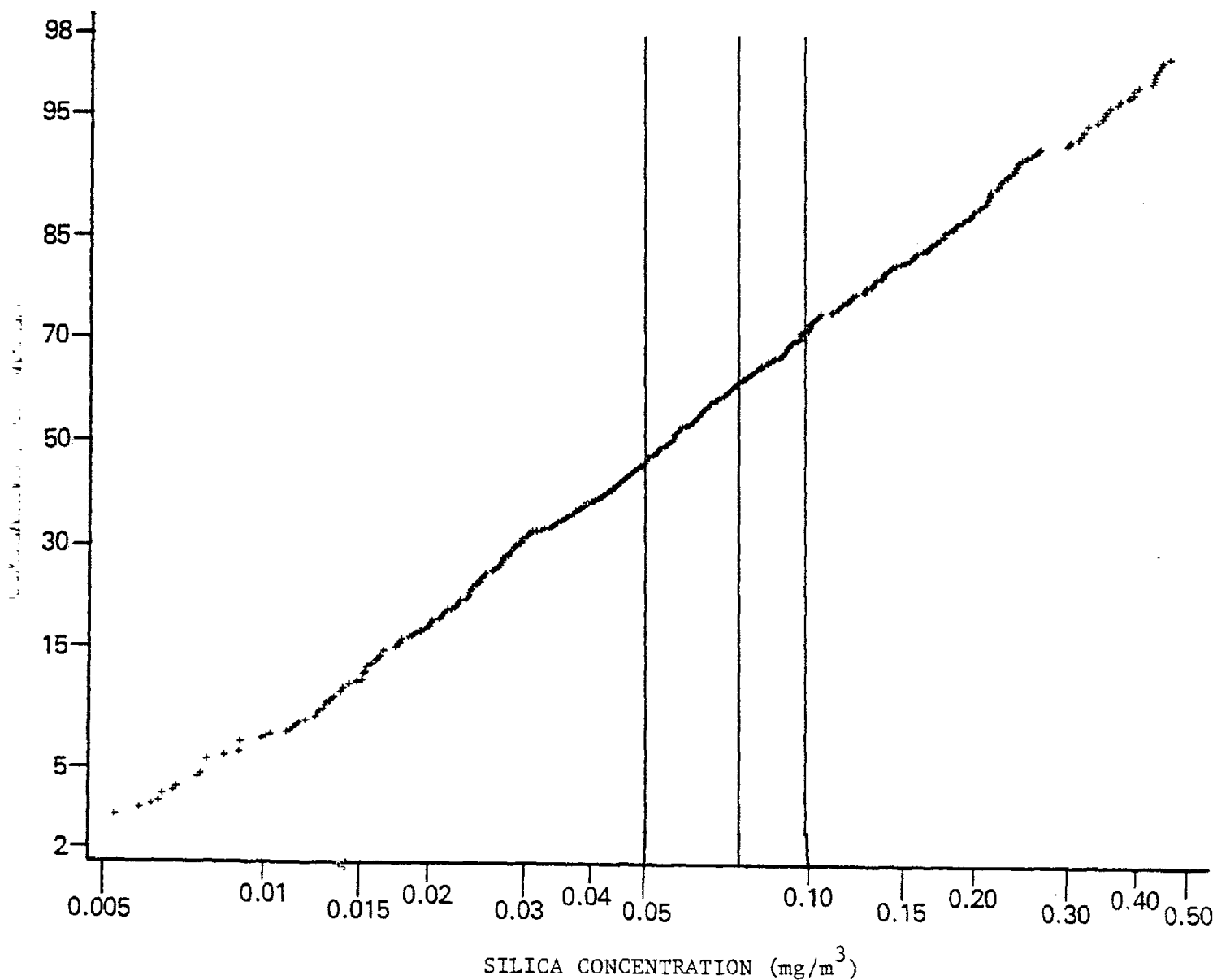
No. of samples: 2,188
 No. of mine ID's represented: 949
 No. of active sites in 1980: 3,351
 Percent of samples less than 0.05 mg/m³: 85
 Percent of samples less than 0.075 mg/m³: 92
 Percent of samples less than 0.1 mg/m³: 95

Figure A-119. Respirable quartz concentrations found in surface mobile transport operations in the sand and gravel industry group.



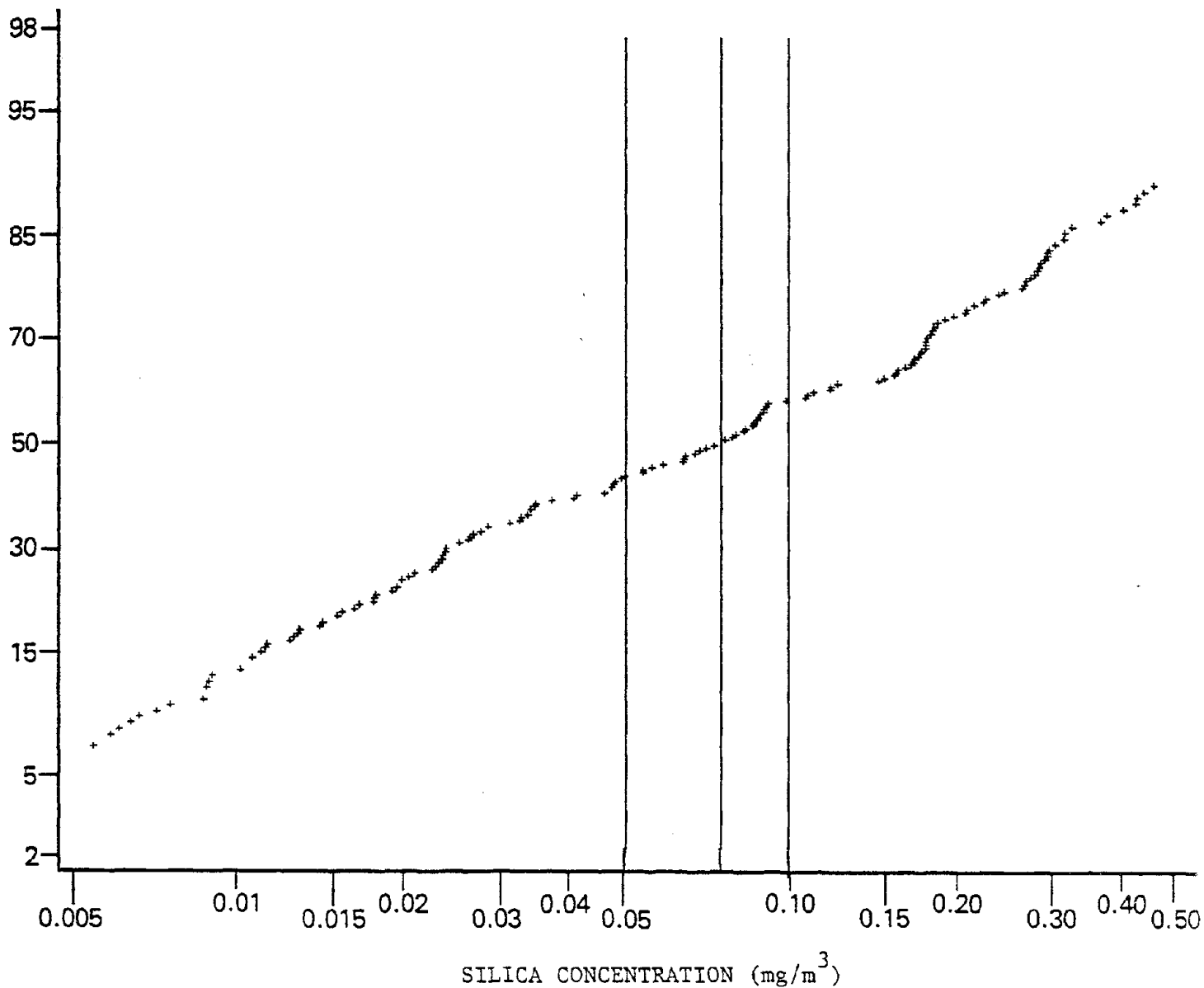
No. of samples: 1,137
No. of mine ID's represented: 654
No. of active sites in 1980: 3,453
Percent of samples less than 0.05 mg/m³: 66
Percent of samples less than 0.075 mg/m³: 78
Percent of samples less than 0.1 mg/m³: 84

Figure A-120. Respirable quartz concentrations found in crushing, grinding, and sizing operations (surface and underground) in the sand and gravel industry group.



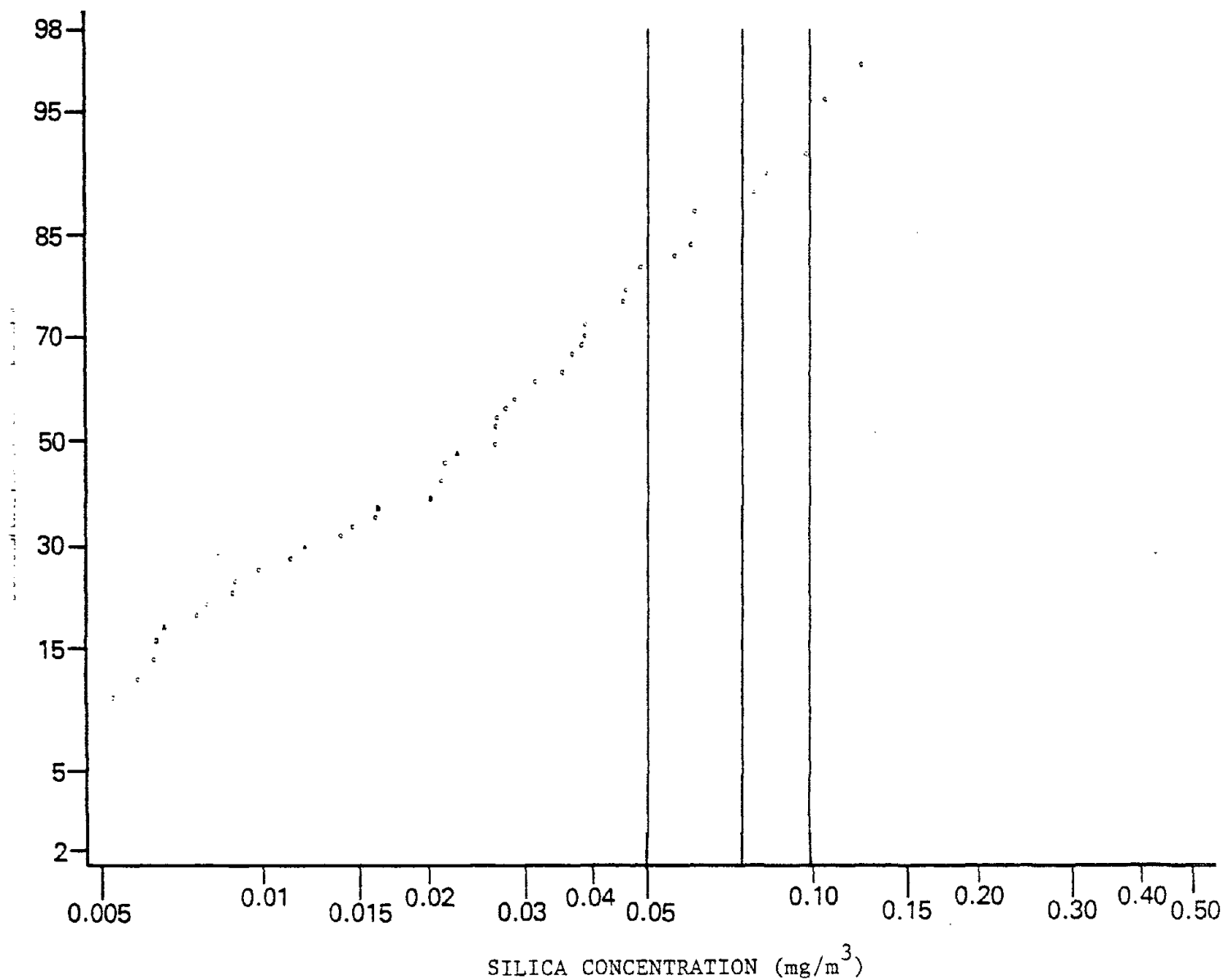
No. of samples: 569
 No. of mine ID's represented: 97
 No. of active sites in 1980: 3,453
 Percent of samples less than 0.05 mg/m³: 46
 Percent of samples less than 0.075 mg/m³: 61
 Percent of samples less than 0.1 mg/m³: 70

Figure A-121. Respirable quartz concentrations found in concentrating and finishing operations (surface and underground) in the sand and gravel industry group.



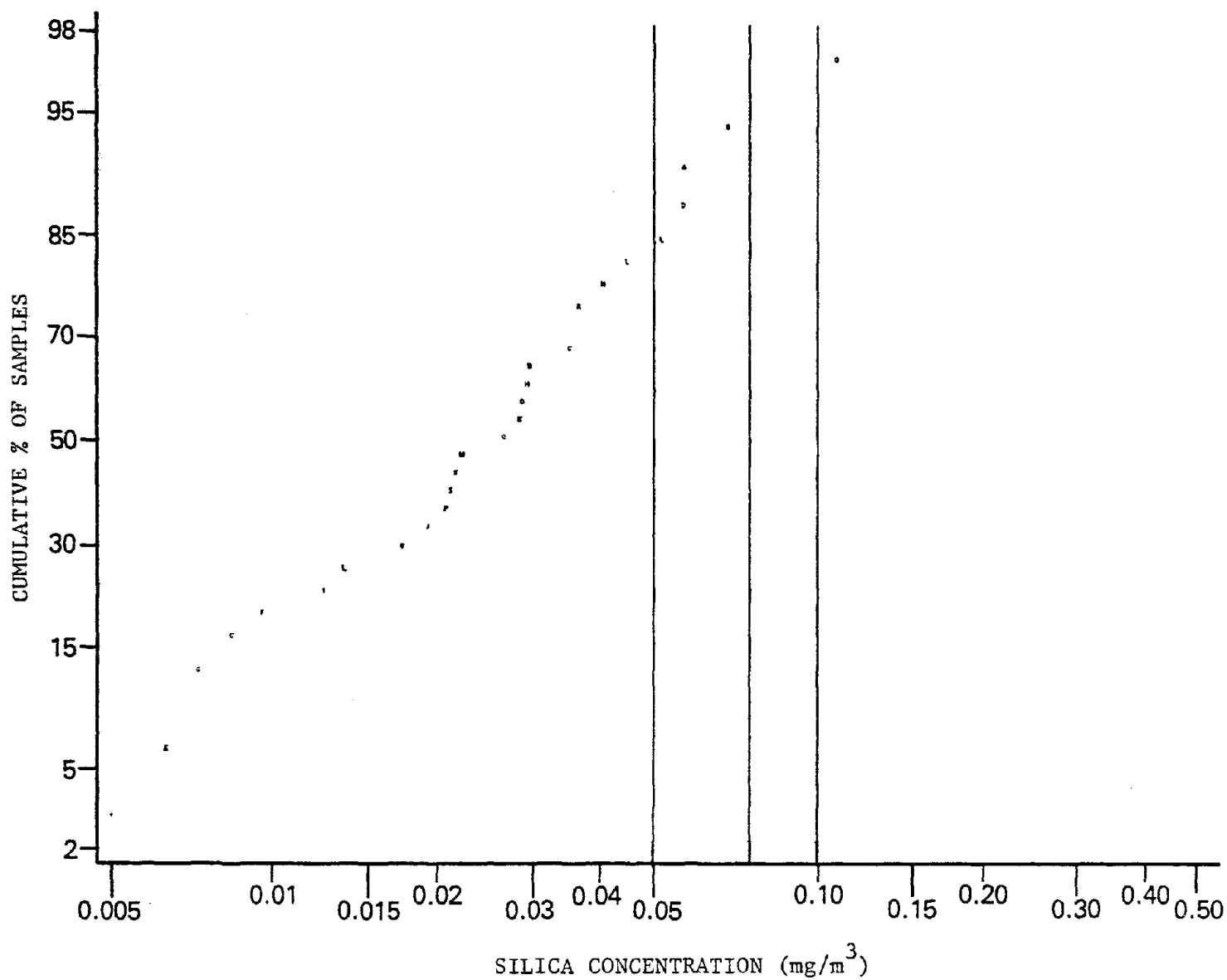
No. of samples: 190
 No. of mine ID's represented: 57
 No. of active sites in 1980: 504
 Percent of samples less than 0.05 mg/m³: 45
 Percent of samples less than 0.075 mg/m³: 51
 Percent of samples less than 0.1 mg/m³: 59

Figure A-122. Respirable quartz concentrations
 found in nonspecific surface
 operations in the other nonmetal
 industry group.



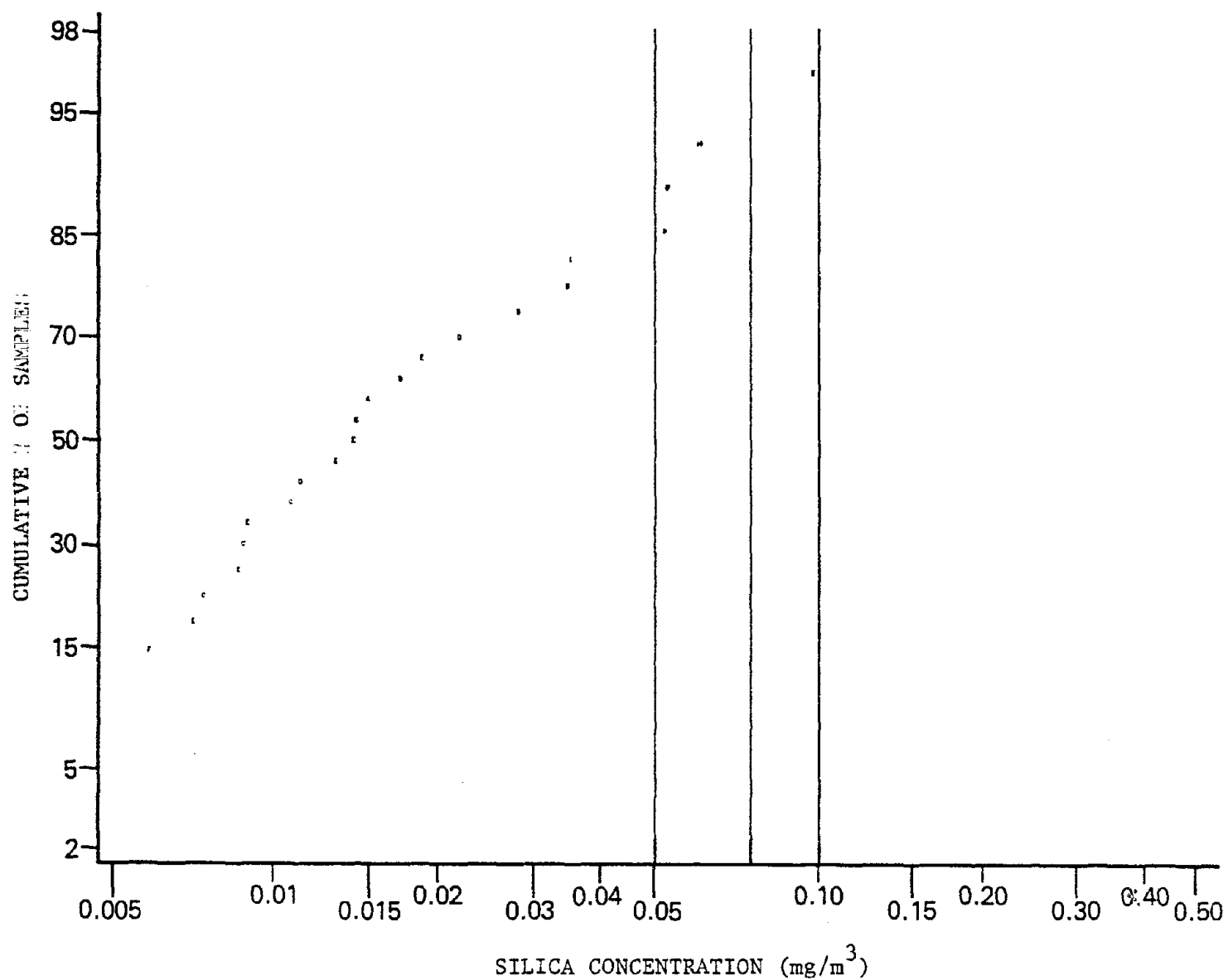
No. of samples: 58
 No. of mine ID's represented: 4
 No. of active sites in 1980: 62
 Percent of samples less than 0.05 mg/m³: 79
 Percent of samples less than 0.075 mg/m³: 86
 Percent of samples less than 0.1 mg/m³: 91

Figure A-123. Respirable quartz concentrations found in nonspecific underground operations in the other nonmetal industry group.



No. of samples: 30
 No. of mine ID's represented: 20
 No. of active sites in 1980: 284
 Percent of samples less than 0.05 mg/m³: 80
 Percent of samples less than 0.075 mg/m³: 93
 Percent of samples less than 0.1 mg/m³: 93

Figure A-124. Respirable quartz concentrations
 found in surface drilling
 operations in the other
 nonmetal industry group.



No. of samples: 26
 No. of mine ID's represented: 9
 No. of active sites in 1980: 62
 Percent of samples less than 0.05 mg/m³: 81
 Percent of samples less than 0.075 mg/m³: 92
 Percent of samples less than 0.1 mg/m³: 96

Figure A-125. Respirable quartz concentrations
 found in underground drilling
 operations in the other
 nonmetal industry group.

Respirable quartz sample data (mg/m ³ silica)	Establishment
0.0082	146 (phosphate)
0.0094	795 (fluorspar)
0.0147	795
0.0194	795
0.0826	146

No. of samples: 5
 No. of mine ID's represented: 2
 No. of active sites in 1980: 62
 Percent of samples less than 0.05 mg/m³: 80
 Percent of samples less than 0.075 mg/m³: 80
 Percent of samples less than 0.1 mg/m³: 100

Figure A-126. Respirable quartz concentrations found
 in underground haulageway maintenance
 operations in the other nonmetals
 industry group.

Respirable quartz sample data (mg/m ³ silica)	Establishment
0.0119	408 (phosphate)
0.0147	094 (phosphate)
0.3429	051 (silica flour)
0.4302	556 (phosphate)

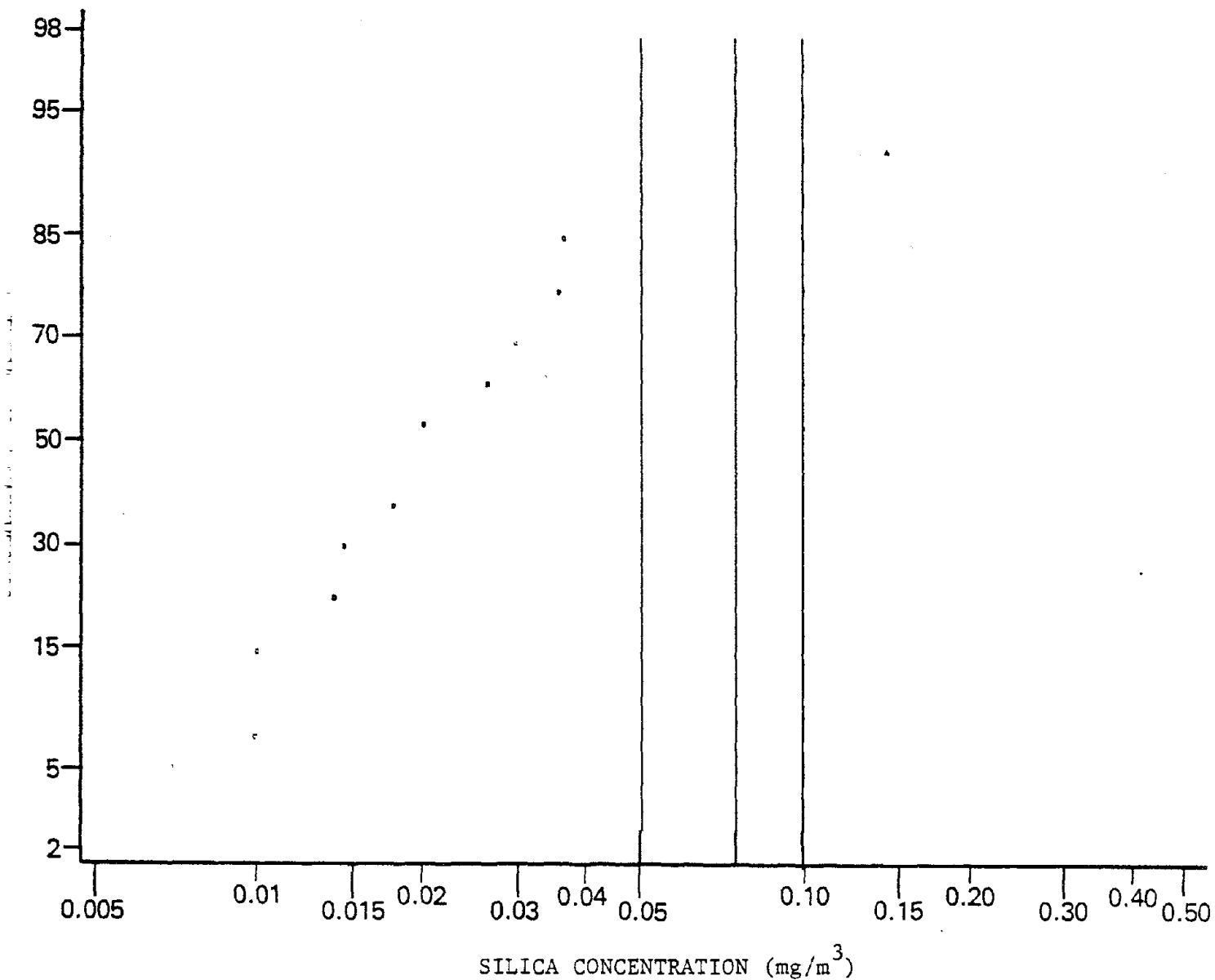
No. of samples: 4
 No. of mine ID's represented: 4
 No. of active sites in 1980: 284
 Percent of samples less than 0.05 mg/m³: 50
 Percent of samples less than 0.075 mg/m³: 50
 Percent of samples less than 0.1 mg/m³: 50

Figure A-127. Respirable quartz concentrations found in surface production operations in the other metals industry group.

Respirable quartz sample data (mg/m ³ silica)	Establishment
0.0119	408 (phosphate)
0.0147	094 (phosphate)
0.3429	051 (silica flour)
0.4302	556 (phosphate)

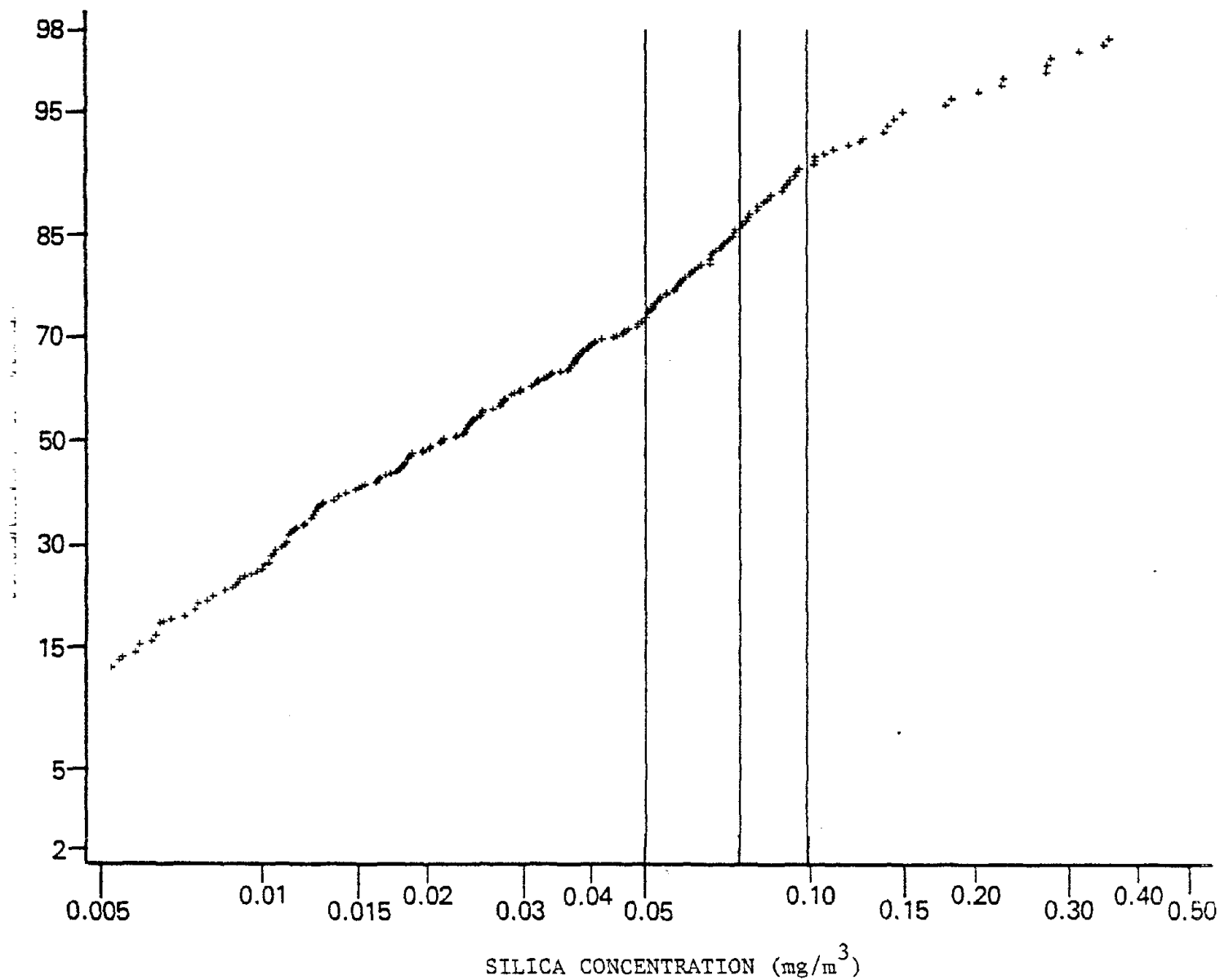
No. of samples: 4
 No. of mine ID's represented: 4
 No. of active sites in 1980: 284
 Percent of samples less than 0.05 mg/m³: 50
 Percent of samples less than 0.075 mg/m³: 50
 Percent of samples less than 0.1 mg/m³: 50

Figure A-127. Respirable quartz concentrations found in surface production operations in the other metals industry group.



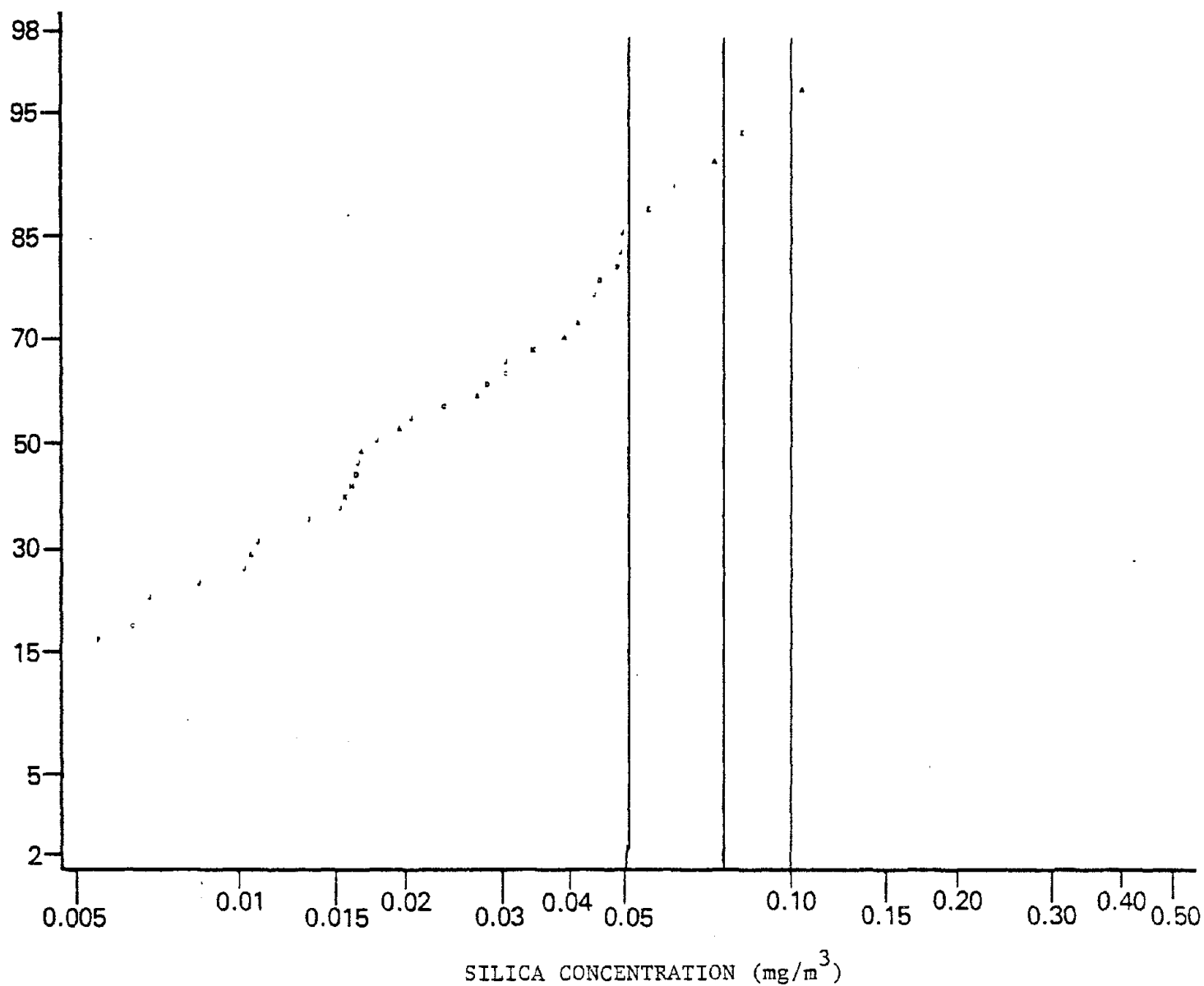
No. of samples: 13
 No. of mine ID's represented: 4
 No. of active sites in 1980: 62
 Percent of samples less than 0.05 mg/m³: 85
 Percent of samples less than 0.075 mg/m³: 85
 Percent of samples less than 0.1 mg/m³: 85

Figure A-128. Respirable quartz concentrations
 found in underground production
 operations in the other
 nonmetal industry group.



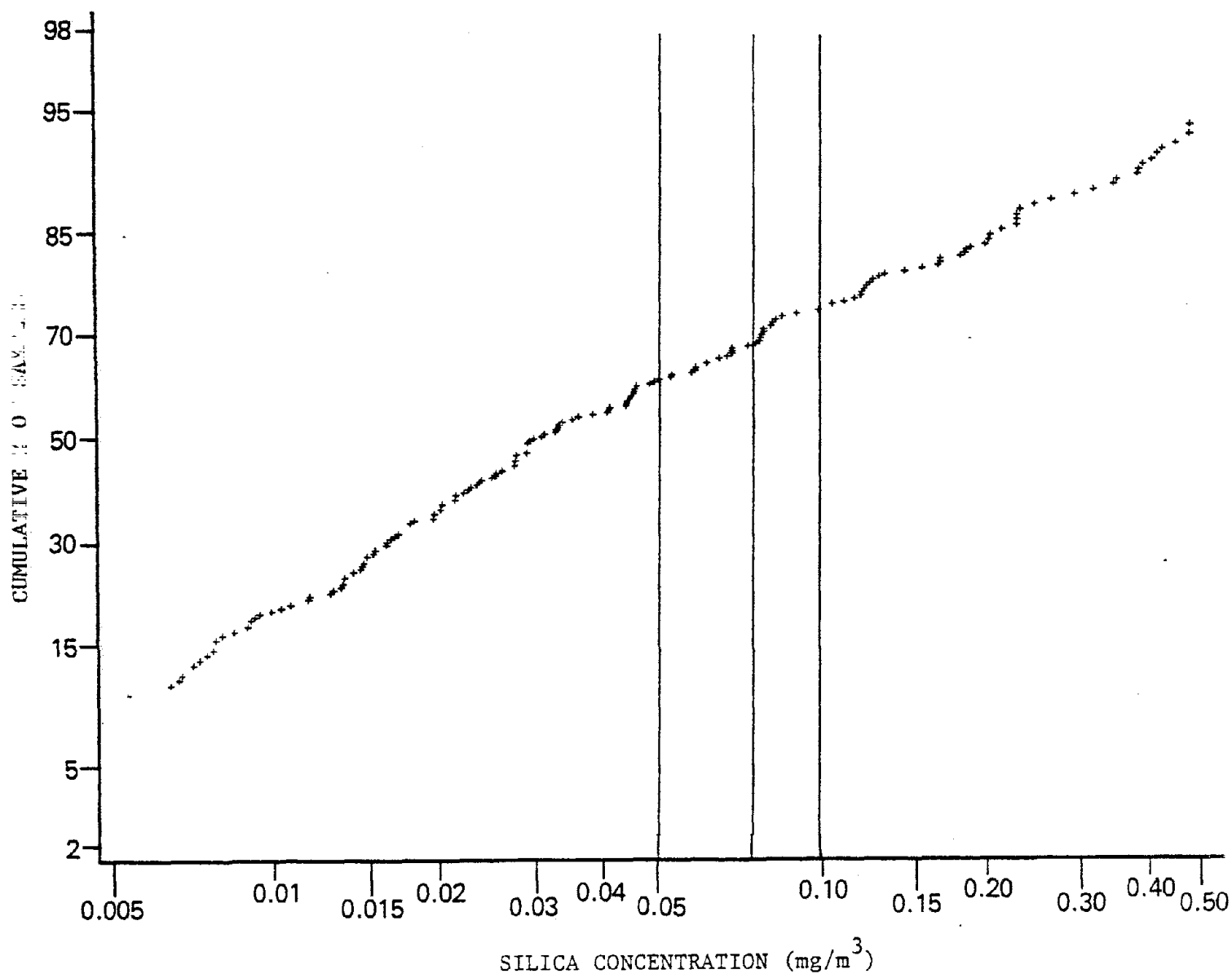
No. of samples: 295
 No. of mine ID's represented: 74
 No. of active sites in 1980: 284
 Percent of samples less than 0.05 mg/m³: 71
 Percent of samples less than 0.075 mg/m³: 85
 Percent of samples less than 0.1 mg/m³: 90

Figure A-129. Respirable quartz concentrations
 found in surface mobile
 transport operations in the
 other nonmetal industry group.



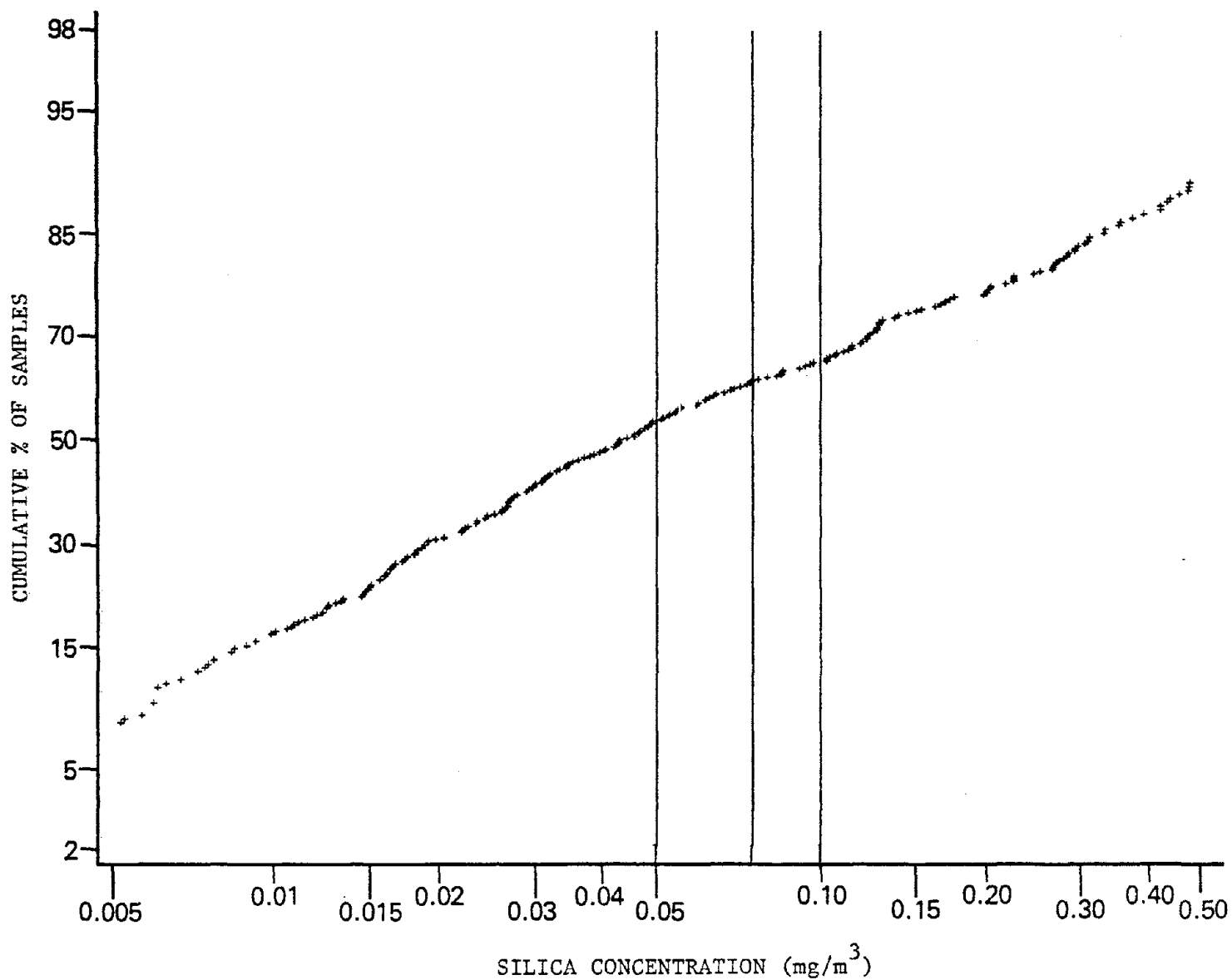
No. of samples: 47
No. of mine ID's represented: 12
No. of active sites in 1980: 62
Percent of samples less than 0.05 mg/m³: 85
Percent of samples less than 0.075 mg/m³: 91
Percent of samples less than 0.1 mg/m³: 94

Figure A-130. Respirable quartz concentrations found in underground mobile transport operations in the other nonmetal industry group.



No. of samples: 216
 No. of mine ID's represented: 77
 No. of active sites in 1980: 504
 Percent of samples less than 0.05 mg/m³: 62
 Percent of samples less than 0.075 mg/m³: 68
 Percent of samples less than 0.1 mg/m³: 74

Figure A-131. Respirable quartz concentrations found in crushing, grinding, and sizing operations (surface and underground) in the other nonmetal industry group.



No. of samples: 289
 No. of mine ID's represented: 58
 No. of active sites in 1980: 504
 Percent of samples less than 0.05 mg/m³: 54
 Percent of samples less than 0.075 mg/m³: 62
 Percent of samples less than 0.1 mg/m³: 65

Figure A-132. Respirable quartz concentrations found in concentrating and finishing operations (surface and underground) in the other nonmetal industry group.

APPENDIX B
EXPOSURE PROFILES FOR AIRBORNE MINERAL FIBERS
IN THE MINING INDUSTRY

APPENDIX B

EXPOSURE PROFILES FOR AIRBORNE MINERAL FIBERS IN THE MINING INDUSTRY

Exposure profiles for airborne mineral fibers in 15 mining industry groups from the 1977-1981 Mine Safety and Health Administration (MSHA) MIDAS files and MSHA fiber survey results are presented as probability distribution graphs in this appendix. The exposure data have been organized into data sets by combinations of industry group, operation category, and location (surface and underground) as discussed in Volume 1, Chapter 2 of this report. Data from personal samples and area samples are further segregated. There are 15 industry groups: copper, gold and silver, iron, lead and zinc, molybdenum, uranium, other metals, limestone, other stone, clay and shale, asbestos, talc, oil shale, sand and gravel, and other nonmetals. Operation and location are classified into 14 categories: surface drilling; underground drilling; blasting; cutting and boring; surface production; surface mobile transport; surface haulageway maintenance; underground production; underground mobile transport; underground haulageway maintenance; crushing, grinding, and sizing; concentrating and finishing; surface nonspecific; and underground nonspecific.

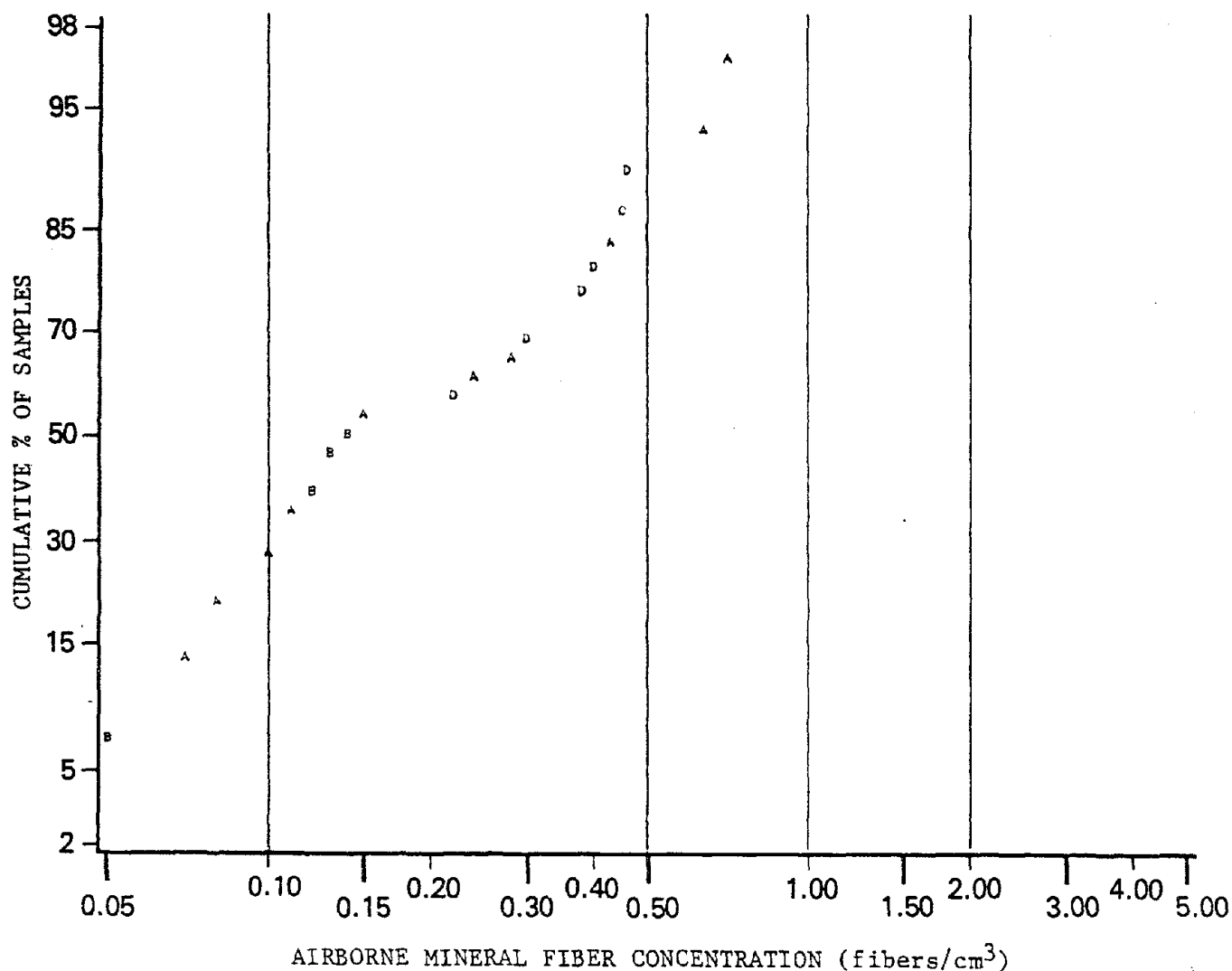
The exposure profiles were developed only for those combinations of industry group and operation category in which there are more than five data points. If a data set contained no more than five samples, the data are not plotted as distribution profiles. Each graph has the following format:

- The horizontal axis, which gives the concentration of mineral fibers in air, is a logarithmic scale from 0.05 to 5.0 fibers/cc.
- The vertical axis is the cumulative percentage of samples with concentrations less than or equal to the concentration of the point plotted. The scale of the axis corresponds to a normal probability distribution, with 50 percent as the median.
- If data for a profile were collected from more than 22 establishments, a plus sign is used to designate data points. If 22 or fewer establishments were sampled, the samples for different establishments are designated with different alphabetic characters.
- Each graph includes four vertical lines at 0.1, 0.5, 1.0, and 2.0 fibers/cc. Three vertical markers correspond to the three alternate PEL's that NIOSH is evaluating in this study. The 2.0 fibers/cc marker corresponds to the current MSHA standard of 2 fibers/ml for asbestos.

Some of the profiles with symbols representing individual establishments may be misleading because of a limitation in the plotting procedure. In the larger data sets, several samples may have the same fiber count. The graphing algorithm arranges these samples in order of increasing mine ID and plots the symbol of the highest mine ID at the coordinates representing the fiber count and the cumulative percentage of the sample. The other samples with the same fiber count are not plotted. Because of this limitation, the distribution of symbols in the graph may not reflect the actual distribution of the samples taken from individual establishments.

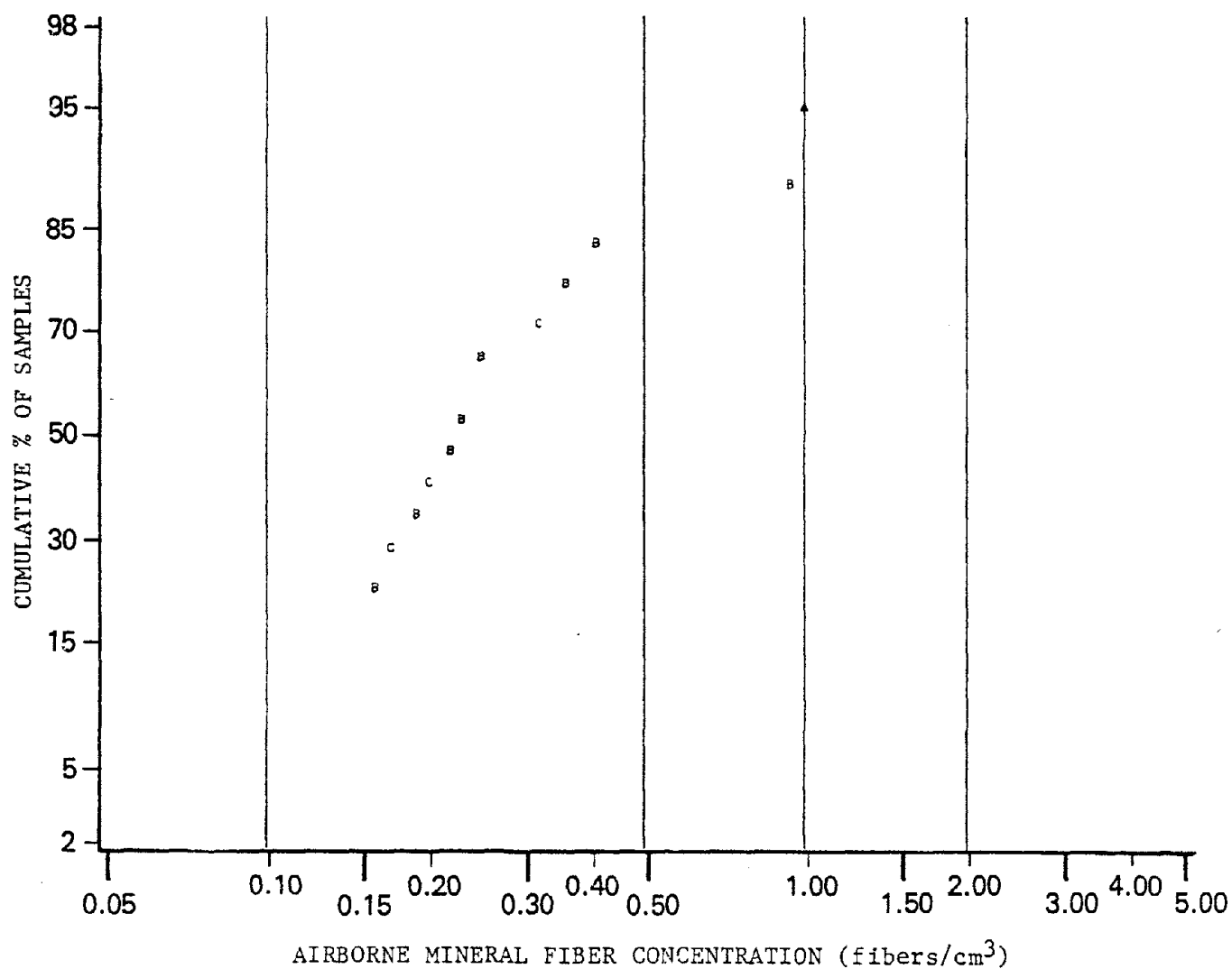
Accompanying each graph is a data summary with the following information:

- The number of samples in the data set, including samples outside the graph limits
- The number of sampled establishments
- The number of establishments listed as active in the 1980 MSHA Address and Employment File
- The cumulative percent of samples at or below each of the four alternate PEL's. This number, which will be called the PEL intercept, corresponds to the cumulative percent represented by the sample point closest to and to the left of the PEL marker.



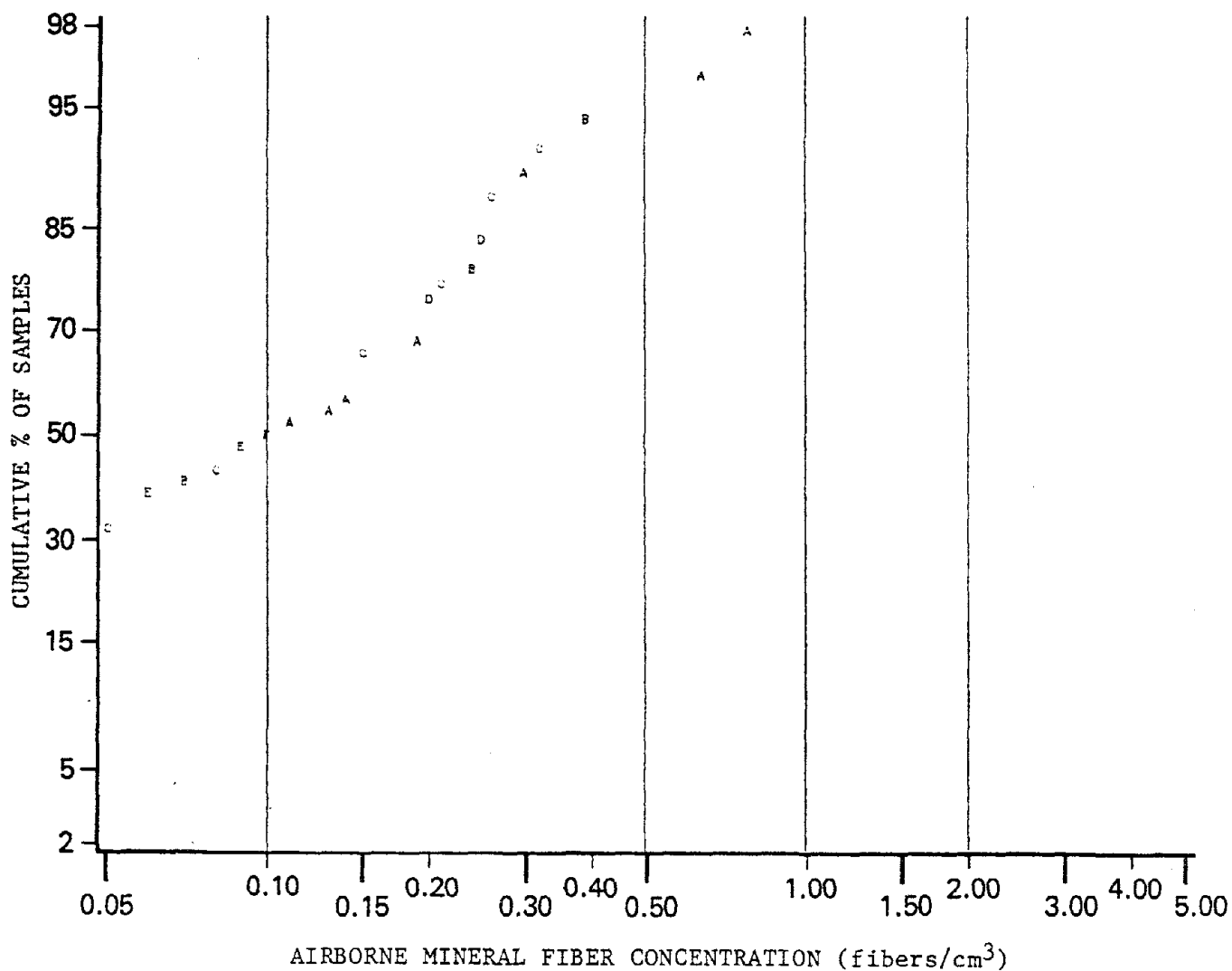
No. of samples: 28
 No. of mine ID's represented: 5
 No. of active sites in 1980: 58
 Percent of samples less than 0.1 fibers/cm³: 21
 Percent of samples less than 0.5 fibers/cm³: 89
 Percent of samples less than 1.0 fibers/cm³: 96
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B -1. Airborne mineral fiber concentrations
 found in nonspecific surface opera-
 tions in the iron industry group (personal
 samples).



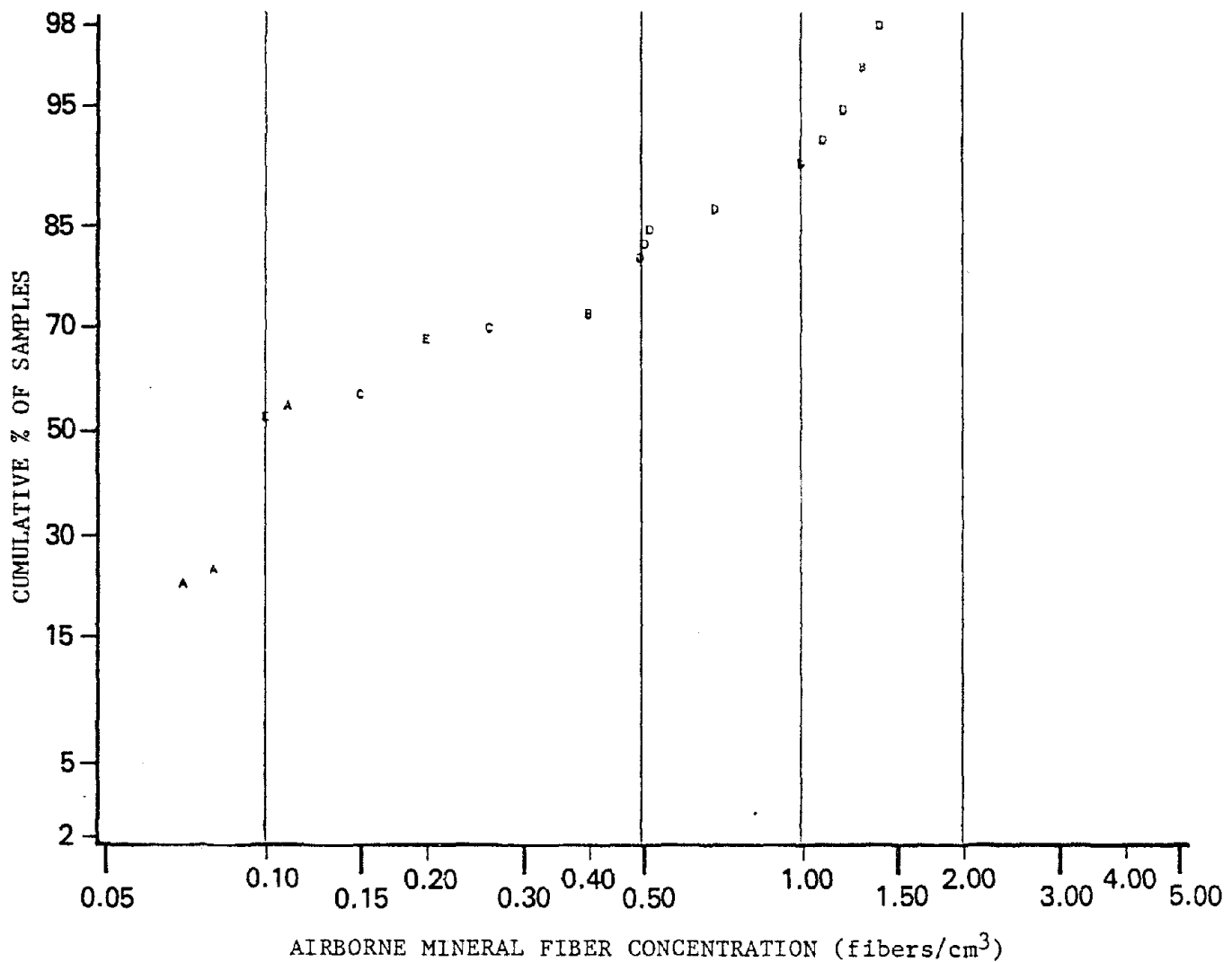
No. of samples: 17
 No. of mine ID's represented: 3
 No. of active sites in 1980: 58
 Percent of samples less than 0.1 fibers/cm³: 18
 Percent of samples less than 0.5 fibers/cm³: 82
 Percent of samples less than 1.0 fibers/cm³: 88
 Percent of samples less than 2.0 fibers/cm³: 94

Figure B-2. Airborne mineral fiber concentrations found in production operations in the iron industry group (area samples).



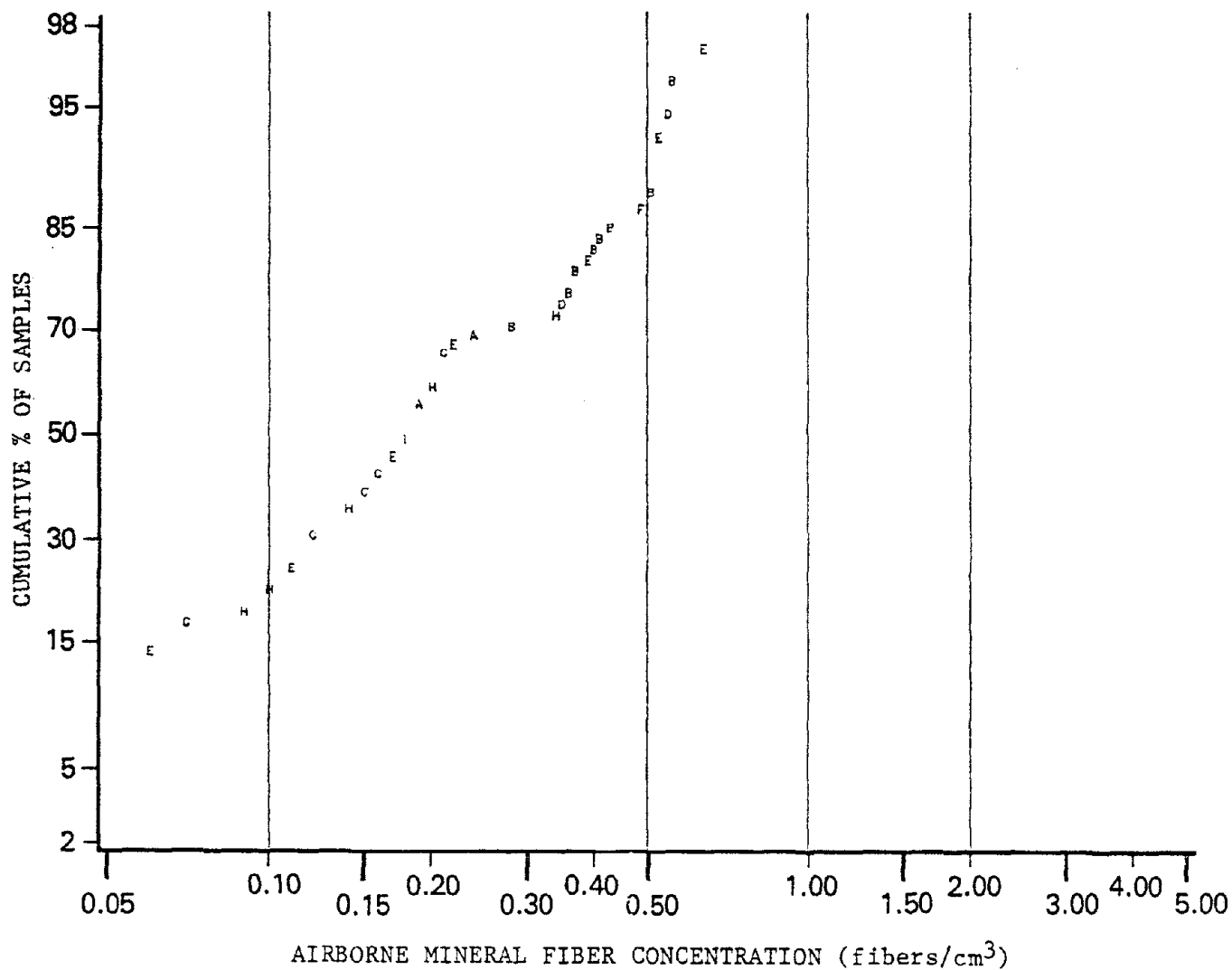
No. of samples: 46
 No. of mine ID's represented: 6
 No. of active sites in 1980: 31
 Percent of samples less than 0.1 fibers/cm³: 48
 Percent of samples less than 0.5 fibers/cm³: 93
 Percent of samples less than 1.0 fibers/cm³: 98
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-3. Airborne mineral fiber concentrations found in surface mobile transport operations in the iron industry group (personal samples).



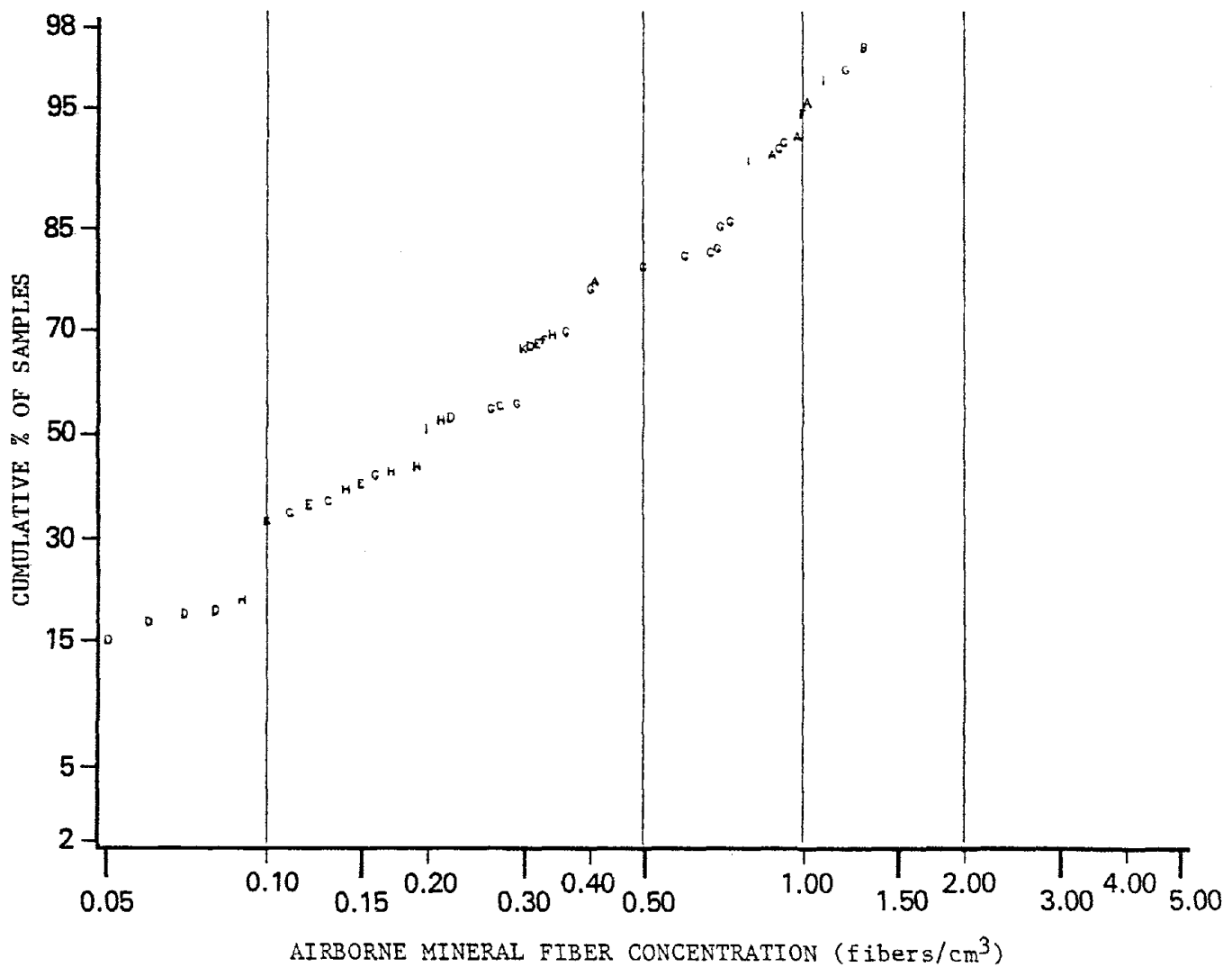
No. of samples: 48
 No. of mine ID's represented: 6
 No. of active sites in 1980: 58
 Percent of samples less than 0.1 fibers/cm³: 25
 Percent of samples less than 0.5 fibers/cm³: 71
 Percent of samples less than 1.0 fibers/cm³: 85
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-4. Airborne mineral fiber concentrations
 found in mobile transport operations
 in the iron industry group (area samples).



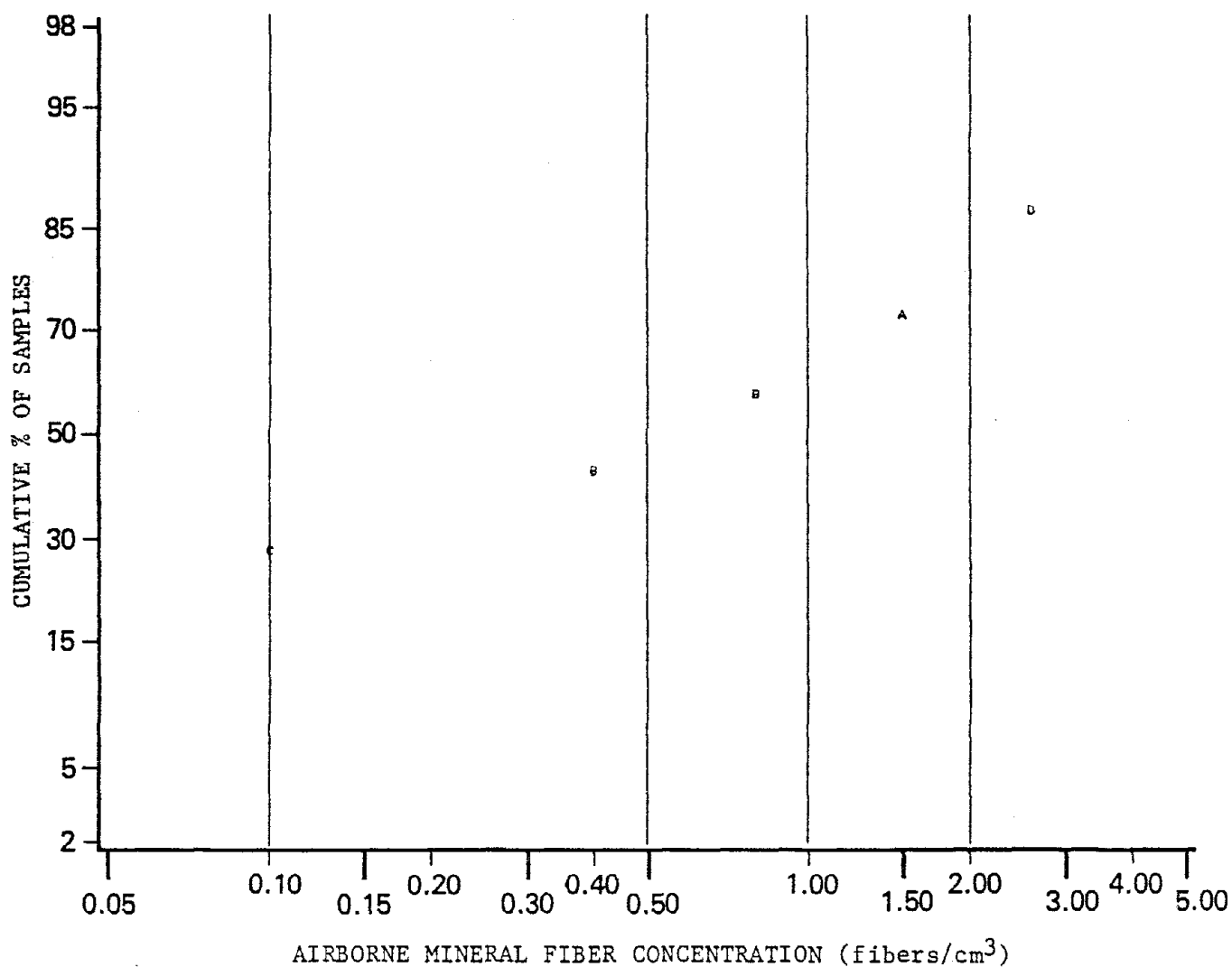
No. of samples: 62
 No. of mine ID's represented: 10
 No. of active sites in 1980: 58
 Percent of samples less than 0.1 fibers/cm³: 19
 Percent of samples less than 0.5 fibers/cm³: 85
 Percent of samples less than 1.0 fibers/cm³: 100
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-5. Airborne mineral fiber concentrations found in crushing, grinding, and sizing operations (surface and underground) in the iron industry group (personal samples).



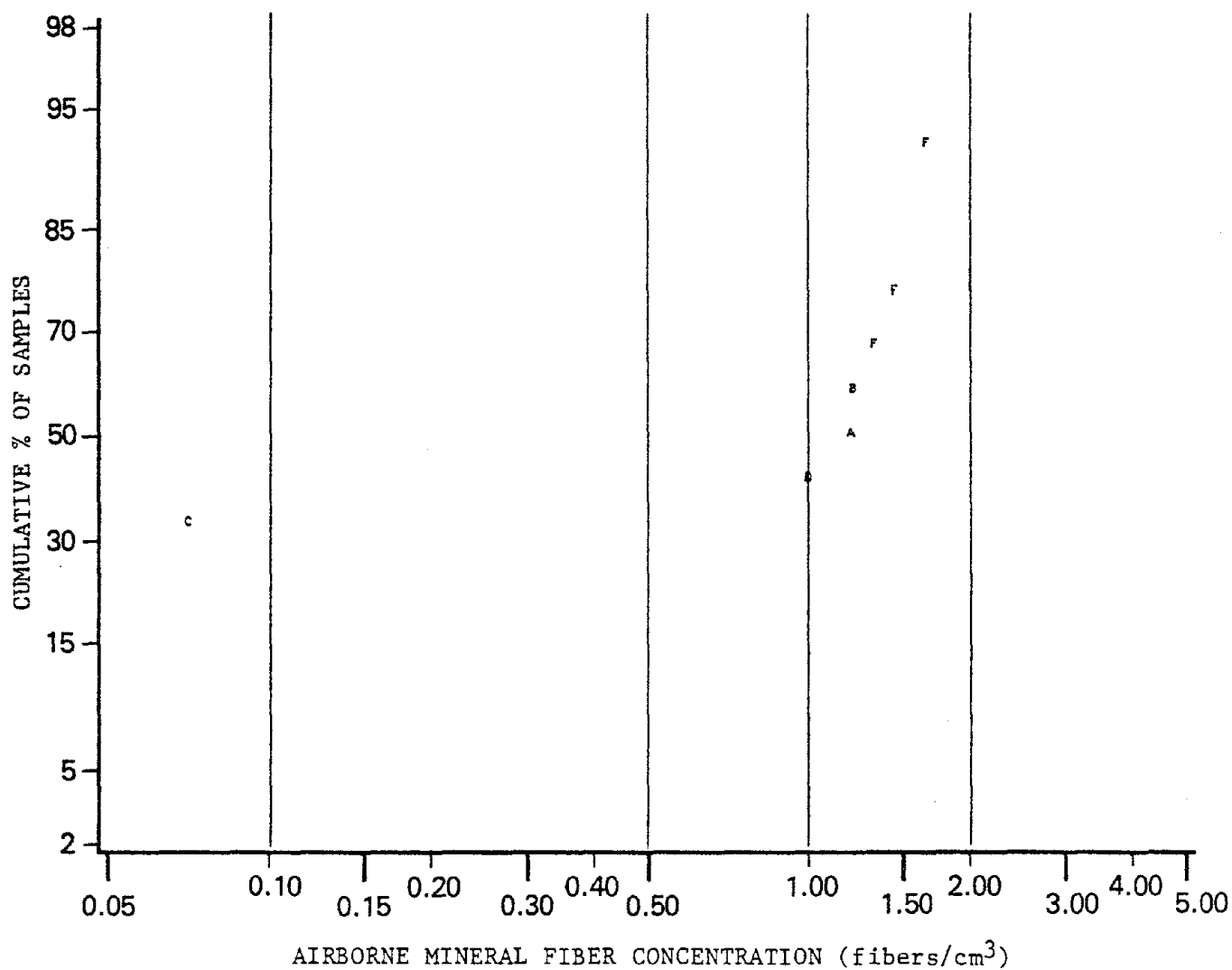
No. of samples: 185
 No. of mine ID's represented: 15
 No. of active sites in 1980: 58
 Percent of samples less than 0.1 fibers/cm³: 21
 Percent of samples less than 0.5 fibers/cm³: 76
 Percent of samples less than 1.0 fibers/cm³: 92
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-6. Airborne mineral fiber concentrations found in crushing, grinding, and sizing operations in the iron industry group (area samples).



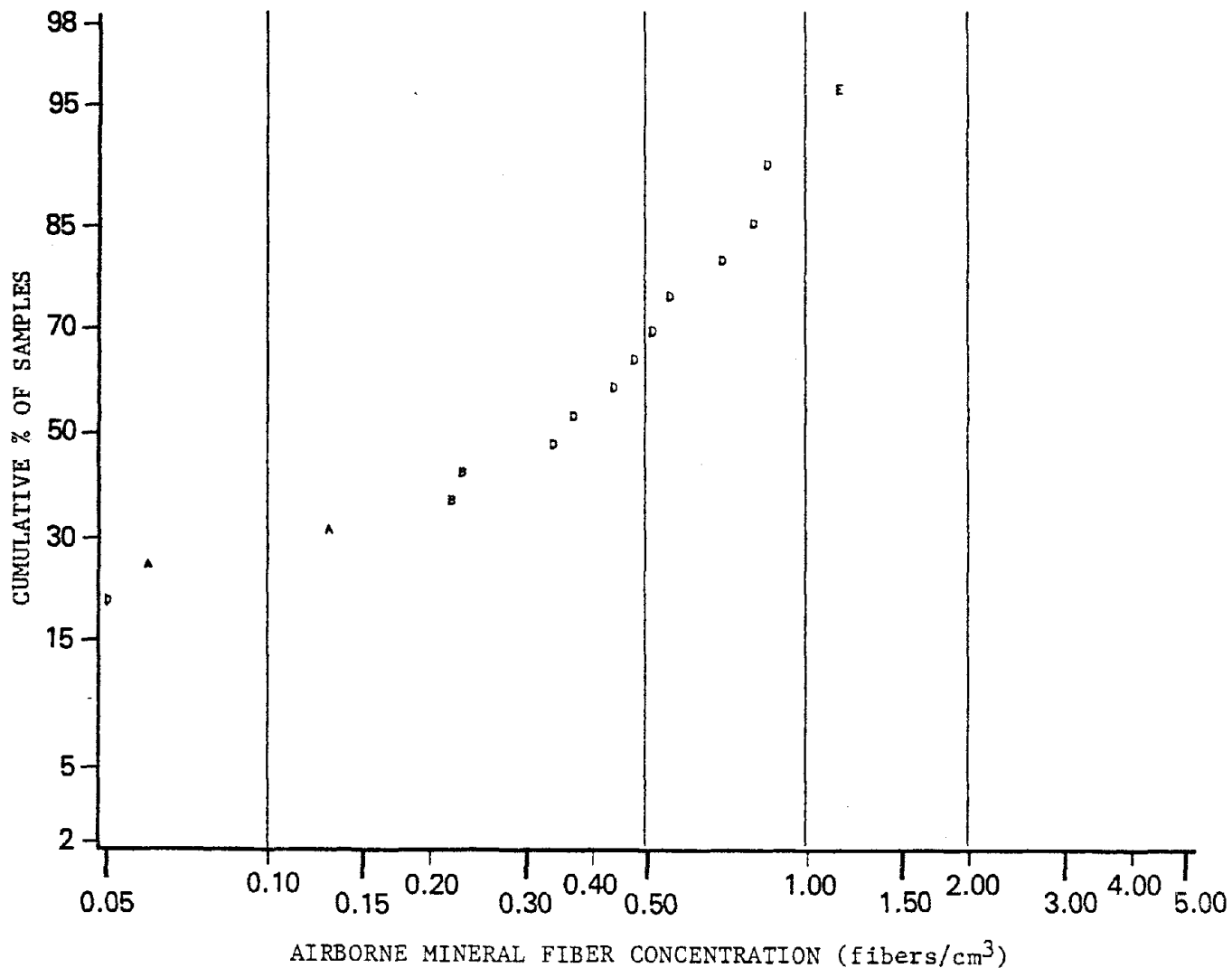
No. of samples: 7
 No. of mine ID's represented: 5
 No. of active sites in 1980: 2094
 Percent of samples less than 0.1 fibers/cm³: 14
 Percent of samples less than 0.5 fibers/cm³: 43
 Percent of samples less than 1.0 fibers/cm³: 57
 Percent of samples less than 2.0 fibers/cm³: 71

Figure B-7. Airborne mineral fiber concentrations
 found in cutting and boring operations
 in the limestone industry group
 (area samples).



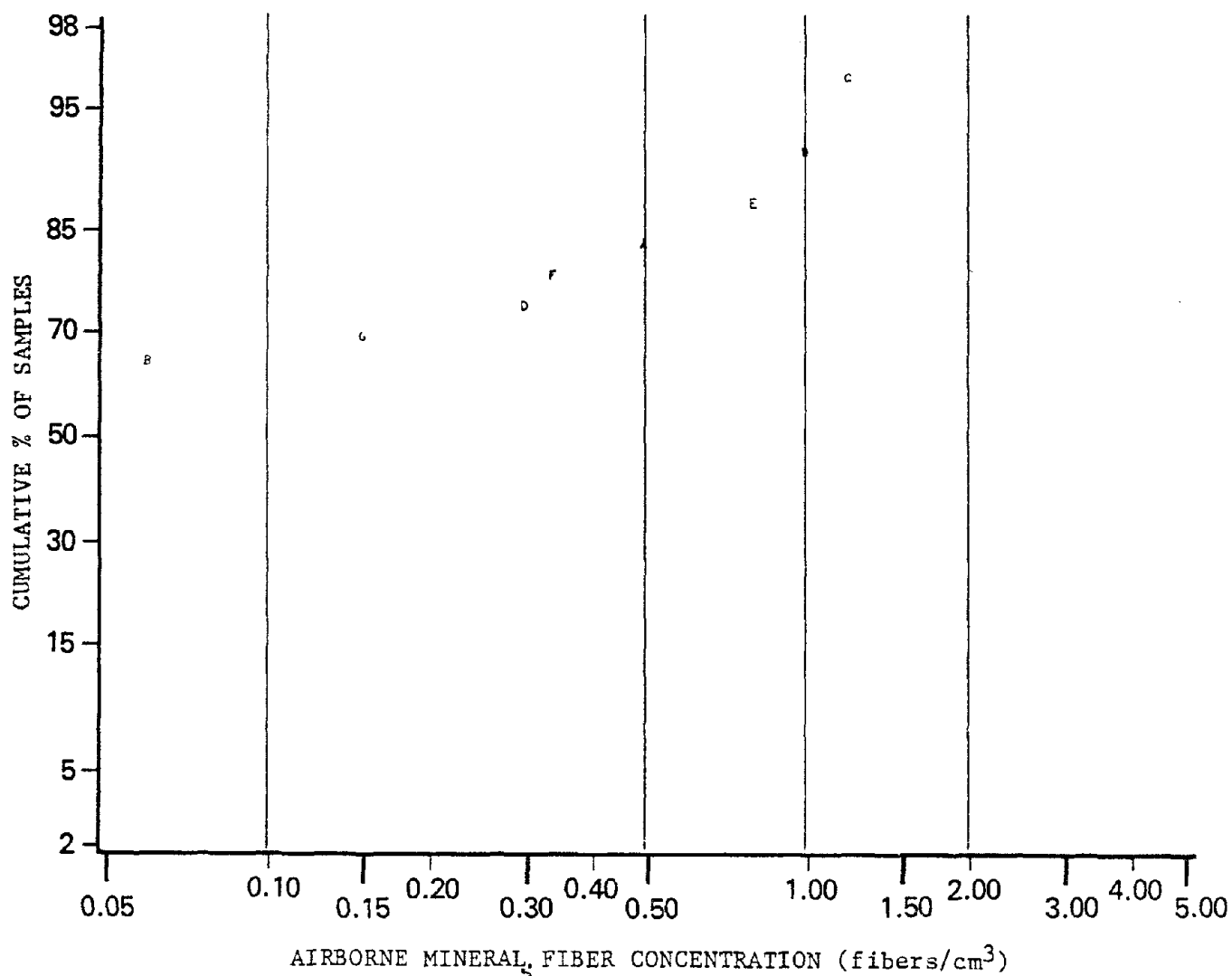
No. of samples: 12
 No. of mine ID's represented: 7
 No. of active sites in 1980: 2094
 Percent of samples less than 0.1 fibers/cm³: 33
 Percent of samples less than 0.5 fibers/cm³: 33
 Percent of samples less than 1.0 fibers/cm³: 33
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-8. Airborne mineral fiber concentrations found in drilling operations in the limestone industry group (area samples).



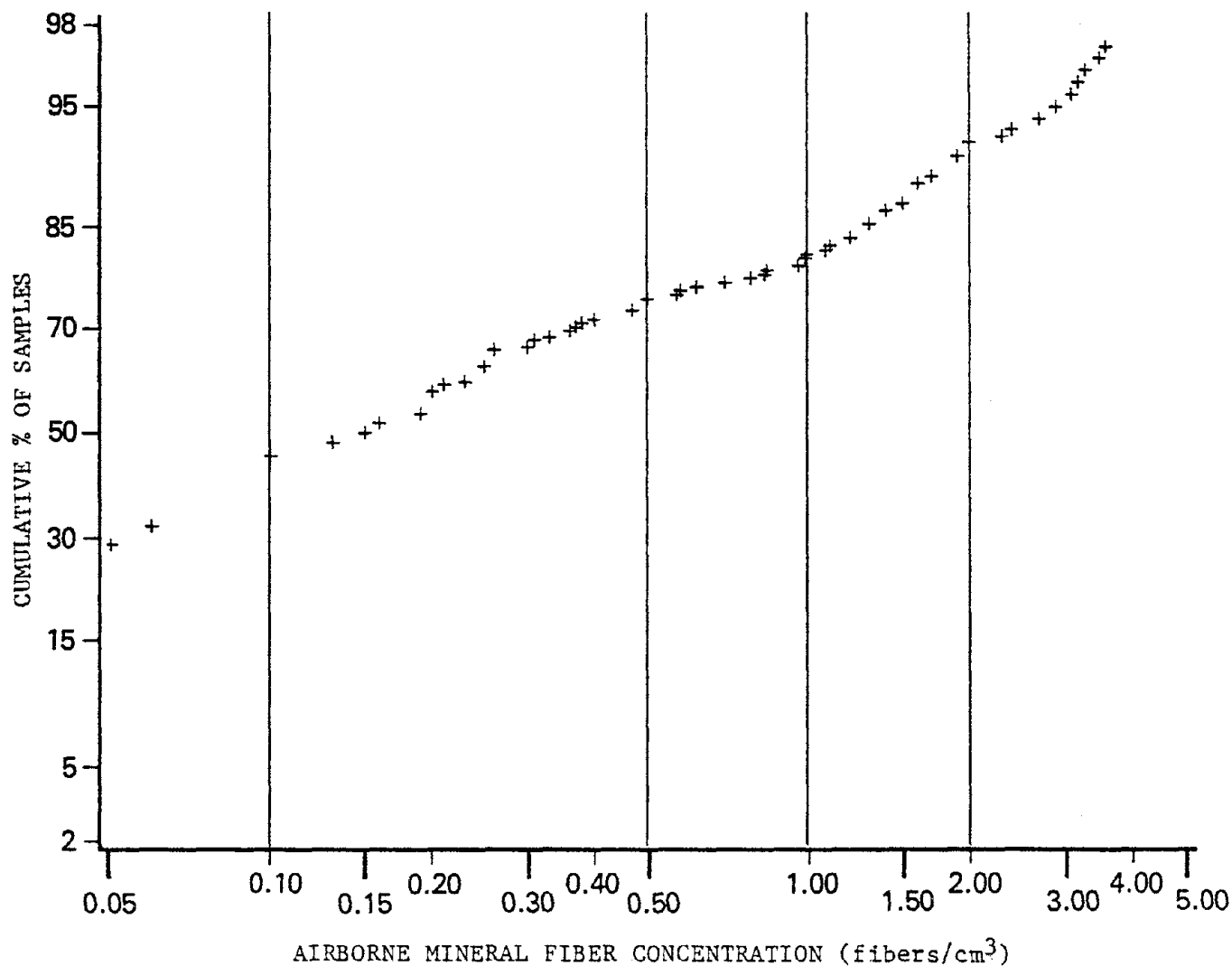
No. of samples: 19
 No. of mine ID's represented: 5
 No. of active sites in 1980: 2094
 Percent of samples less than 0.1 fibers/cm³: 26
 Percent of samples less than 0.5 fibers/cm³: 63
 Percent of samples less than 1.0 fibers/cm³: 89
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-9. Airborne mineral fiber concentrations found in mobile transport operations in the limestone industry group (area samples).



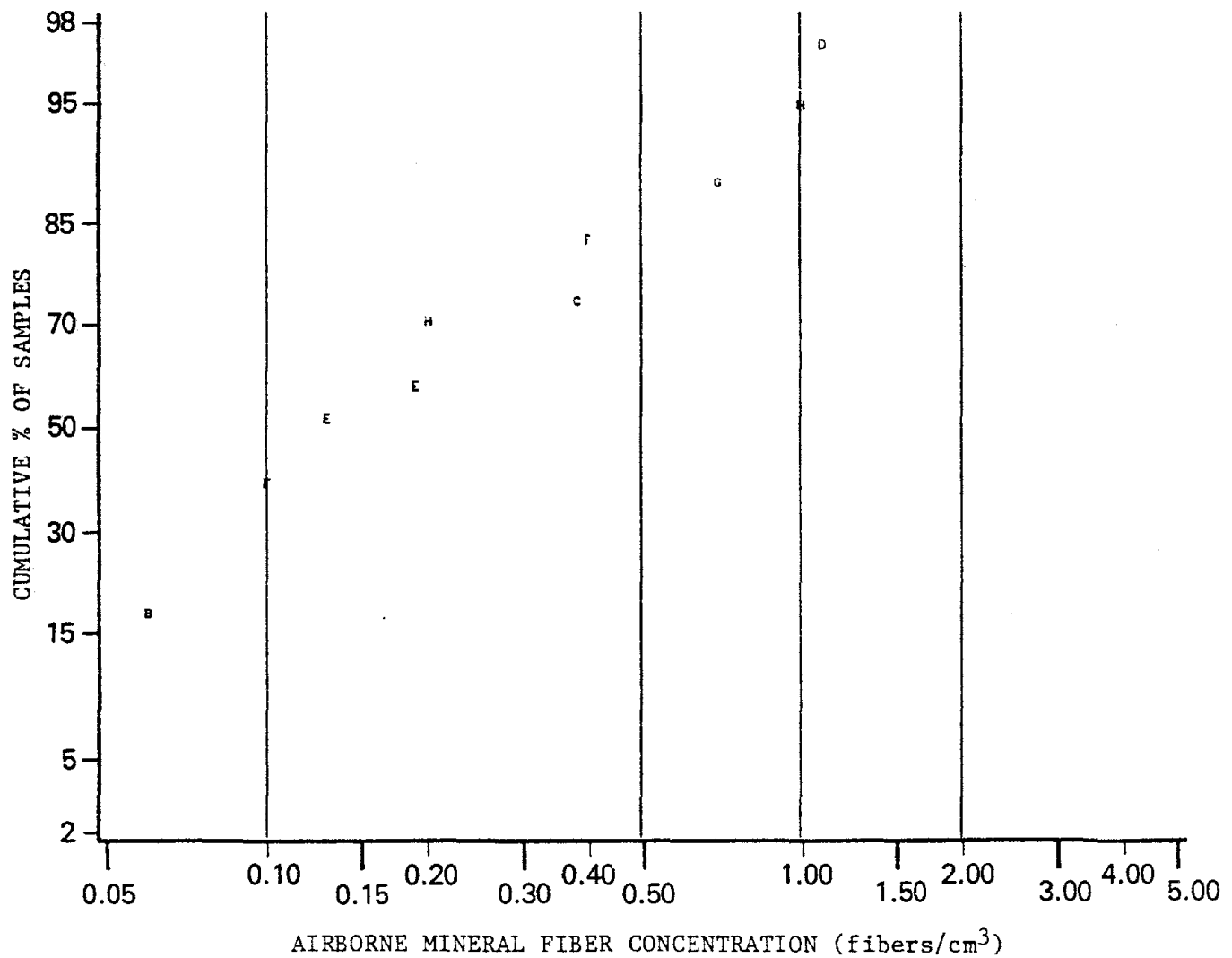
No. of samples: 22
 No. of mine ID's represented: 11
 No. of active sites in 1980: 2094
 Percent of samples less than 0.1 fibers/cm³: 64
 Percent of samples less than 0.5 fibers/cm³: 77
 Percent of samples less than 1.0 fibers/cm³: 86
 Percent of samples less than 2.0 fibers/cm³: 95

Figure B-10. Airborne mineral fiber concentrations found in crushing, grinding, and sizing operations (surface and underground) in the limestone industry group (personal samples).



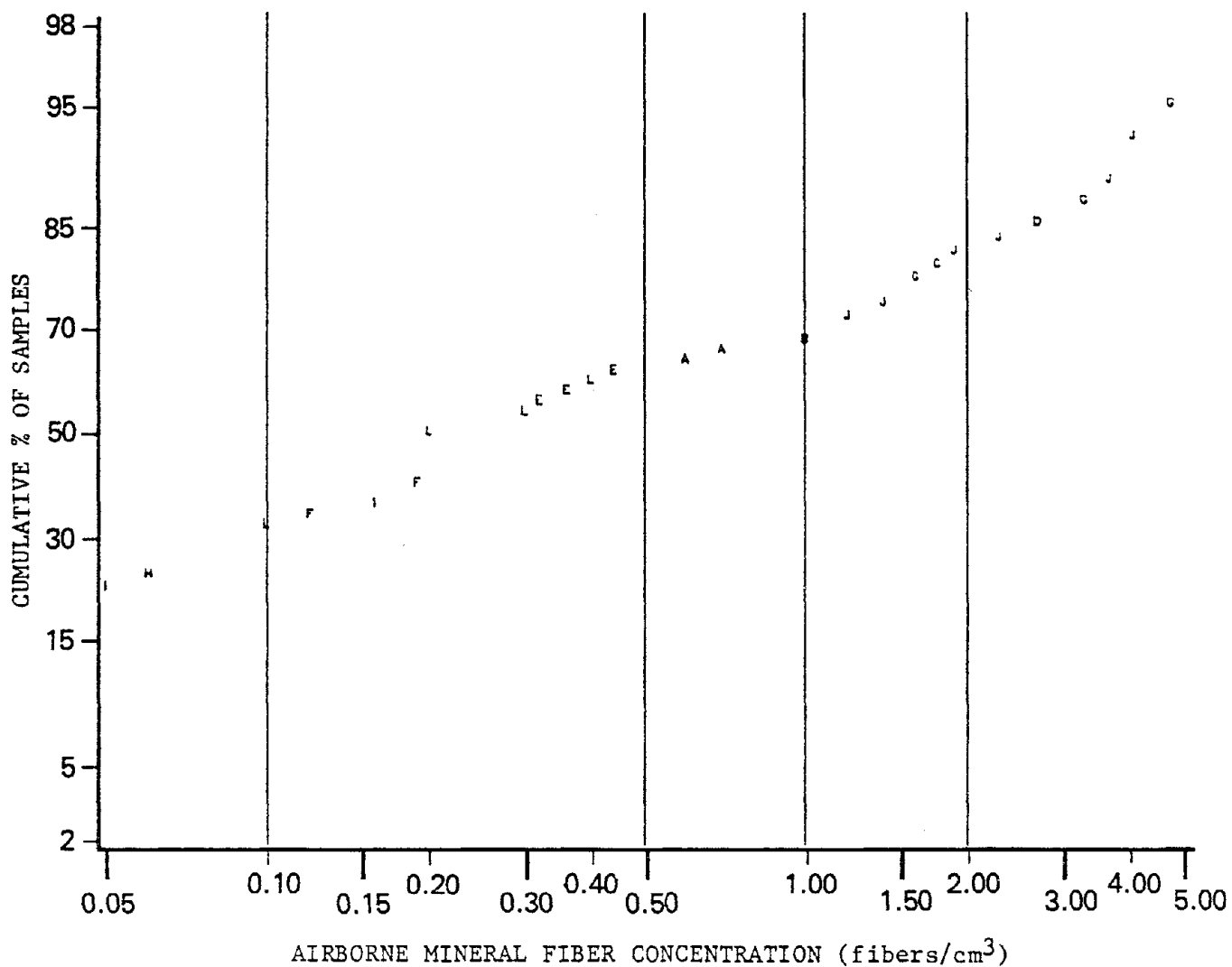
No. of samples: 167
 No. of mine ID's represented: 63
 No. of active sites in 1980: 2094
 Percent of samples less than 0.1 fibers/cm³: 32
 Percent of samples less than 0.5 fibers/cm³: 72
 Percent of samples less than 1.0 fibers/cm³: 80
 Percent of samples less than 2.0 fibers/cm³: 90

Figure B-11. Airborne mineral fiber concentrations found in crushing, grinding, and sizing operations in the limestone industry group (area samples).



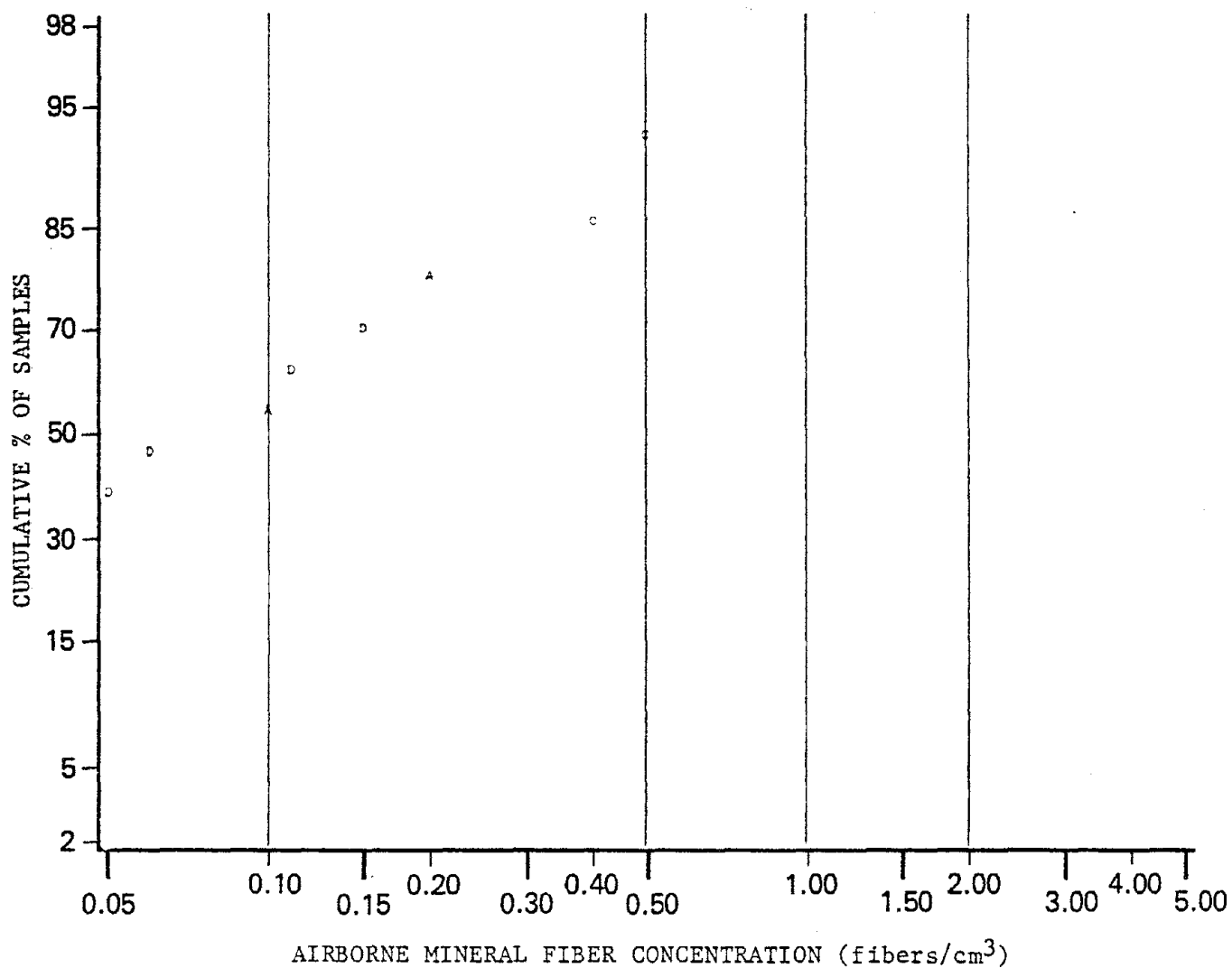
No. of samples: 33
 No. of mine ID's represented: 18
 No. of active sites in 1980: 925
 Percent of samples less than 0.1 fibers/cm³: 18
 Percent of samples less than 0.5 fibers/cm³: 82
 Percent of samples less than 1.0 fibers/cm³: 88
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-12. Airborne mineral fiber concentrations found in cutting and boring operations in the other stone industry group (area samples).



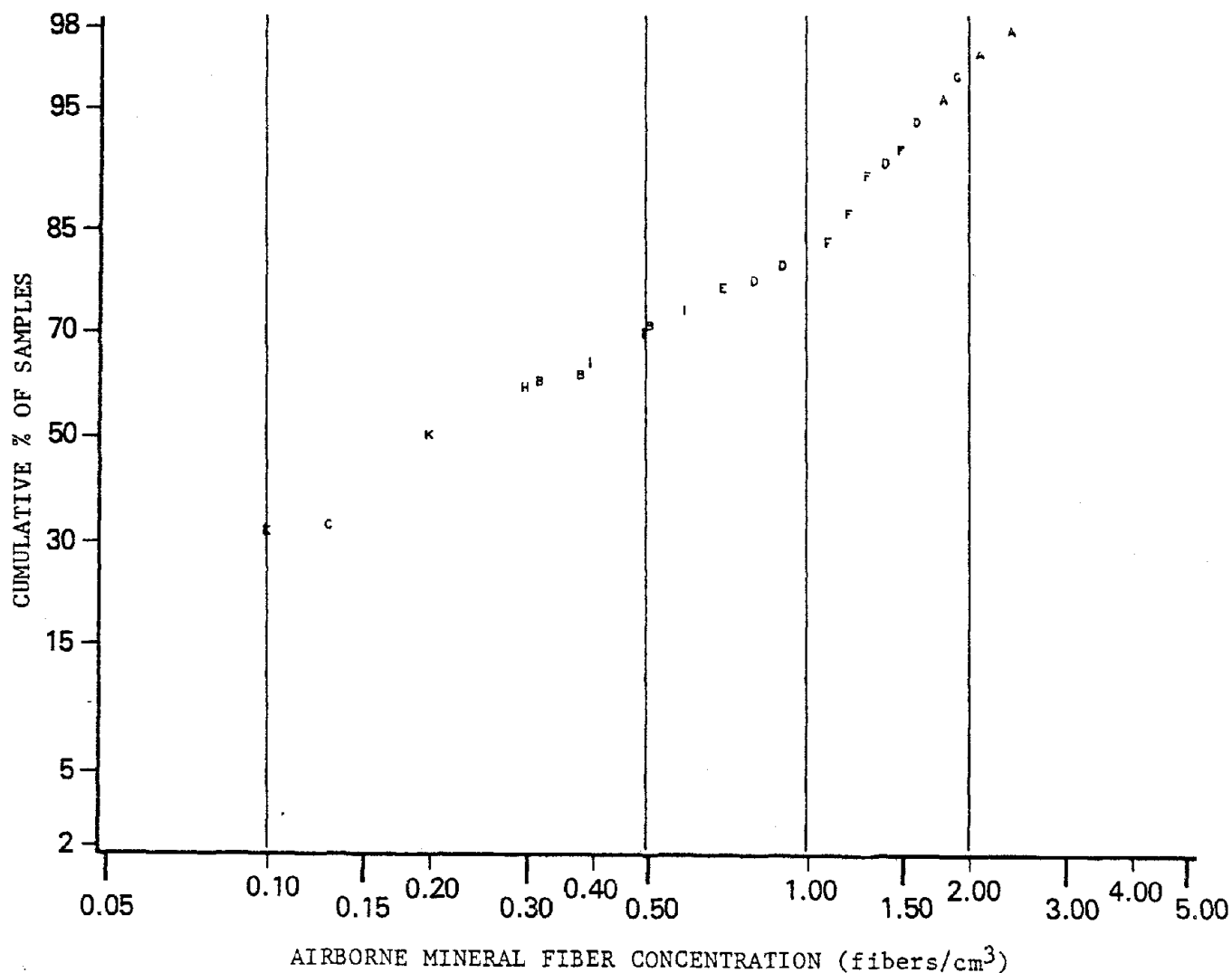
No. of samples: 52
 No. of mine ID's represented: 18
 No. of active sites in 1980: 925
 Percent of samples less than 0.1 fibers/cm³: 25
 Percent of samples less than 0.5 fibers/cm³: 62
 Percent of samples less than 1.0 fibers/cm³: 65
 Percent of samples less than 2.0 fibers/cm³: 81

Figure B-13. Airborne mineral fiber concentrations found in drilling operations in the other stone industry group (area samples).



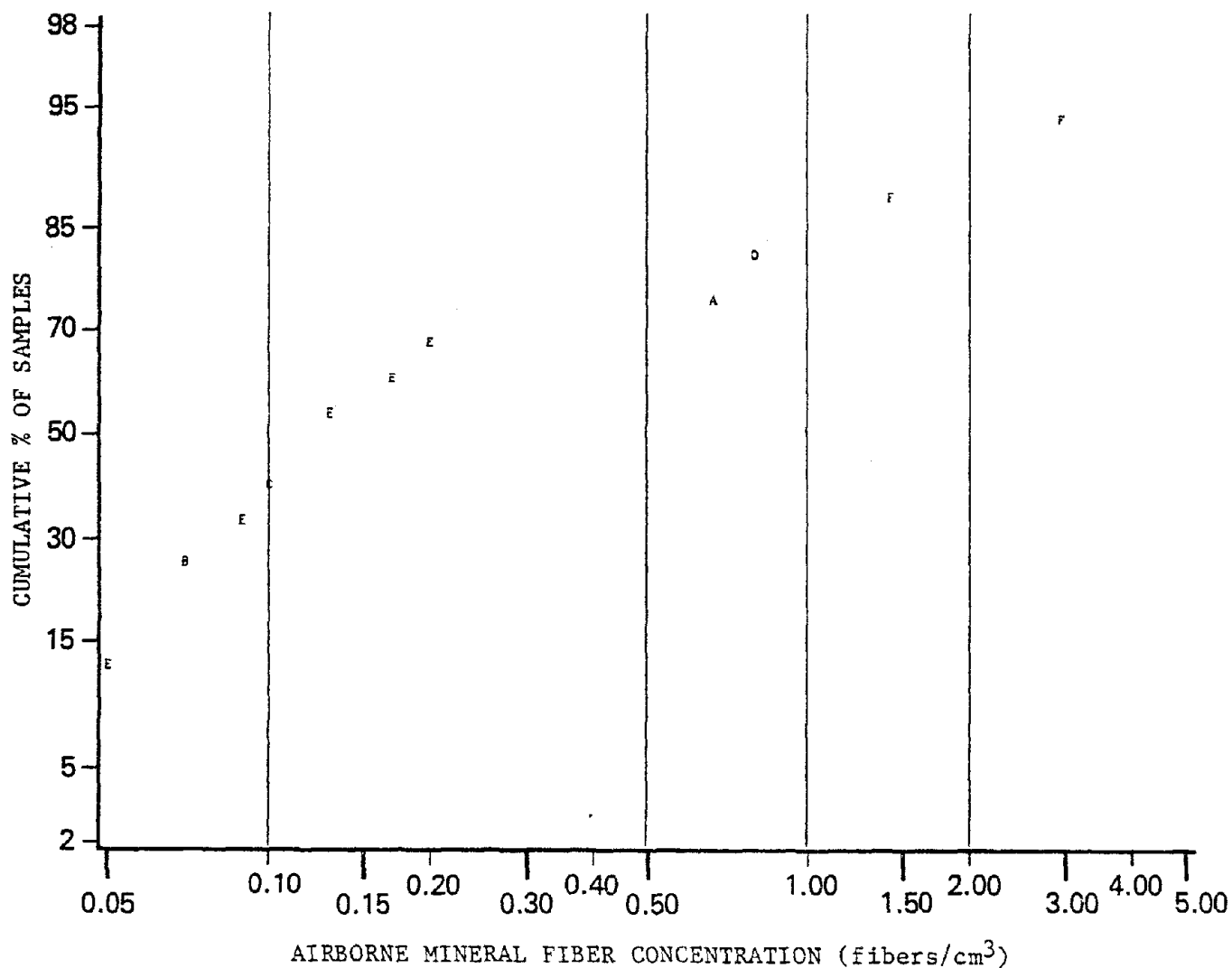
No. of samples: 13
 No. of mine ID's represented: 4
 No. of active sites in 1980: 832
 Percent of samples less than 0.1 fibers/cm³: 46
 Percent of samples less than 0.5 fibers/cm³: 85
 Percent of samples less than 1.0 fibers/cm³: 100
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-14. Airborne mineral fiber concentrations found in surface mobile transport operations in the other stone industry group (personal samples).



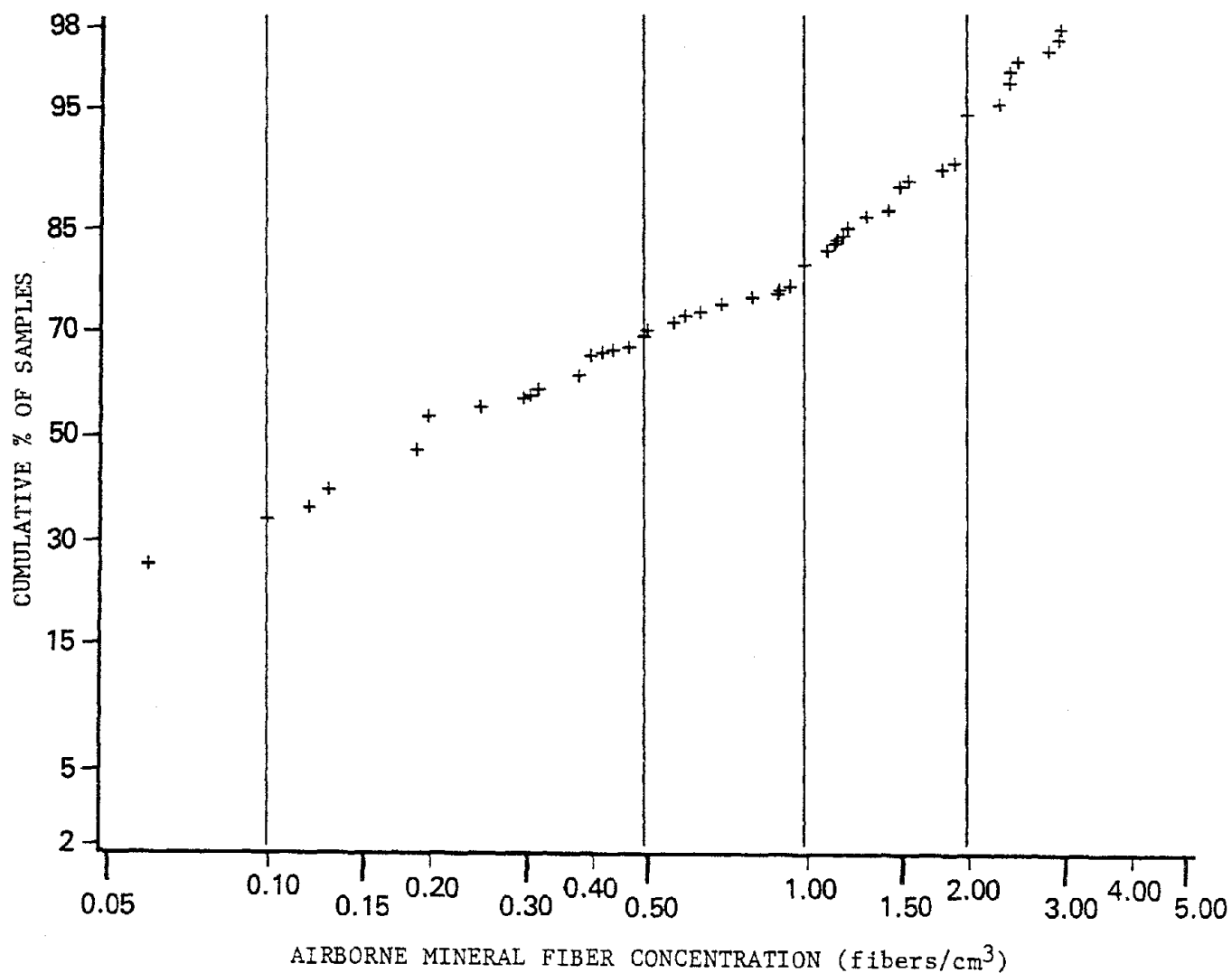
No. of samples: 90
 No. of mine ID's represented: 15
 No. of active sites in 1980: 925
 Percent of samples less than 0.1 fibers/cm³: 12
 Percent of samples less than 0.5 fibers/cm³: 63
 Percent of samples less than 1.0 fibers/cm³: 79
 Percent of samples less than 2.0 fibers/cm³: 96

Figure B-15. Airborne mineral fiber concentrations found in mobile transport operations in the other stone industry group (area samples).



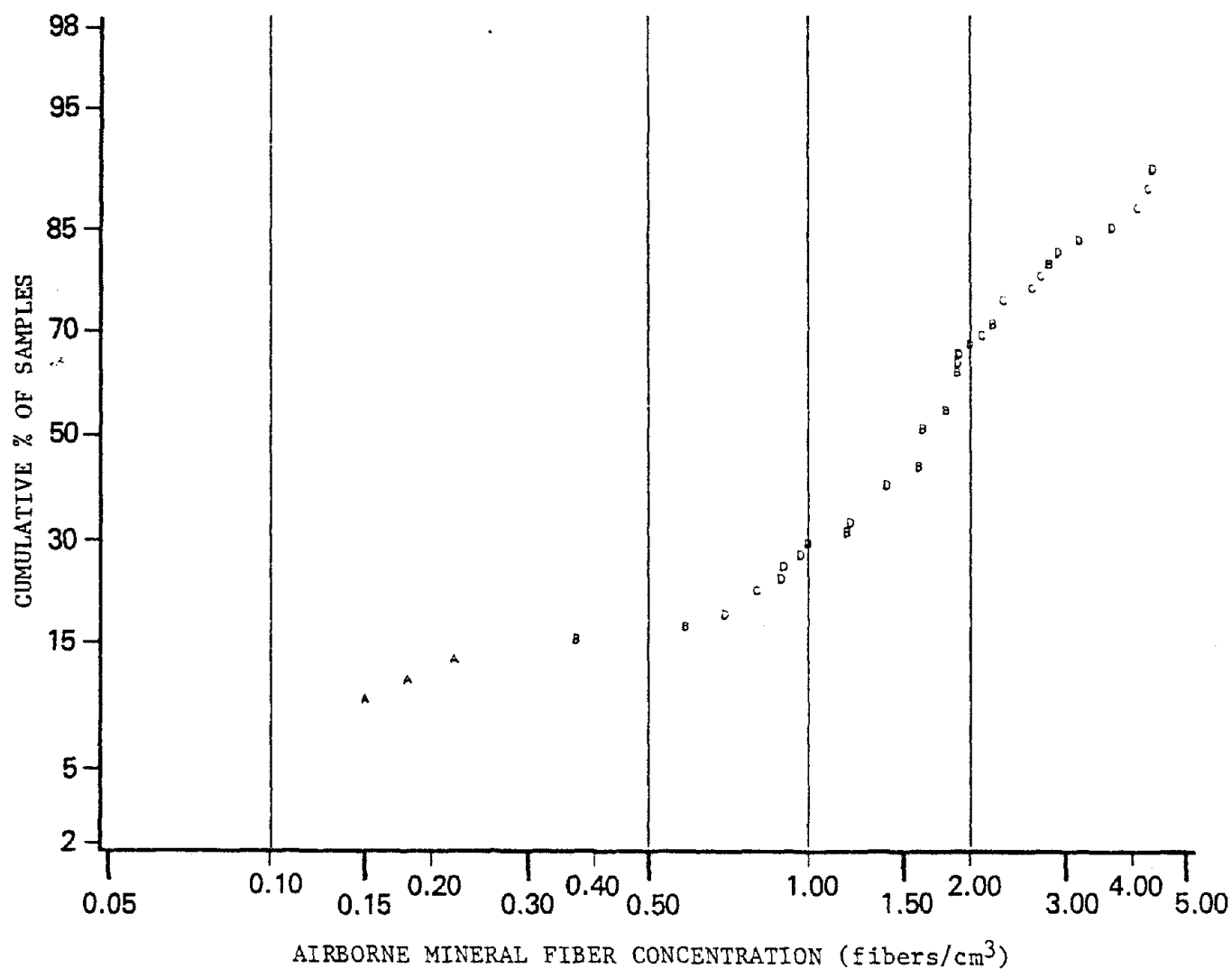
No. of samples: 15
 No. of mine ID's represented: 6
 No. of active sites in 1980: 925
 Percent of samples less than 0.1 fibers/cm³: 33
 Percent of samples less than 0.5 fibers/cm³: 67
 Percent of samples less than 1.0 fibers/cm³: 80
 Percent of samples less than 2.0 fibers/cm³: 87

Figure B-16. Airborne mineral fiber concentrations found in crushing, grinding, and sizing operations (surface and underground) in the other stone industry group (personal samples).



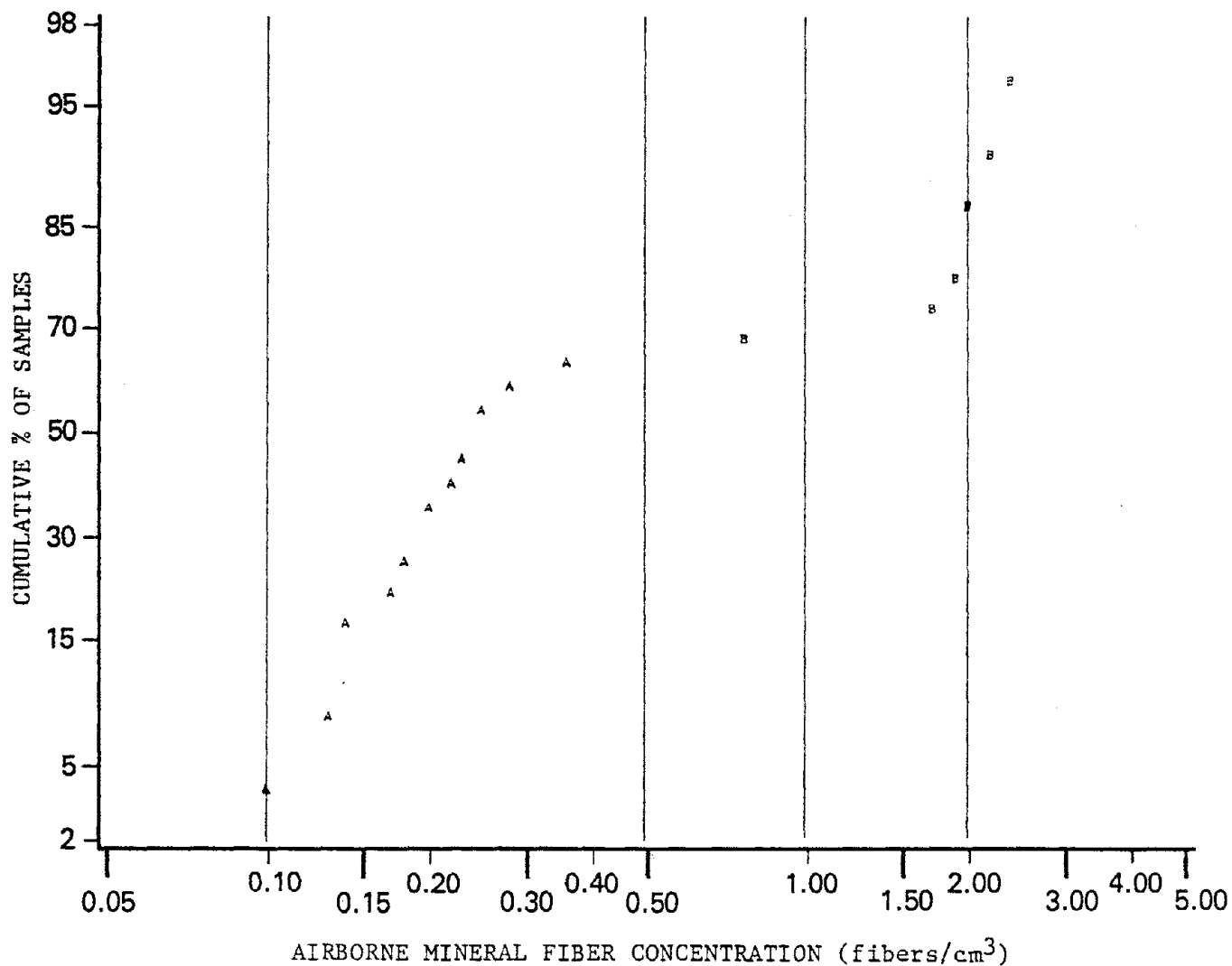
No. of samples: 189
 No. of mine ID's represented: 64
 No. of active sites in 1980: 925
 Percent of samples less than 0.1 fibers/cm³: 27
 Percent of samples less than 0.5 fibers/cm³: 66
 Percent of samples less than 1.0 fibers/cm³: 76
 Percent of samples less than 2.0 fibers/cm³: 90

Figure B-17. Airborne mineral fiber concentrations found in crushing, grinding, and sizing operations in the other stone industry group (area samples).



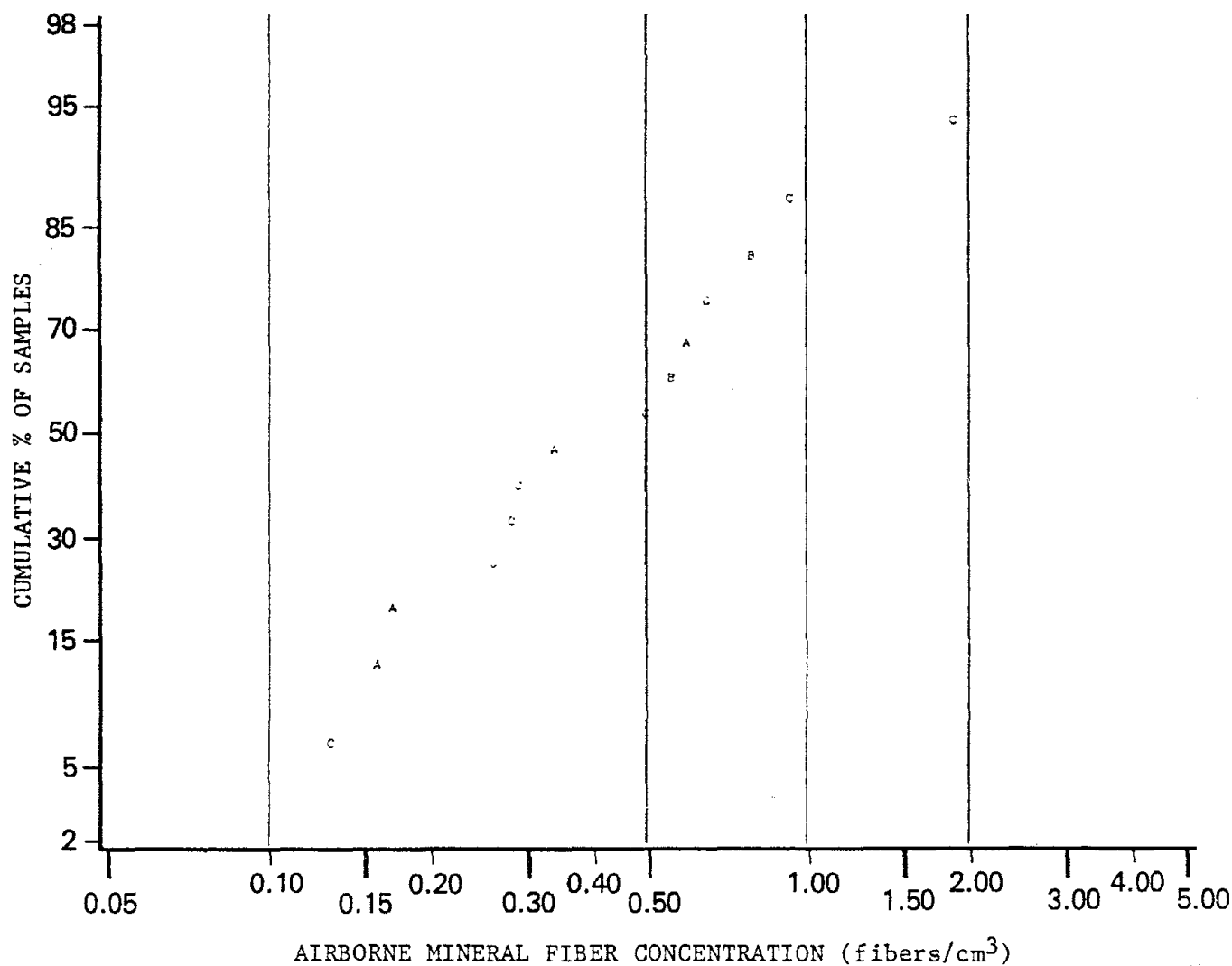
No. of samples: 57
 No. of mine ID's represented: 4
 No. of active sites in 1980: 7
 Percent of samples less than 0.1 fibers/cm³: 9
 Percent of samples less than 0.5 fibers/cm³: 16
 Percent of samples less than 1.0 fibers/cm³: 28
 Percent of samples less than 2.0 fibers/cm³: 65

Figure B-18. Airborne mineral fiber concentrations
 found in nonspecific surface operations
 in the asbestos industry group (personal
 samples).



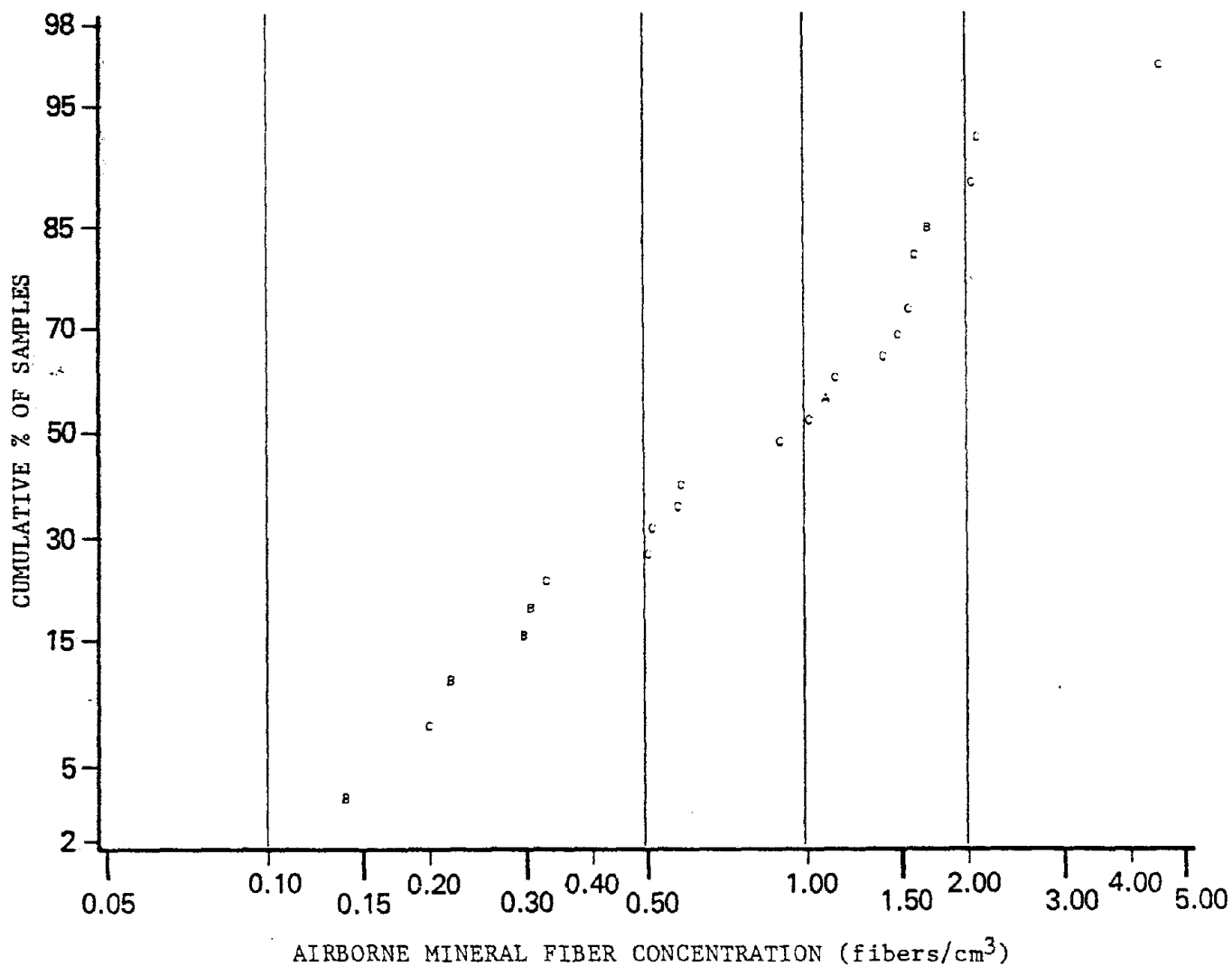
No. of samples: 22
 No. of mine ID's represented: 2
 No. of active sites in 1980: 7
 Percent of samples less than 0.1 fibers/cm³: 0
 Percent of samples less than 0.5 fibers/cm³: 64
 Percent of samples less than 1.0 fibers/cm³: 68
 Percent of samples less than 2.0 fibers/cm³: 77

Figure B-19. Airborne mineral fiber concentrations found in nonspecific underground operations in the asbestos industry group (personal samples).



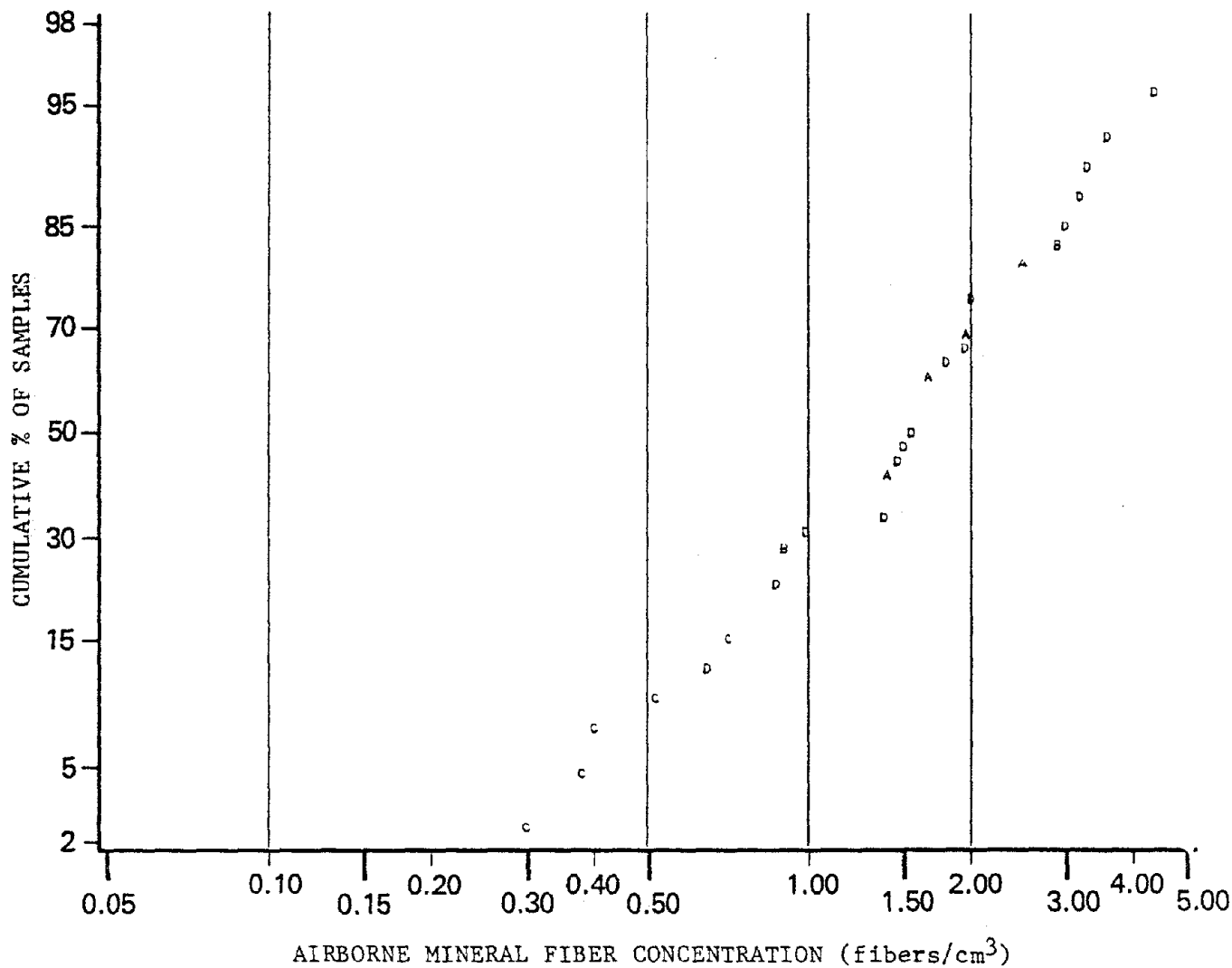
No. of samples: 15
 No. of mine ID's represented: 3
 No. of active sites in 1980: 3
 Percent of samples less than 0.1 fibers/cm³: 0
 Percent of samples less than 0.5 fibers/cm³: 47
 Percent of samples less than 1.0 fibers/cm³: 87
 Percent of samples less than 2.0 fibers/cm³: 93

Figure B-20. Airborne mineral fiber concentrations found in surface mobile transport operations in the asbestos industry group (personal samples).



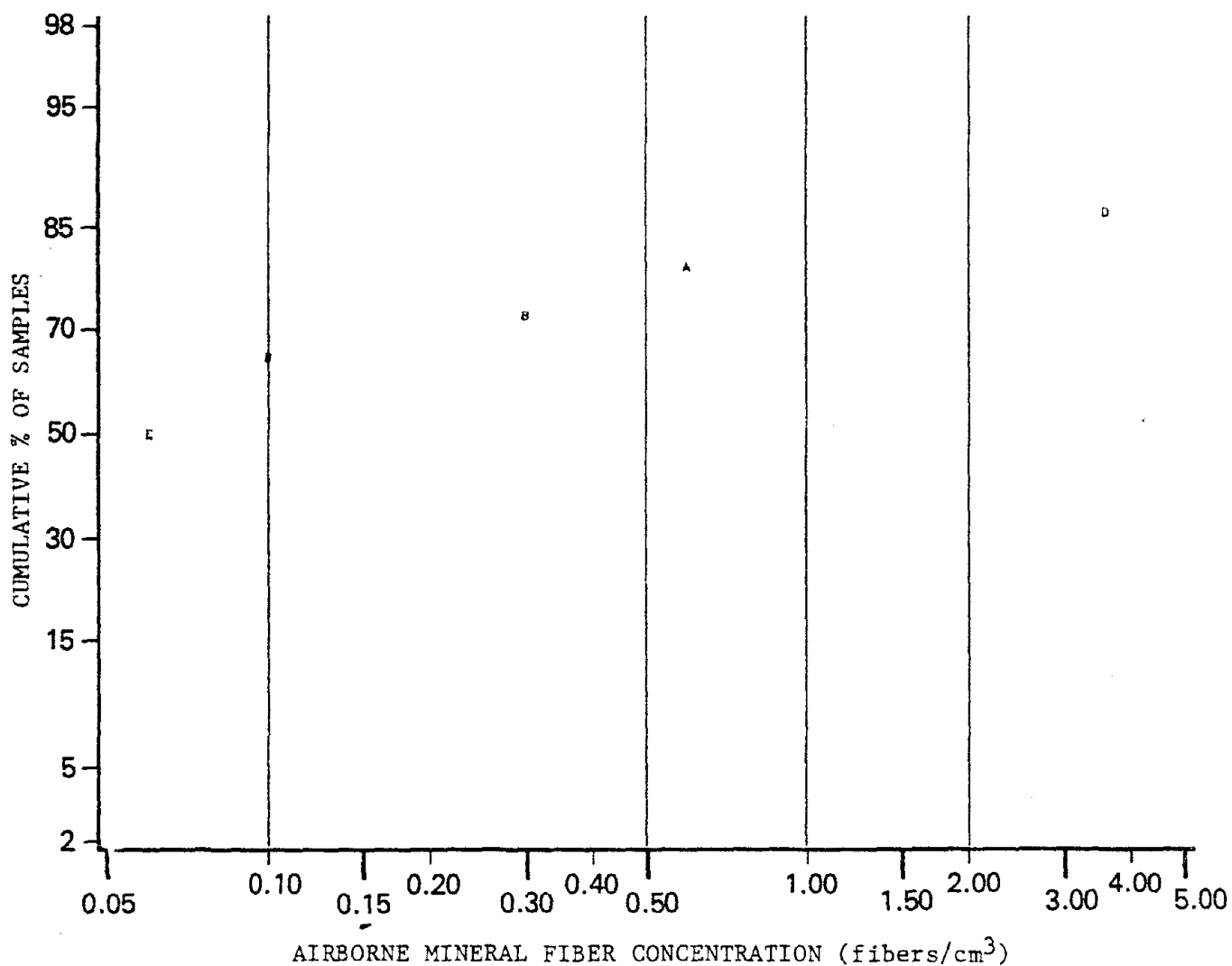
No. of samples: 25
 No. of mine ID's represented: 3
 No. of active sites in 1980: 7
 Percent of samples less than 0.1 fibers/cm³: 0
 Percent of samples less than 0.5 fibers/cm³: 24
 Percent of samples less than 1.0 fibers/cm³: 48
 Percent of samples less than 2.0 fibers/cm³: 84

Figure B -21. Airborne mineral fiber concentrations found in crushing, grinding, and sizing operations (surface and underground) in the asbestos industry group (personal samples).



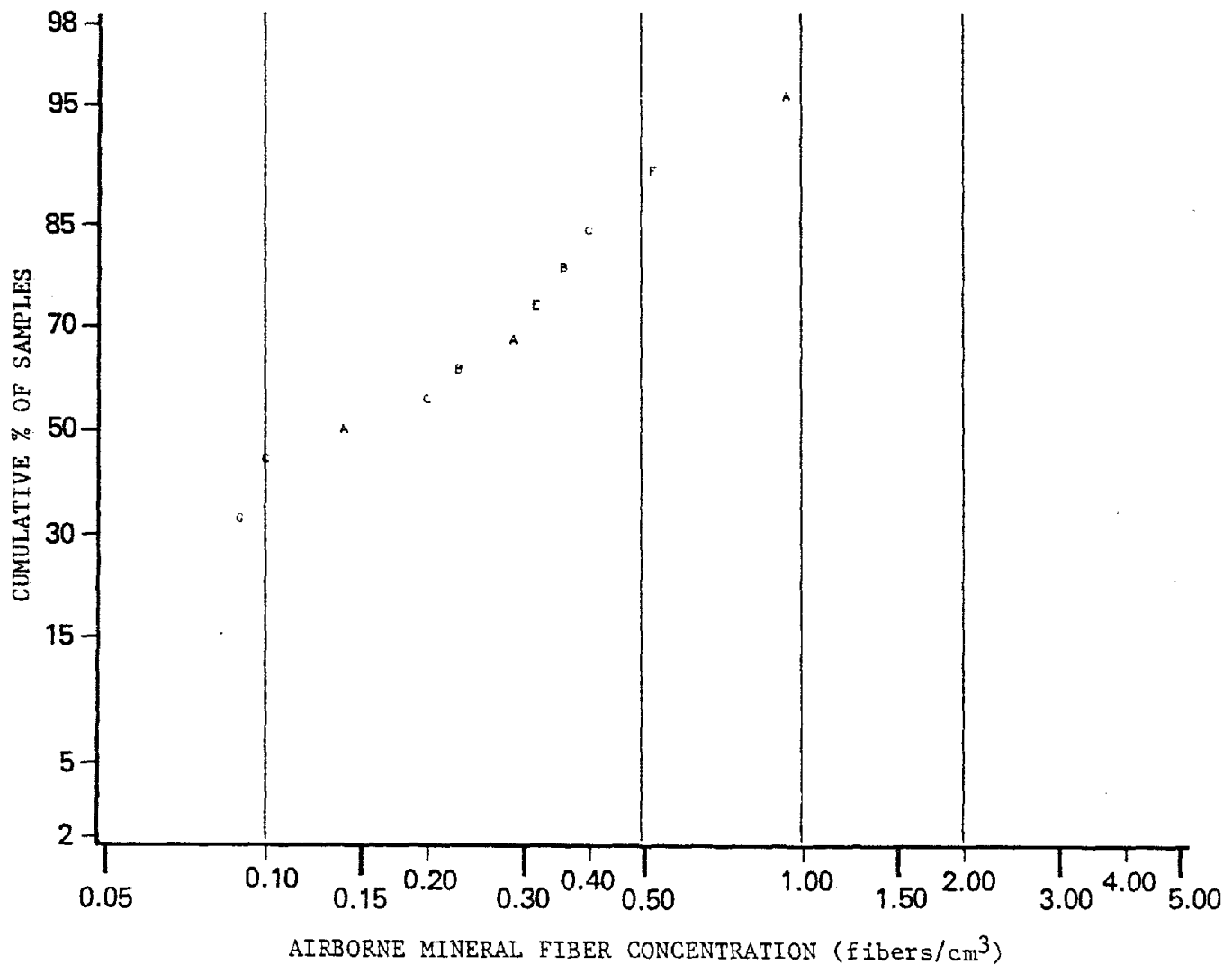
No. of samples: 38
 No. of mine ID's represented: 4
 No. of active sites in 1980: 7
 Percent of samples less than 0.1 fibers/cm³: 0
 Percent of samples less than 0.5 fibers/cm³: 8
 Percent of samples less than 1.0 fibers/cm³: 32
 Percent of samples less than 2.0 fibers/cm³: 68

Figure B-22. Airborne mineral fiber concentrations found in concentrating and finishing operations (surface and underground) in the asbestos industry group (personal samples).



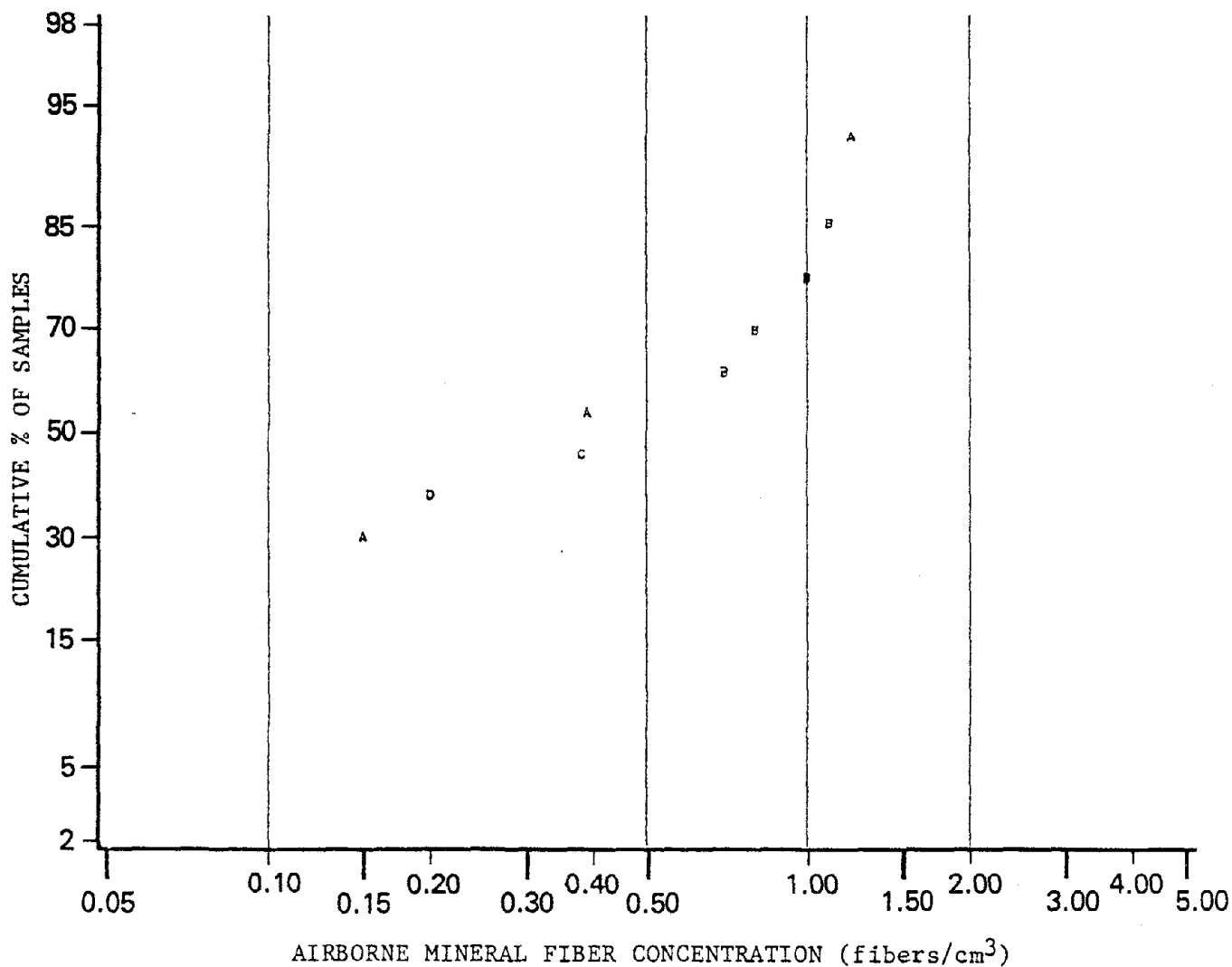
No. of samples: 18
 No. of mine ID's represented: 9
 No. of active sites in 1980: 507
 Percent of samples less than 0.1 fibers/cm³: 39
 Percent of samples less than 0.5 fibers/cm³: 61
 Percent of samples less than 1.0 fibers/cm³: 72
 Percent of samples less than 2.0 fibers/cm³: 78

Figure B-23. Airborne mineral fiber concentrations found in crushing, grinding, and sizing operations in the clay and shale industry group (area samples).



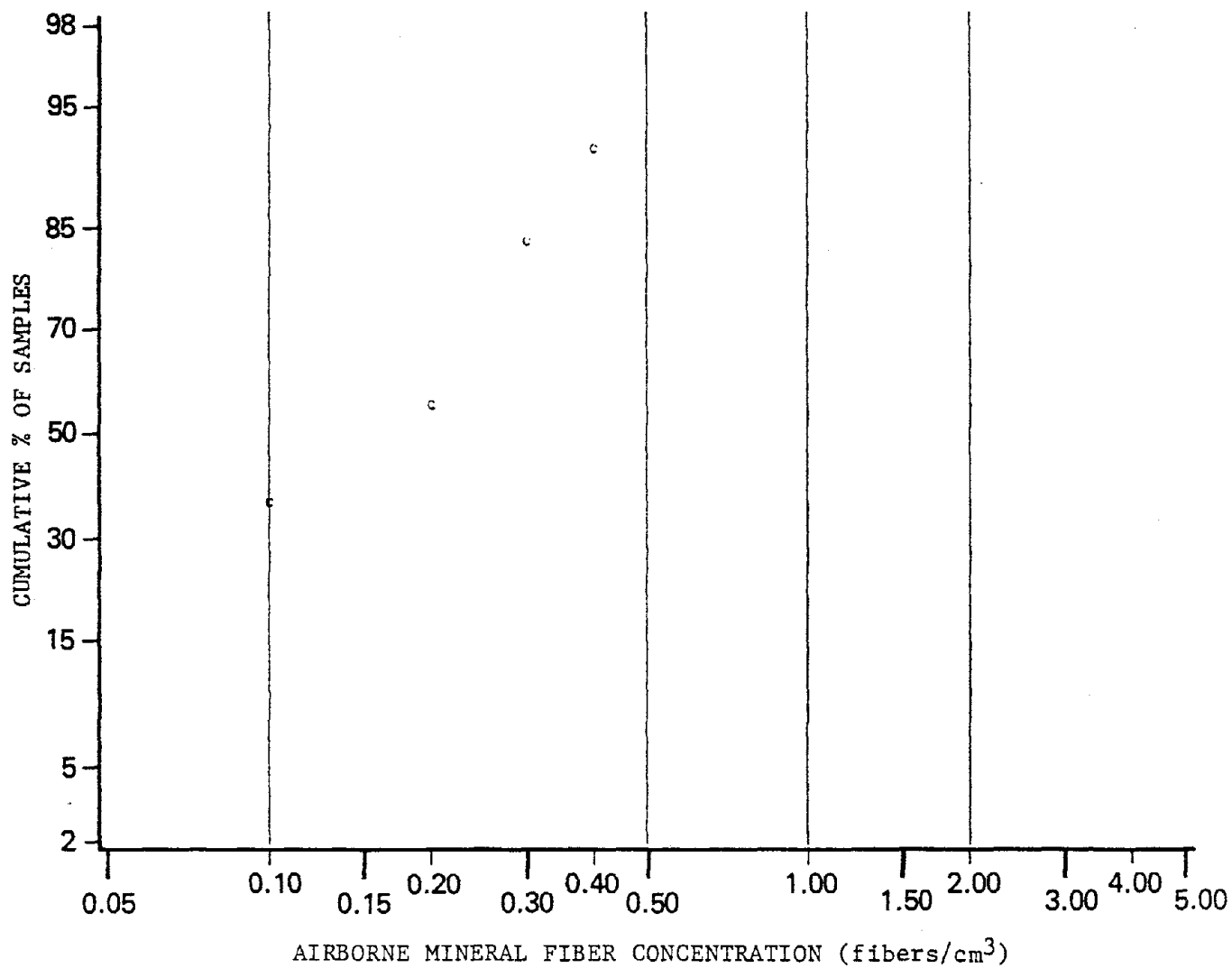
No. of samples: 18
 No. of mine ID's represented: 8
 No. of active sites in 1980: 49
 Percent of samples less than 0.1 fibers/cm³: 33
 Percent of samples less than 0.5 fibers/cm³: 83
 Percent of samples less than 1.0 fibers/cm³: 94
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-24. Airborne mineral fiber concentrations found in nonspecific surface operations in the talc, etc. industry group (personal samples).



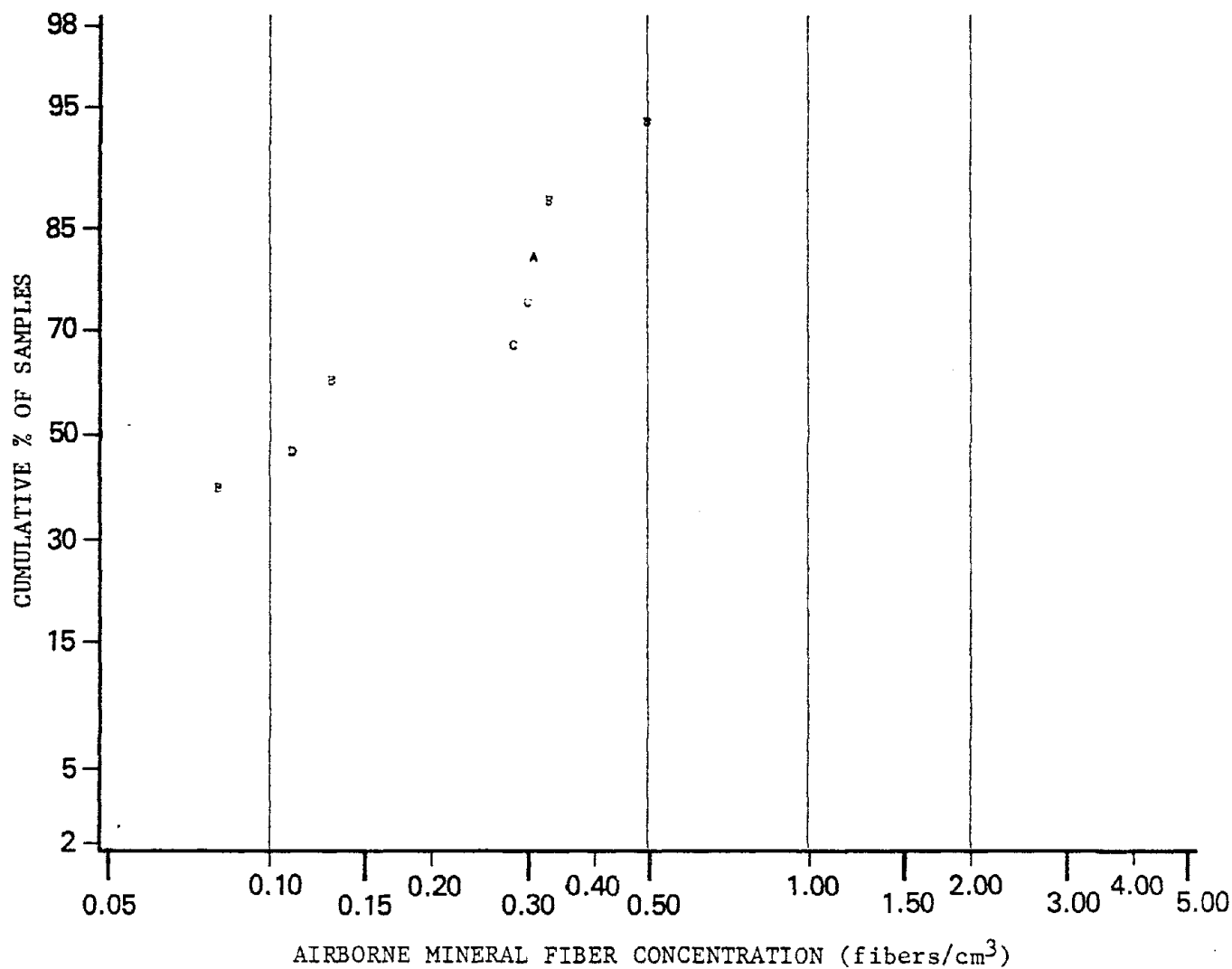
No. of samples: 13
 No. of mine ID's represented: 4
 No. of active sites in 1980: 8
 Percent of samples less than 0.1 fibers/cm³: 23
 Percent of samples less than 0.5 fibers/cm³: 54
 Percent of samples less than 1.0 fibers/cm³: 69
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-25. Airborne mineral fiber concentrations found in underground production operations in the talc, etc. industry group (personal samples).



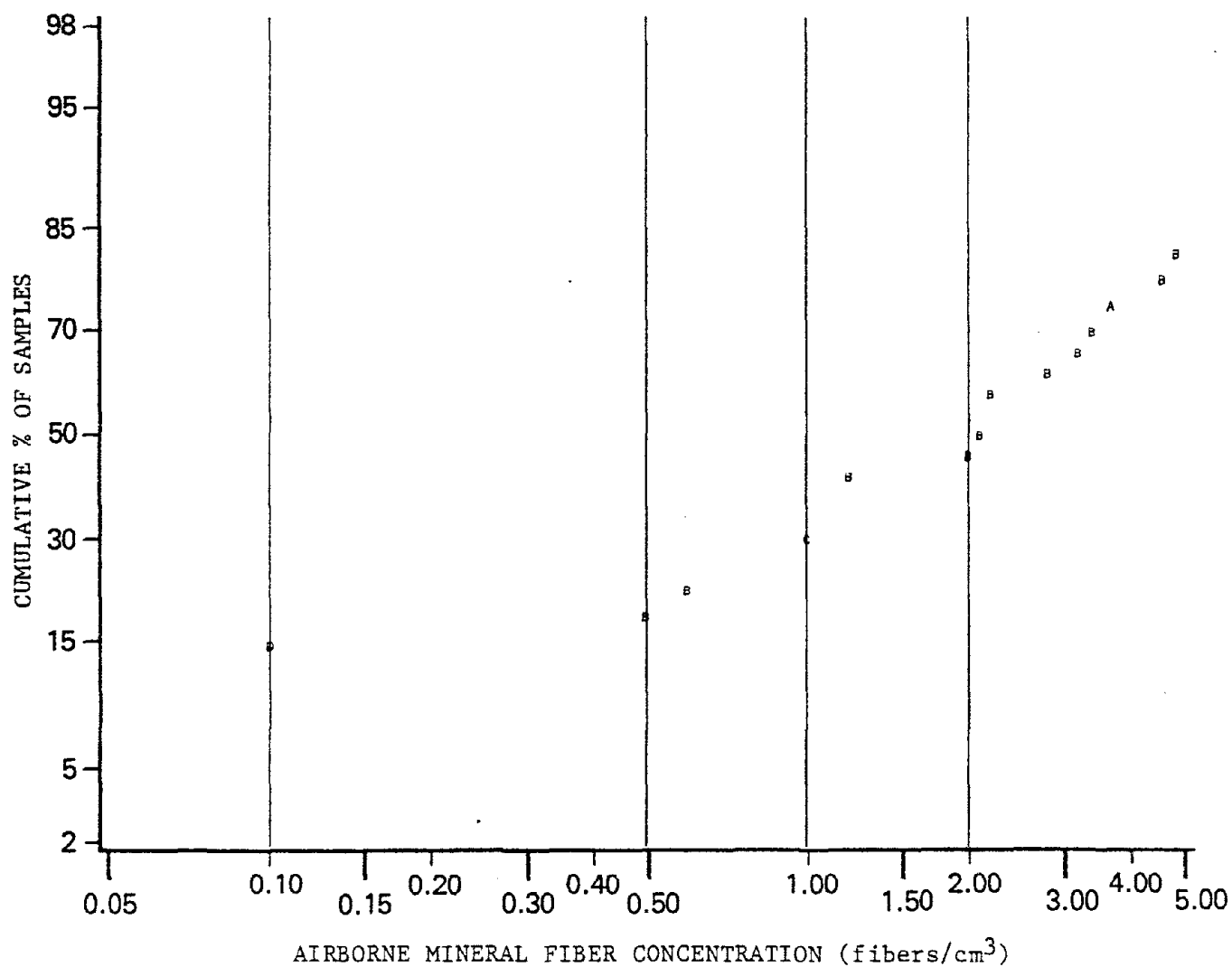
No. of samples: 11
 No. of mine ID's represented: 3
 No. of active sites in 1980: 25
 Percent of samples less than 0.1 fibers/cm³: 9
 Percent of samples less than 0.5 fibers/cm³: 91
 Percent of samples less than 1.0 fibers/cm³: 91
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-26. Airborne mineral fiber concentrations found in surface mobile transport operations in the talc, etc. industry group (personal samples).



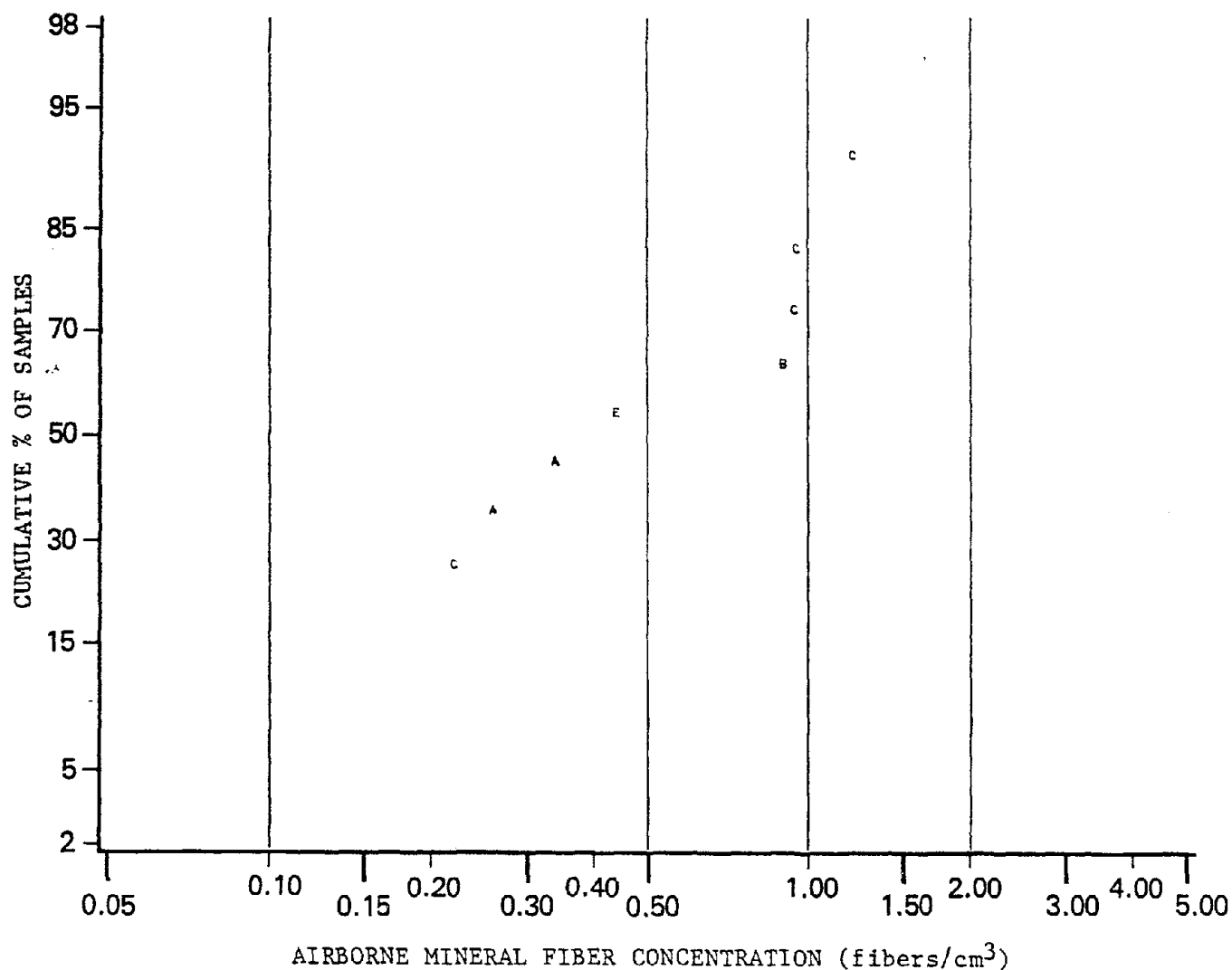
No. of samples: 15
 No. of mine ID's represented: 4
 No. of active sites in 1980: 8
 Percent of samples less than 0.1 fibers/cm³: 40
 Percent of samples less than 0.5 fibers/cm³: 87
 Percent of samples less than 1.0 fibers/cm³: 93
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B -27. Airborne mineral fiber concentrations found in underground mobile transport operations in the talc, etc. industry group (personal samples).



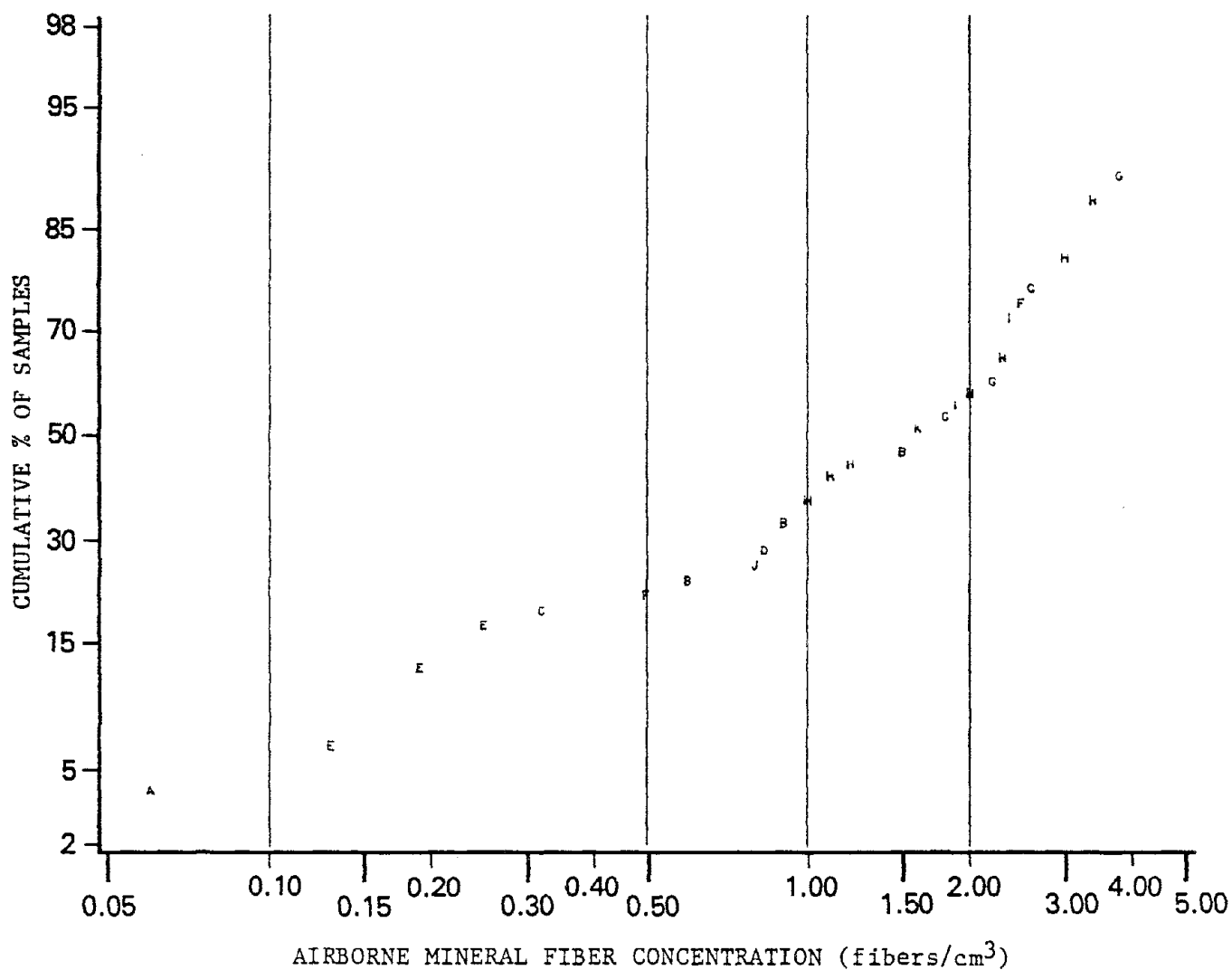
No. of samples: 26
 No. of mine ID's represented: 5
 No. of active sites in 1980: 49
 Percent of samples less than 0.1 fibers/cm³: 12
 Percent of samples less than 0.5 fibers/cm³: 15
 Percent of samples less than 1.0 fibers/cm³: 23
 Percent of samples less than 2.0 fibers/cm³: 42

Figure B-28. Airborne mineral fiber concentrations found in mobile transport operations in the talc, etc. industry group (area samples).



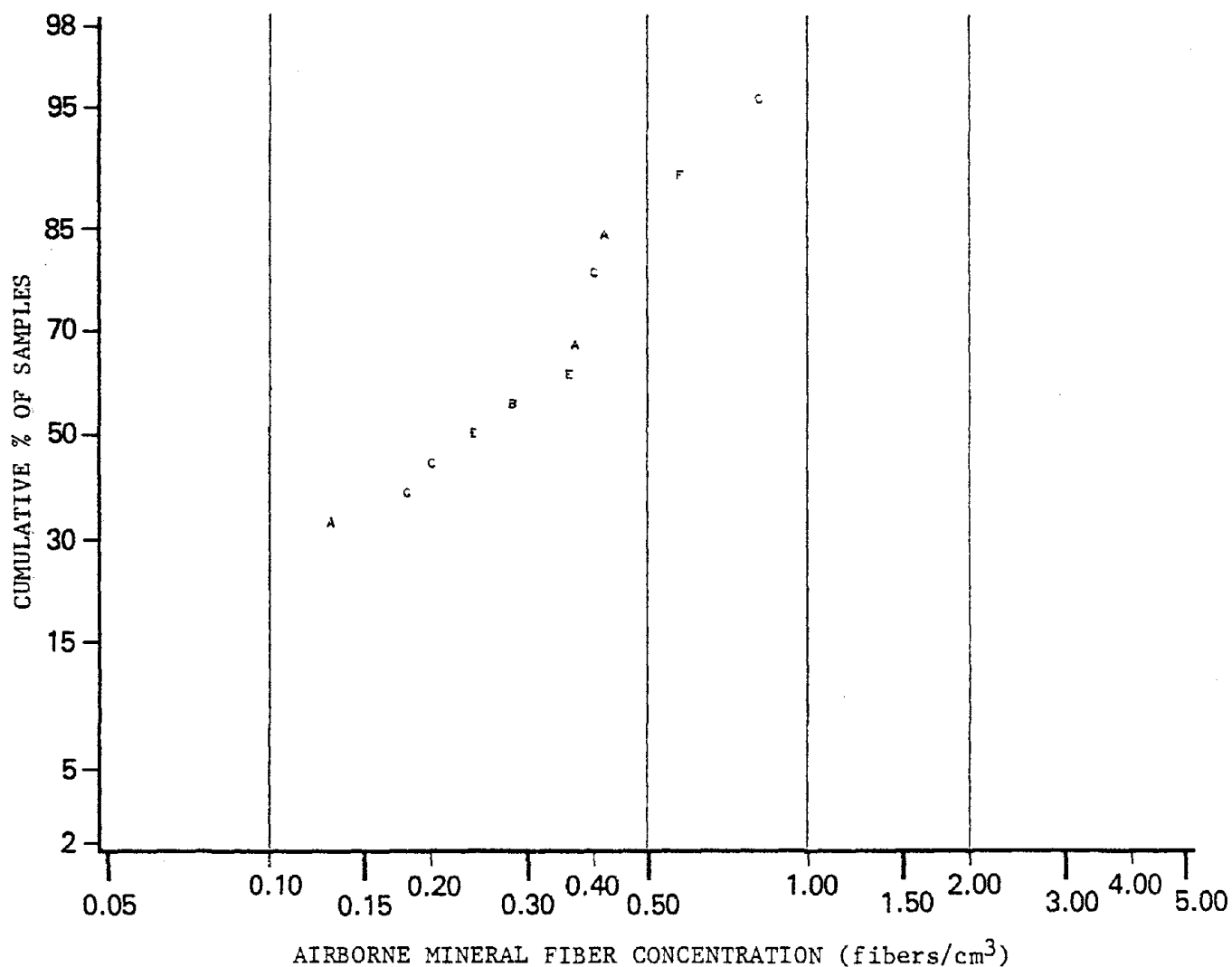
No. of samples: 11
 No. of mine ID's represented: 5
 No. of active sites in 1980: 49
 Percent of samples less than 0.1 fibers/cm³: 18
 Percent of samples less than 0.5 fibers/cm³: 55
 Percent of samples less than 1.0 fibers/cm³: 82
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B -29. Airborne mineral fiber concentrations found in crushing, grinding, and sizing operations (surface and underground) in the talc, etc. industry group (personal samples).



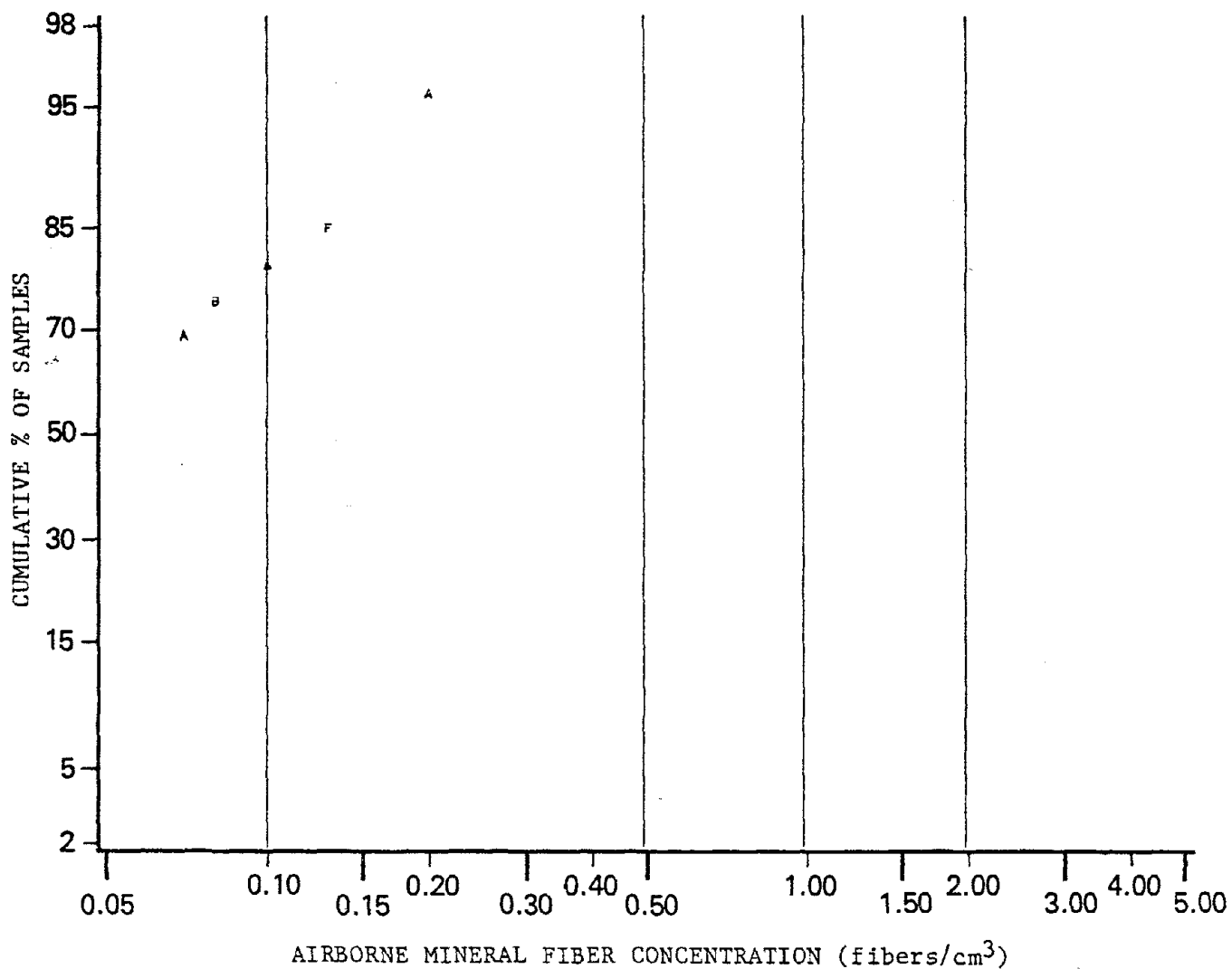
No. of samples: 45
 No. of mine ID's represented: 12
 No. of active sites in 1980: 49
 Percent of samples less than 0.1 fibers/cm³: 4
 Percent of samples less than 0.5 fibers/cm³: 20
 Percent of samples less than 1.0 fibers/cm³: 33
 Percent of samples less than 2.0 fibers/cm³: 56

Figure B-30. Airborne mineral fiber concentrations found in crushing, grinding, and sizing operations in the talc, etc. industry group (area samples).



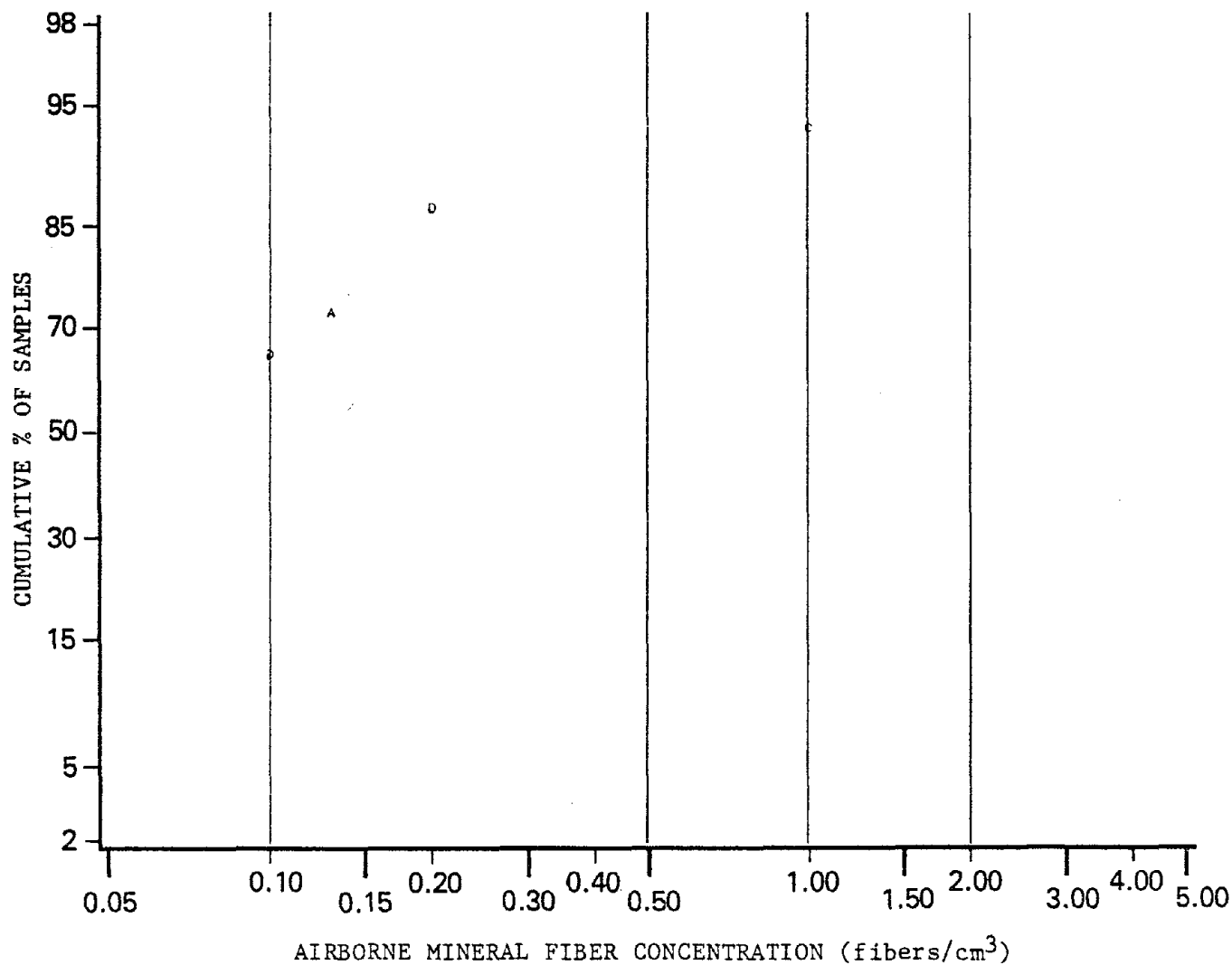
No. of samples: 18
 No. of mine ID's represented: 7
 No. of active sites in 1980: 49
 Percent of samples less than 0.1 fibers/cm³: 28
 Percent of samples less than 0.5 fibers/cm³: 83
 Percent of samples less than 1.0 fibers/cm³: 94
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-31. Airborne mineral fiber concentrations found in concentrating and finishing operations (surface and underground) in the talc, etc. industry group (personal samples).



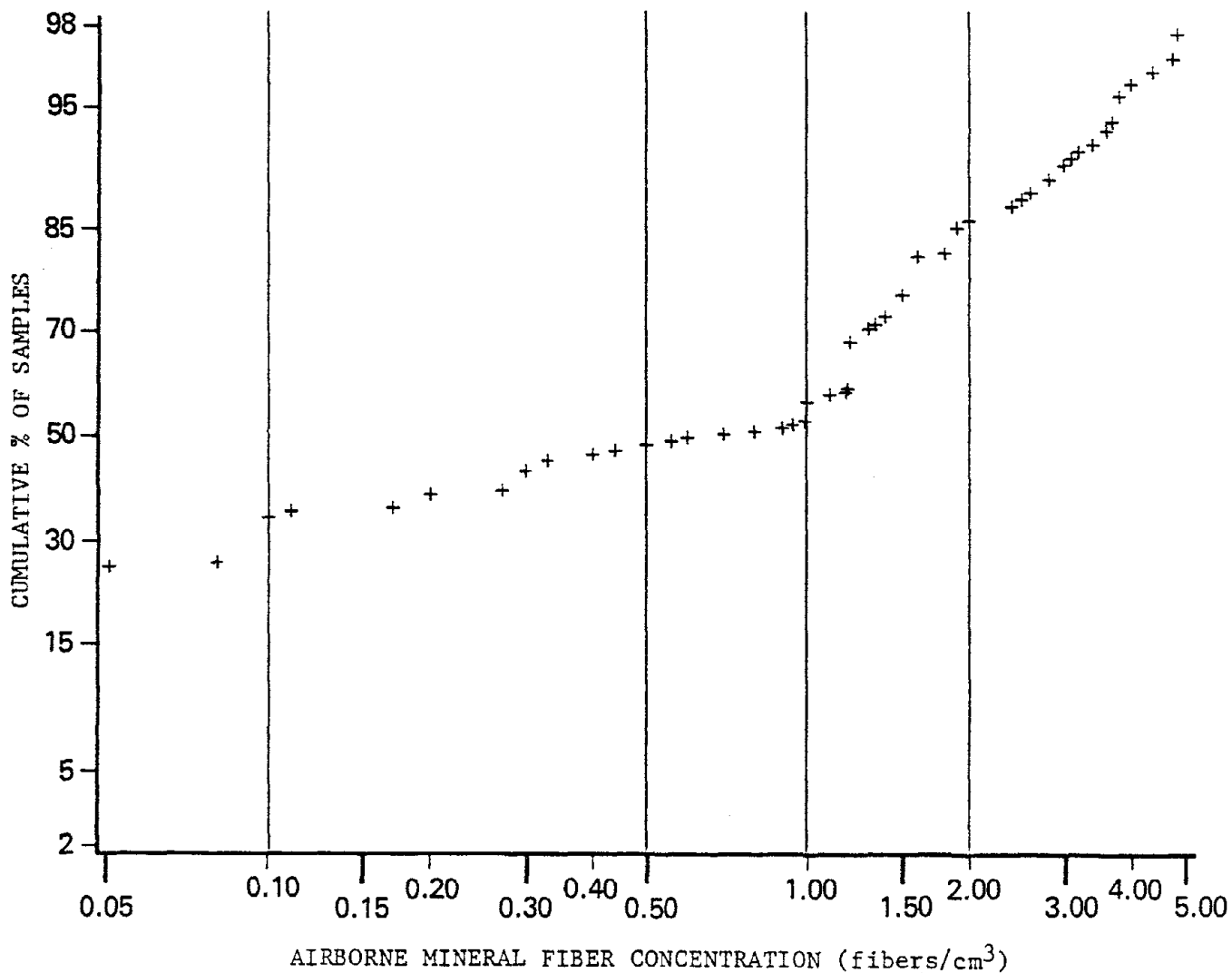
No. of samples: 19
 No. of mine ID's represented: 10
 No. of active sites in 1980: 3351
 Percent of samples less than 0.1 fibers/cm³: 74
 Percent of samples less than 0.5 fibers/cm³: 100
 Percent of samples less than 1.0 fibers/cm³: 100
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-32. Airborne mineral fiber concentrations found in surface mobile transport operations in the sand and gravel industry group (personal samples).



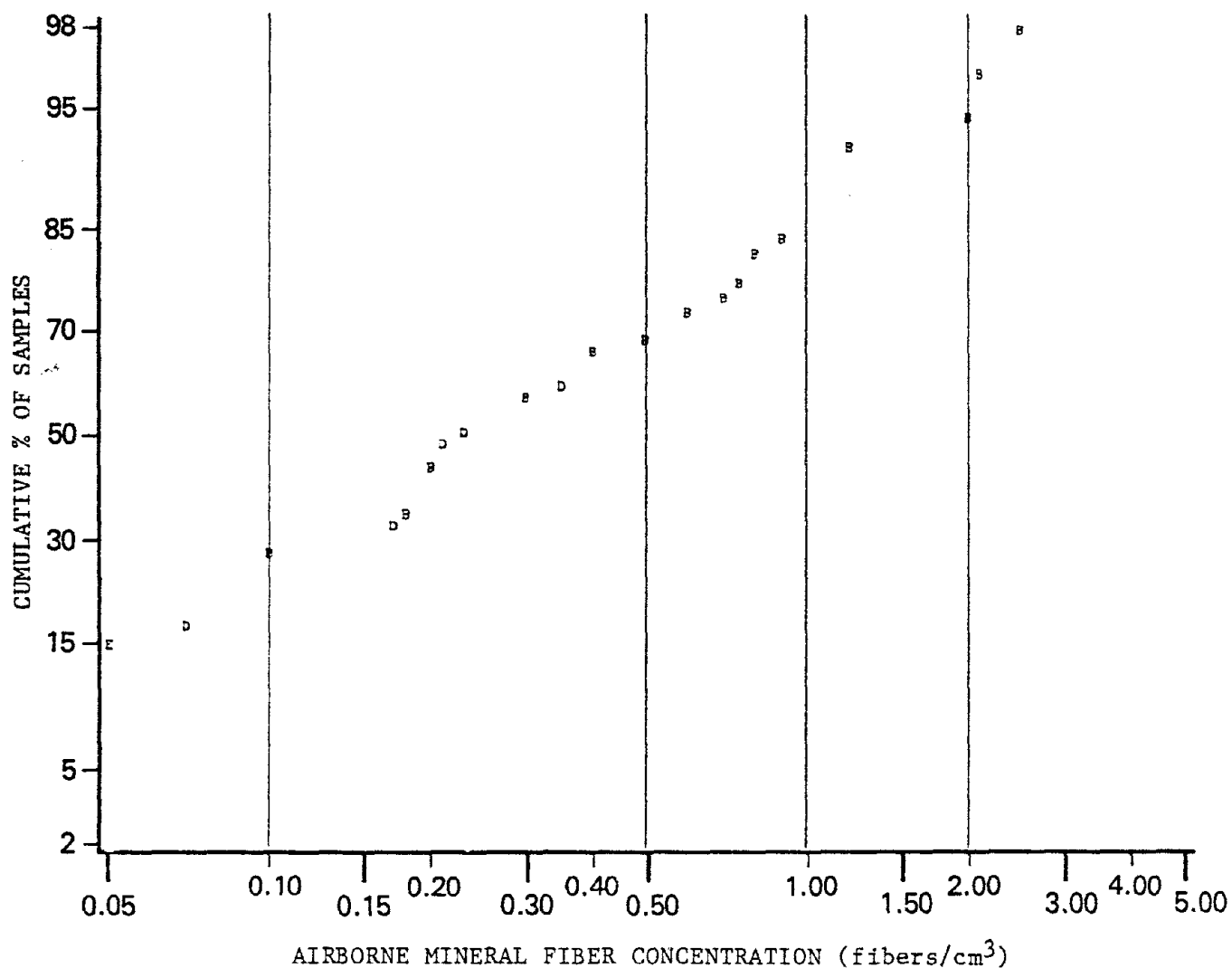
No. of samples: 14
 No. of mine ID's represented: 10
 No. of active sites in 1980: 3453
 Percent of samples less than 0.1 fibers/cm³: 14
 Percent of samples less than 0.5 fibers/cm³: 86
 Percent of samples less than 1.0 fibers/cm³: 86
 Percent of samples less than 2.0 fibers/cm³: 100

Figure B-33. Airborne mineral fiber concentrations found in mobile transport operations in the sand and gravel industry group (area samples).



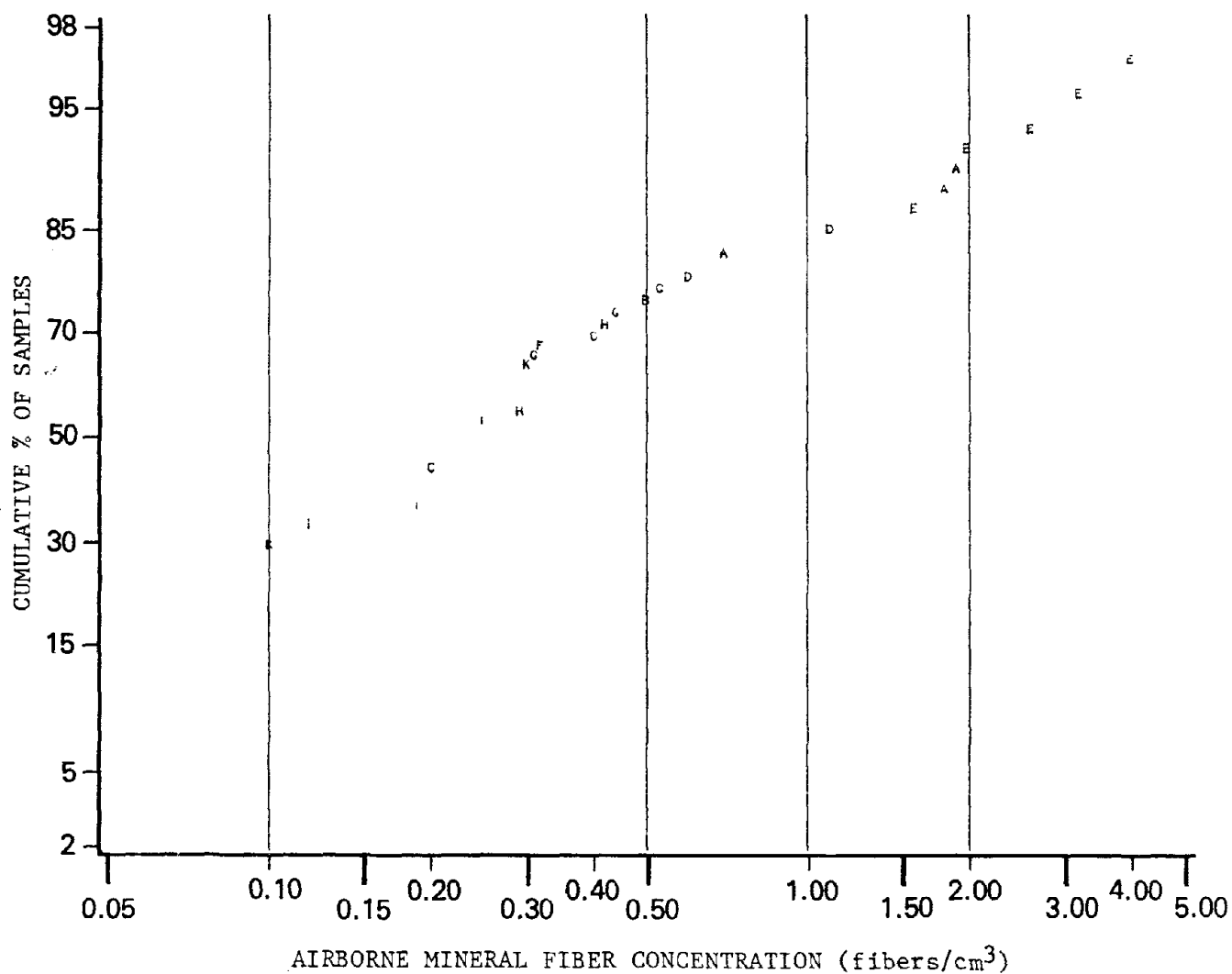
No. of samples: 163
 No. of mine ID's represented: 110
 No. of active sites in 1980: 3453
 Percent of samples less than 0.1 fibers/cm³: 27
 Percent of samples less than 0.5 fibers/cm³: 47
 Percent of samples less than 1.0 fibers/cm³: 52
 Percent of samples less than 2.0 fibers/cm³: 84

Figure B-34. Airborne mineral fiber concentrations found in crushing, grinding, and sizing operations in the sand and gravel industry group (area samples).



No. of samples: 46
 No. of mine ID's represented: 5
 No. of active sites in 1980: 504
 Percent of samples less than 0.1 fibers/cm³: 17
 Percent of samples less than 0.5 fibers/cm³: 65
 Percent of samples less than 1.0 fibers/cm³: 83
 Percent of samples less than 2.0 fibers/cm³: 91

Figure B-35. Airborne mineral fiber concentrations found in nonspecific surface operations in the other nonmetal industry group (personal samples).



No. of samples: 53
 No. of mine ID's represented: 16
 No. of active sites in 1980: 504
 Percent of samples less than 0.1 fibers/cm³: 15
 Percent of samples less than 0.5 fibers/cm³: 75
 Percent of samples less than 1.0 fibers/cm³: 83
 Percent of samples less than 2.0 fibers/cm³: 92

Figure B-36. Airborne mineral fiber concentrations found in crushing, grinding, and sizing operations in the other nonmetal industry group (area samples).

APPENDIX C
SITE VISIT REPORTS

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No. 4. Granite Quarry, Southeastern U.S.	C-18
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No. 6. Potash Mine, Southwestern U.S.	C-43
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TECHNOLOGICAL FEASIBILITY OF CONTROLLING
ASBESTOS AND SILICA AT MINES AND MILLS

Site Visit Report No. 1
Uranium Mine, Southwestern U.S.

The mine at Site No. 1 was visited by JRB and SAI personnel on March 22, 1982, to obtain information regarding dust control technology employed at the mine site. The site visit was conducted under NIOSH Contract 210-81-4104 and in accordance with Title 42, Section 85a, of the Code of Federal Regulations.

At this mine, approximately 1,250 tons of ore are extracted daily by room-and-pillar mining techniques. During our visit, mining was done at a reduced rate because of the low demand for the uranium. Major activities currently consist of developing known areas of the ore body and delineating ore zones for future mining. Mining is done using a conventional room-and-pillar system. The extraction operations in each heading consist of drilling, blasting, loading, scaling, and bolting; this cycle is then repeated. Currently, 20 headings are worked at the same time.

For a typical full round of blasting, 18 holes are drilled in the softer sandstone ore and 25 to 28 holes in harder sandstone. The drill steel used is 7-1/2 feet long. Drillhole patterns optimize ore recovery and are not necessarily the best pattern for dust control. Holes are drilled wet using Ingersoll jacklegs equipped with air-water interlocks. Water is used to cool the bit and reduce respirable dust. We observed little dust during drilling operations.

Drillholes are loaded with explosives and blasted both during and off shift. Miners allow 15 minutes for dust to settle before entering an area that has been blasted.

Face areas are naturally wet and do not need to be wet down before blasting. The blasted ore contains moisture; therefore, muck piles are not wet down before loading and dumping operations. Ore is usually mucked with

load-haul-dump machines immediately after blasting and does not have a chance to dry out.

All transfer and loading operations that were observed generated little dust. Dust problems do exist on the main haulageway because high air velocities dry out the road surfaces. Dust has been controlled in this area by spraying Nalco 8808, a chemical mixture containing high molecular weight polymer binders, on the haulageway surface.

The Nalco polymer is mixed with water in a 1:100 ratio and sprayed on haulageways during each mining shift. Previously, waste oil was used on haulageways. However, this practice was discontinued due to the fire hazard of the oil. Calcium chloride and magnesium chloride were also tried in the past with limited success. The cost of applying the calcium chloride and magnesium chloride by hand was very high; approximately 6 man-shifts per mining shift were required for application. A mechanical spreader was tried, but it was unacceptable because the spreader head frequently clogged with solid material.

The mine ventilation system is under negative pressure, which is the most practical and effective way to control air contamination from radon gas and its decay products. A common source of air contamination with radon is the introduction of air isolated by bulkheads in non-active areas. Because an absolute bulkhead seal is impossible to obtain, any seal with a positive or even neutral pressure differential will become a contamination source. To prevent this problem, negative pressure is provided to isolated areas through direct connections to exhaust vent holes. When a direct connection to an exhaust vent is not possible, a pipe is connected from one bulkhead seal to another sealed area with sufficient negative pressure.

All non-active working areas are isolated by bulkheads made with plywood and sealed with MSA foam. The foam is a two-part mixture. When the parts are mixed, pressure is created in the mixing box so that the foam can be sprayed onto the bulkhead. Site No. 1 personnel found the foam to be nonflammable and efficient in sealing bulkheads.

Collapsible tubing manufactured by Peabody ABC Corporation is used in the mine for auxiliary ventilation purposes. Intake air is delivered through tubing to the immediate face without contamination from recirculation. This tubing is used exclusively for blower (positive pressure) applications. Substantially lower costs and ease of installation were noted for the flexible tubing as opposed to metal ducting. The tube fabric is also tough and resists tears.

A split system of ventilation is used to draw air into the haulageways and stope level. A separate air split is drawn into the working area from the track level. The split system is most effective in controlling radon gas and dust because contamination will affect only the split of air in which it is released and will not contaminate subsequent working areas.

The combined haulage intake air and the track air returning from the active working areas are drawn directly into a return aircourse that is not used by miners. Most of the underground personnel are in the active working areas or near well-ventilated station areas. The primary ventilation system appeared very effective. High air velocities were maintained in haulageways and working areas, and little airborne dust was observed.

Brattice curtains manufactured by Peabody ABC Corporation are also used for ventilation control. The efficiency of the curtains in reducing air flow depends on how they are hung. MSA foam applied to chicken wire is used to seal gaps between the curtains and drift surfaces. Parachute stoppings are not used in the mine because they require 0.1 inch water pressure differential. This cannot be obtained in some dead-end areas. Worker acceptance might also be a problem in utilizing parachute stoppings, according to the mining company's ventilation engineers.

Ore is transferred to the surface by skip. The ore is wet and usually is stockpiled to allow it to air dry before entering the grinding circuit. Occasionally, if the material dries out, dust is dispersed by winds from the ore and waste stockpiles.

The ore processing cycle is shown in Figure 1. Run-of-mine or stockpiled ore is passed through a grizzly into a hopper. During the dumping operation, water is sprayed on the grizzly. From the hopper, the ore is conveyed by belt to semi-autogenous grinding (SAG) mills. The ore is ground with water to form a slurry. Dust is controlled at the SAG mills by a wet scrubber. The slurry is mixed with sulfuric acid and sodium chlorate in leaching tanks to dissolve the uranium. Until the final drying and packaging processes, the uranium is in a wet stage. During the drying stage, the ore is heated to drive off water and ammonia for conversion to the final product, yellowcake. Impinjet wet scrubbers manufactured by Sly Corporation are used to control dust from the drying, bin unloading, and product packaging operations.

The mill was clean and little visible airborne dust was observed. Dust accumulations were not seen on the beams, equipment, or floors. The floors and conveyors are hosed down frequently to prevent dust buildups. Maintenance of equipment and ductwork is conducted as soon as a problem occurs. Ductwork was in good condition and no visible dust leaks were seen.

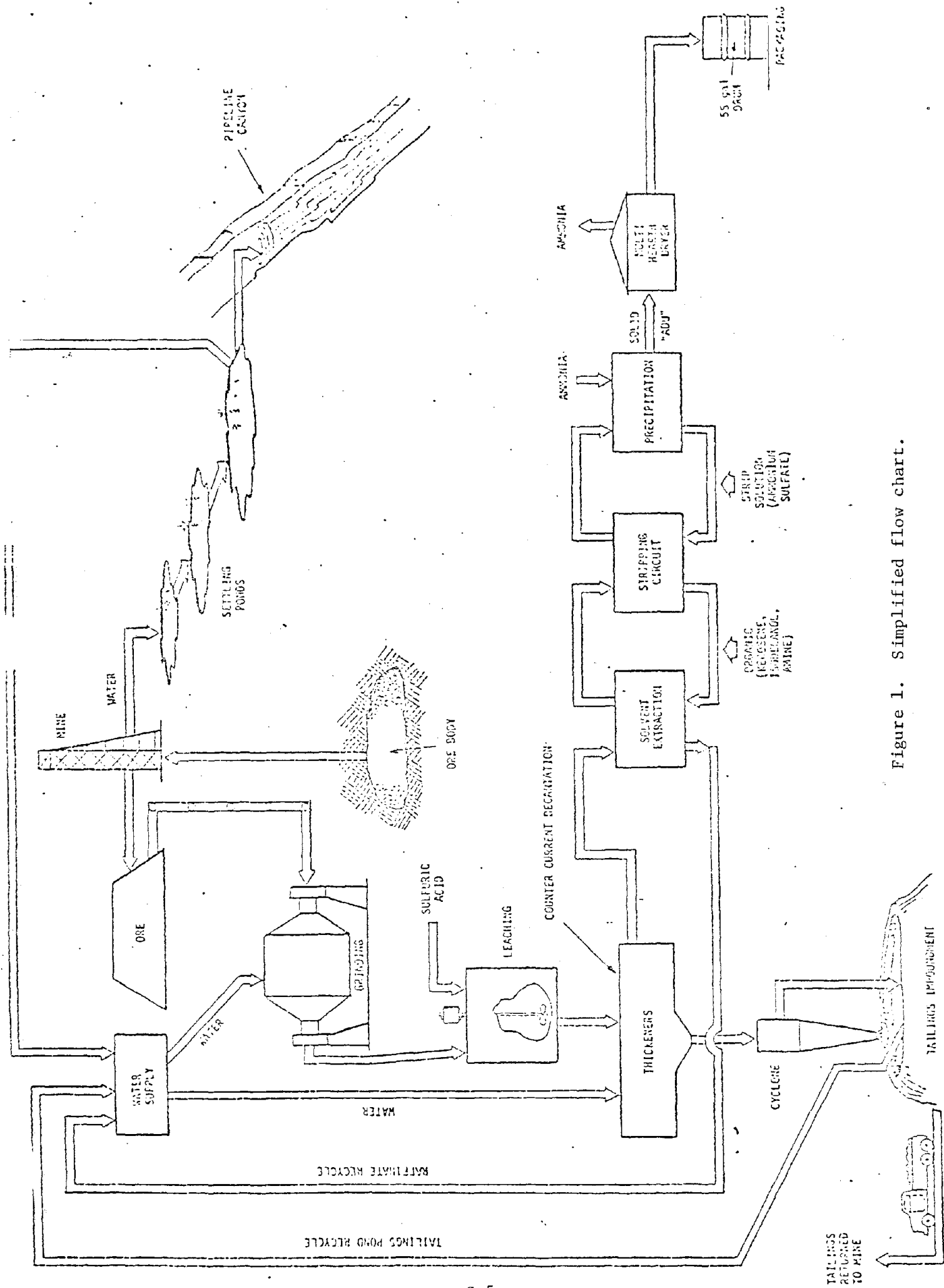


Figure 1. Simplified flow chart.

TECHNOLOGICAL FEASIBILITY OF CONTROLLING
ASBESTOS AND SILICA AT MINES AND MILLS

Site Visit Report No. 2
Copper Mine, Southwestern U.S.

Personnel of JRB Associates and Science Applications, Inc. (SAI), conducted a site visit on March 25, 1982, at the copper mining operations at Site No. 2. The purpose of the visit was to observe dust control methods used in mining and milling processes.

The overburden at the Site No. 2 copper operation consists of low-grade leached capping in intrusive and locally sedimentary limestone and shale rocks. Precambrian granite is the dominant country rock, while Laramide monzonite porphyry hosts 75 percent of the supergene ore.

The mineralization of the copper ore consists of a supergene-enriched hypogene system of disseminated micro-veinlet and vein pyrite, chalcopyrite, and bornite, with moderate amounts of molybdenite occurring in quartz veins and as fracture coatings. The supergene enrichment is concentrated in the phyllic zone and consists of chalcocite and minor amounts of covellite. These minerals almost completely replace the bornite and chalcopyrite and partially replace the pyrite of the hypogene system.

The mining process consists of

- Drilling holes
- Loading explosives
- Blasting ore, leach, and waste material
- Loading blasted materials with power shovels
- Hauling ore by rail or trucks to the primary crusher
- Hauling leach and waste to dumps by rail or trucks
- Transferring ore to the mill.

The major equipment consists of the following:

Rotary drills:	One 9-inch Four 9-7/8 inch Five 13-3/4 inch Three 15-inch
Electric shovels:	Seven 9-cubic yd Three 12-cubic yd Three 15-cubic yd Three 22-cubic yd
Haulage:	Three diesel electric 1,200 hp locomotives Sixteen diesel electric 1,750 hp locomotives Twelve diesel electric 2,000 hp locomotives Three diesel electric 1,000 hp locomotives 330 40- to 42-cubic yd side dump cars Two track maintainers Two spot tampers Ten track shifters Twelve tracked dozers One 150-ton locomotive crane Three 40-ton cranes Four 4-cubic yd rubber-tired, front-end loaders Six motor graders.

The mine benches are 50 feet high and average 150 feet wide in active mining areas. The average shovel cut along a bench is 45 feet wide. The railroad tracks are shifted after every other cut. The overall working slope is 3:1; the final slope will be 1.3:1 or less.

Blastholes are drilled from 12-1/2 inch diameter to 15 inch diameter on 33- to 45-foot centers in single rows. Diesel and electric powered rotary drills are used. The smaller diameter drill averages 320 feet per shift and the larger 470 feet. The average bit life is 6,500 feet.

The powder factor for the mine is 4.9 tons of material per pound of explosives (ANFO). ANFO is used for dry holes, and gel is used for wet holes when dewatering is not successful. The holes are subdrilled to a depth of approximately 20 percent of the total hole length. Figure 1 shows a typical loading pattern. The charge is primed using two boosters placed about 2 feet apart. The charges are bottom primed. The firing is done using detonating cord.

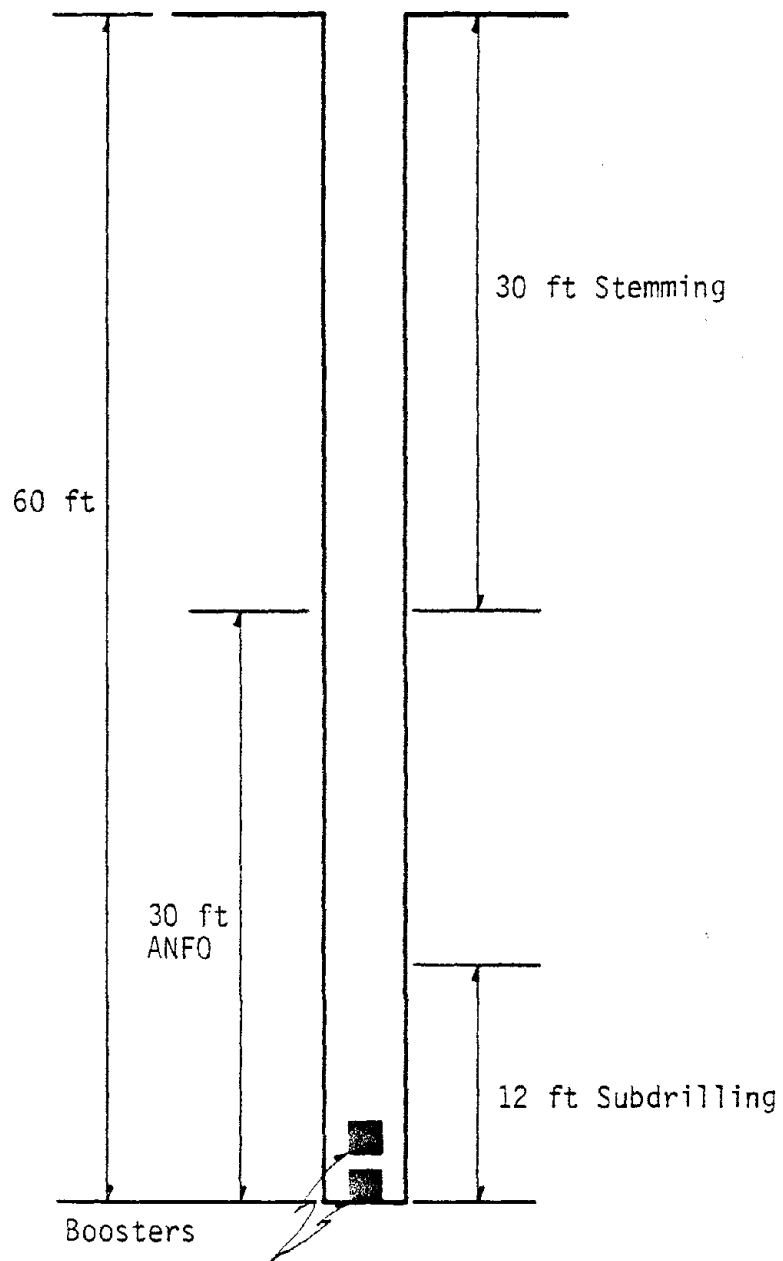


Figure 1. Typical drillhole loading pattern.

Cuttings from drillholes are used for stemming. Dust suppression in the drilling process is achieved by water injection. A tank on the drill chassis delivers water to the bit. The water saturates the rising drill cuttings. Little dust was observed from the drilling process.

A blasting operation was observed during the site visit. Normally, blasting is done between shifts. The material broke well, and the amount of dust produced was not excessive. The material being dumped at the crusher was not large. Average fragment size appeared to be no greater than 18 inches. The worker responsible for blasting indicated that they do get large blocks in oxidized and blocky parts of the ore body. Secondary breakage is accomplished by percussion drilling and secondary blasting.

Enclosed cabs and air-conditioning are not used on the equipment, with the exception of one new bulldozer. The site visit team observed that some equipment was operated with the cab windows open.

Mine access roads are sprayed with CS-1H asphalt emulsion. This emulsion is applied with special water trucks that have separate tanks for the emulsion and water. Problems occurred when the emulsion and water were mixed in the same tank; it was difficult to achieve the proper mix ratio. In the pit areas where the road changes on a daily basis, water alone is used.

Calcium chloride and magnesium chloride had been tried for road dust suppression but were thought to be cost-ineffective; however, more testing is planned. Manually operated sprinklers have been tried on one section of a haul road with poor results. Mine personnel mentioned that the sprinklers were hard to control and tended to overwater the road.

Water is applied at the loading face with rainbird sprinklers. This spraying system has been effective in controlling dust during loading operations. There have been several problems with the sprinklers. First, large quantities of water are needed in this system for effective dust control; water is in short supply at the mine. Second, the sprinklers must be

moved as the loading shovel moves. Two employees per shift are assigned to maintain the sprinklers. Third, a water system is needed to feed the sprinklers.

The rail cars are both bottom-dumping (100-ton capacity) and side-dumping (72-ton capacity). The average haul cycle time is 3 hours. When the ore is dumped into the primary gyratory crusher, the downwind velocity of the ore creates large dust clouds. A dust collecting system is installed at the crusher pocket, but may not have been operating on the day of the site visit.

Because the operator at the dumping operation must control equipment at the dump point for each rail car, he does not work in an enclosed control booth. By contrast, the crusher operator works in an enclosed, positive-pressure booth. No visible dust was observed in the booth.

The crushed ore is transported to the concentrator by conveyor belt for processing. Some material spillage was noticed. Dust controls used for conveyors and screens in the milling processes are

- Water sprays at some transfer points
- Exhaust hoods and enclosures for many of the conveyor and feeder transfer points
- Exhaust hoods for screens
- Scrubbers to clean collected air.

Water sprays operate at the transfer point from the crusher conveyor to the tripper. The sprays were not operating during the survey because of problems with buildup of material on the conveyor belt and clogged nozzles. The pan-feeders that lead to the secondary crushers are completely enclosed and exhaust to wet scrubbers (see Table 1). Oversize rock, which is screened by vibrating screens, is gravity-fed to tertiary crushers. The vibrating screens are also enclosed.

Primary grinding, which is accomplished in single-stage ball mills, is followed by classifying. The classifier overflow is fed by gravity to the

Table 1. Dust control systems.¹

<u>Site No. 2 Crusher</u>		
<u>Location of unit²</u>	<u>Type of collector</u>	<u>Fan volume (ft³/min)</u>
1. Primary crusher	Ducon	32,000
2. Coarse ore bins substructure-extension side	Buffalo	22,000
3. Coarse ore bins substructure-original side	Buffalo	22,000
4. Coarse ore bins substructure-unit 2A	Ducon	9,100
5. Coarse ore bins substructure-unit 2B	Ducon	9,100
6. Coarse ore bins substructure-unit 2C	Ducon	9,100
7. Coarse ore bins substructure-unit 2D	Ducon	9,100
8. Secondary crushing plant-unit 1	Ducon	20,000
9. Secondary crushing plant-unit 2	Ducon	25,000
10. Secondary crushing plant-unit 3	Ducon	22,000
11. Secondary crushing plant-unit 4	Ducon	22,000
12. Secondary crushing plant-unit 5	Ducon	17,000
13. Secondary crushing plant-units 3-4-5	Ducon	20,000
14. Secondary crushing plant-units 3A-4A-5A	Ducon	17,000
<u>Site No. 2 Concentrator</u>		
15. Fine ore bins - unit #1	Ducon	9,100
16. Fine ore bins - unit #2	Ducon	9,100
17. Fine ore bins - unit #3	Ducon	9,100
18. Fine ore bins - unit #4	Ducon	9,100
19. Fine ore bins - unit #5	Ducon	9,100
20. Fine ore bins - unit #6	Ducon	9,100
21. Mill - unit #1	Ducon	18,000
22. Mill - unit #2	Ducon	16,500
23. Mill - unit #3	Ducon	18,000
24. Molybdenum plant	Phelps Dodge	---
25. Concentrator dryer - No. 1	Ducon	34,200
26. Concentrator dryer - No. 2	Ducon	32,600

¹Locations are listed in order of process flow - from the primary crushers to the coarse ore bins, secondary crusher areas, fine ore bins, mills, and dryers.

²A location listing indicates that the associated collector provides dust collection for the area operation.

flotation circuit. The grinding circuit is a closed system, and little visible dust was seen in the grinding area. The classifying and flotation process areas were also dust-free because of the wet nature of these processes.

Visible airborne dust was observed around transfer points and conveyor belts. Most of this dust appeared to be dispersed from conveyors located on the lower floors of the crusher building.

Many of the head and tail pulleys on the conveyors are enclosed by hoods. Dust-laden air collected by the hoods is exhausted to wet scrubbers. The plenums, which connect the hoods and the ductwork, are graduated. This design is effective for capturing contaminated air because opposing air currents are minimized at the connection between the hood and ductwork. The plenum areas are at least four times the diameter of the connecting ductwork. Their size minimizes pressure (entry) losses in the transition from the hood to the ductwork.

The crusher building and concentrator are equipped with 27 wet scrubbers, most of which were manufactured by Ducon. Scrubber locations are listed in Table 1. The scrubbers, which are located on the higher levels of the buildings, are made of stainless steel to prevent corrosion problems. Dust collected from the scrubbers is mixed with water into a slurry and recycled to the classifiers. Scrubbers are used to control dust at the crusher trippers, pan feeders, and various conveyor belts. All of these scrubbers have an operational efficiency of 99.5 percent.

Visible airborne dust was observed on lower levels at scrubber intake points. Friction losses in the extensive lengths of ductwork can result in insufficient dust transport velocities. This may explain the dust problem that occurred on the lower levels. Some scrubber ducting had sharp elbows and upward slopes, which increase the likelihood of clogged ducts. Maintenance inspections are done twice weekly on all scrubbers to prevent the accumulation of material in the scrubbers. Clogging of nozzles and filters has been the major maintenance problem.

TECHNOLOGICAL FEASIBILITY OF CONTROLLING
ASBESTOS AND SILICA AT MINES AND MILLS

Site Visit Report No. 3
Oil Shale Mine, Southwestern U.S.

Personnel of JRB Associates and Science Applications, Inc. (SAI), conducted a site visit on April 26, 1982, at the Site No. 3 oil shale mine. The purpose of the visit was to observe dust control methods used in mining and milling processes.

The mine is under jurisdiction of the Bureau of Mines (BOM) and has been the site of many mining operations since the late 1940's. Currently, the mine is leased from the BOM and several companies are conducting research at the mine and at the associated surface retorting facility. No production mining is currently being conducted in any of the areas.

In air samples taken at Site No. 3, the BOM (Volkwein and Flink 1977) reported 13 to 22 percent alpha-quartz in the crusher areas and lower but variable content (4.1 percent average) in the mine. Los Alamos Scientific Laboratories approximated a 10 percent silica content from airborne dust samples taken in the mine (Rudnick et al. 1980). Both studies showed a wide variation in silica concentration levels among samples taken at the same operations. Mine mucking and loading operation sample concentrations were between 0.001 and 0.227 mg/m³. These values range from below the current MSHA standard for dust (0.1 mg/m³) to well above the standard. Roof bolting and scaling operation air samples ranged from 0.002 to 0.179 mg/m³, and 0.006 to 0.016 mg/m³, respectively.

The mine consists of three separate areas, which are referred to as the demonstration mine, the selective mine, and the experimental mine. All areas are dry, with no groundwater.

Mining was performed in the demonstration mine during the late 1960's and early 1970's. This part of the operation is a massive room and pillar mine with cross-cuts and drifts as large as 60 feet wide and 60 feet high. The

large size is a result of trying to recover as much of the available oil shale as possible. Large-scale room and pillar mining will be the primary type of mining used in commercial oil shale mines that use surface processing.

There is no dust problem in the demonstration mine because of very limited activity there at the present time. The only source of dust generation is vehicle traffic. Where traffic is present, the roadways are wetted by a water truck on a daily basis. Because the amount of traffic is very limited, no additives have been used with the water.

Fresh air is drawn into the mine from one main adit using exhaust ventilation. Return air is exhausted into an abandoned mine adjacent to the mine at Site No. 3. Although large quantities of air are exchanged in the mine, there was no noticeable movement of air in the large size drifts. Because the working faces are located some distance from the main adit, they are not ventilated effectively. When operational, the massive room and pillar mine will have a major dust control problem because airflows will remove airborne dust at a very slow rate.

In the demonstration mine, high cuts were made to recover a high percentage of the ore. In the selective mine, only a small percentage of very high grade ore was recovered. Figure 1, which is a typical histogram of the oil shale present in the Piceance Basin, shows how the grade varies as a function of location. The selective mine was worked only in the higher grade areas. Mining was conducted in the selective mine in the late 1940's; no work is currently being conducted.

The experimental mine is the main area where mining is now being conducted, and only on a very limited basis. Here, research is in progress to improve the effectiveness of Vertical Modified In-Situ (VMIS) retorting.

In the research experiments currently being conducted, 30-ft by 30-ft by 12-ft rooms are mined on two levels separated by 60 ft of shale. One room is located directly over the other. Mining in these rooms and in the associated access drifts is conducted by conventional mining methods. The ore is drilled

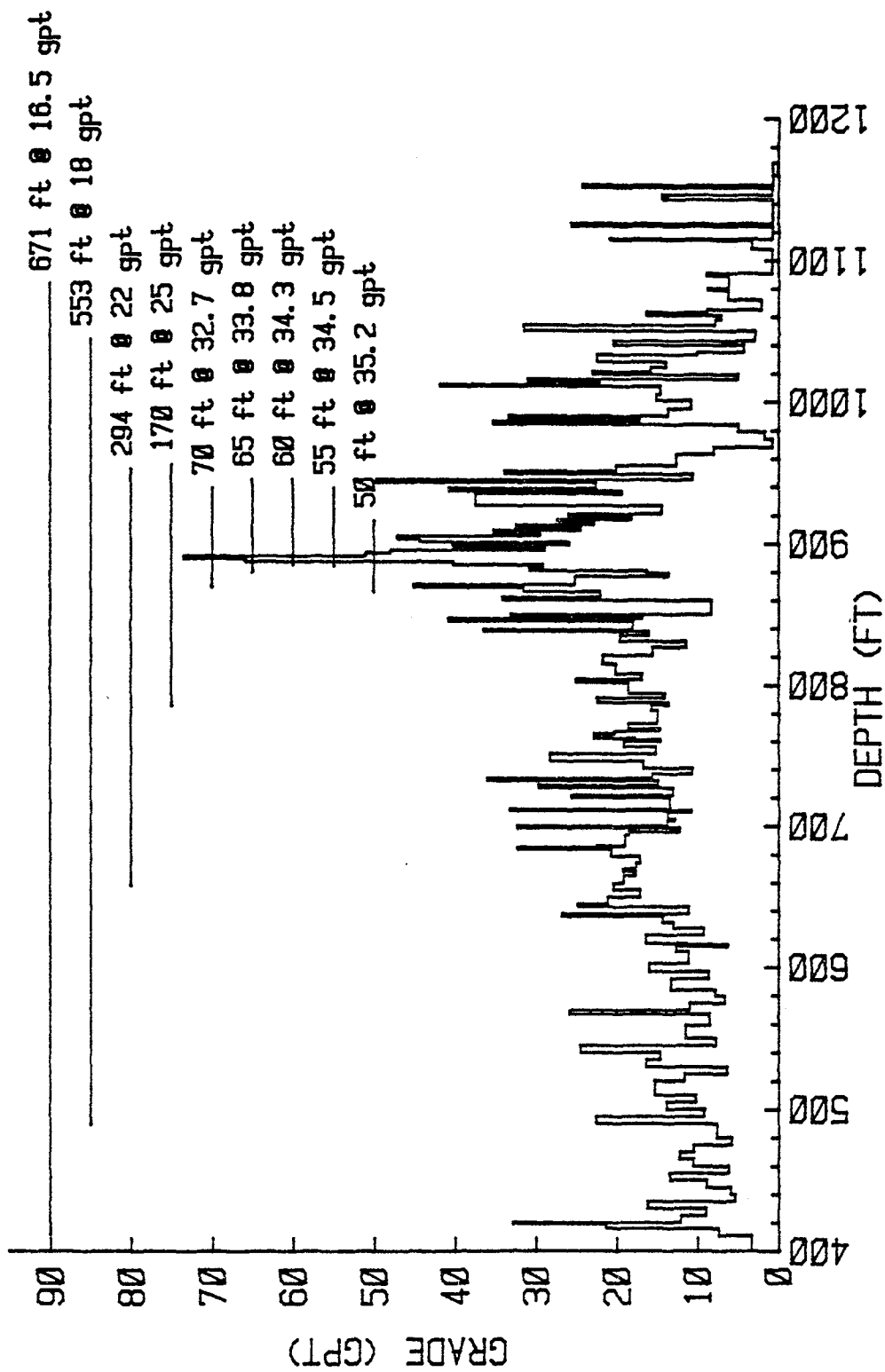


Figure 1. Piceance Basin oil shale.

using a Secoma air-powered, single-boom jumbo that drills 1-inch holes. The drill is designed with an air-water interlock so that water injected through the drill steel at 100 psi is sprayed in the hole from the bit. Although drilling of this type was not conducted at the time of the visit, it was reported that dust was controlled very well by the wet drilling. Approximately 28 to 40 holes are drilled in a face. The holes are pneumatically loaded with ammonium nitrate and fuel oil (ANFO). Stemming is not used.

After the holes have been shot, the blasted material is loaded with an Eimco 912D LHD or a Bobcat loader and transported to a dumpsite located in the demonstration mine. No dust controls, other than road wetting, are used during the mucking portion of the operation.

Holes are drilled from the upper rooms into the lower rooms with an Ingersoll-Rand air-powered drill that can operate in a rotary, percussion, or rotary-percussion mode. Wet drilling is required in all of the modes and rotary-percussion has been found to be the mode best suited for drilling oil shale.

The spacing, type, and location of explosives are varied from shot to shot, and these data are proprietary in nature. The objective of the research is to provide a uniformly sized material throughout the retort. It is very important that the size be 4- by 6-inch diameter rubble to achieve optimum recovery from the VMIS process.

The team visited an upper level room where drilling had just been finished. The air appeared to be very dusty. However, what appeared to be dust may have been water mist from the drill. It was mentioned that the driller wears a respirator at all times while drilling. Ventilation to the drilling area is supplied through Peabody ABC flexible tubing with intake from the demonstration mine.

Currently the dust problems at Site No. 3 are minor because there are so few people employed (5 full time workers and several scientists). Mining is not conducted on a full-time basis or on a commercial scale.

There are few air sampling data to evaluate the dust controls currently in use at this mine. Because of the low level of production and other activities, it would not be possible to extrapolate the effectiveness of controls at this mine to a mine in full production. However, dust control at Site No. 3 will present a major problem when commercial operations begin. Daily production may be in excess of 200,000 tons/day with large numbers of workers underground.

The BOM study (Volkwein and Flink 1977) found that the major dust sources at Site No. 3 are blasthole drilling and scaling operations. These operations are usually conducted at face areas. Because the primary ventilation was not judged to be effective in removing airborne dust from face areas, a more efficient ventilation system will be needed to reduce respirable silica dust levels.

The existing auxiliary exhaust ventilation systems should be extended to within 10 feet of each face working area. Machine-mounted wet scrubbers may be potentially effective for reducing dust levels at face areas. This ventilation technique will reduce the amount of airborne respirable dust in the total ventilation airstream, thus reducing the dust exposures of personnel located downstream.

TECHNOLOGICAL FEASIBILITY OF CONTROLLING
ASBESTOS AND SILICA AT MINES AND MILLS

Site Visit Report No. 4
Granite Quarry, Southeastern U.S.

Personnel of JRB Associates (JRB) conducted site visits on May 12-13, 1982, at granite quarries and plants at Site No. 4. The purpose of the visits was to observe dust control methods used in mining and milling processes.

The site visit team visited quarry operations and granite monument fabrication operations at various sites in the area.

Quarrying Operations

The granite quarrying sequence used at all the operations visited consists of the following steps:

- Jet piercing to burn channels, which separate blocks from granite deposits
- Drilling lift holes at the base of each block
- Raising or blasting each granite block with black powder
- Drilling wedge and shim holes at the top of blocks
- Inserting and hammering wedges to completely loosen the blocks
- Removing the dimension block from the quarry.

At large quarries, all of these operations occur simultaneously. However, most of the quarries are smaller operations, employing less than 10 persons. Quarrying and jet piercing are not conducted simultaneously at the smaller sites.

The basic equipment employed in jet piercing is actually a miniature rocket motor attached to a long, hollow steel shaft called the air burner, which burns a pressurized mixture of hydrocarbon fuel and air. The fuel is usually No. 2 fuel oil. The flame leaves the burner at approximately five

times the speed of sound, or 4,000 feet per second, and generates a heat of 2,800 degrees Fahrenheit. The flame from the burner tip, which is really a pressurized combustion chamber, quickly and smoothly cuts a 4-inch channel (kerf) through the solid granite as the intense heat crystallizes and expands the granite surface. The heated granite flakes off approximately 1/4-inch each time the flame passes over a given area, without any damage to the adjacent surfaces. Only the jet flame comes in contact with the stone.

With this method, it is possible to quarry 12 to 16 square feet of surface per hour. The depth of the cut is typically 20 feet. Flakes and dust generated during jet piercing shoot out of the far end of the channel that is being cut. Dust particles become suspended in the hot air plume, which rises from the channel cut. Dust was observed throughout the quarry pit and at the crane dimension block loading level during all of the jet piercing operations.

An alternative cutting method currently being developed at Site No. 4 is a water jet machine. Depending on the design, water at 40,000 psi is forced through 1 to 3 rotating nozzles on a long, hollow lance. The pressurized water shatters and disintegrates the stone. A lower pressure system (18,000 psi) was tested on granite. It was determined that the lower pressure was not efficient for cutting purposes. The cutting rate of the high pressure water jet ranges from 20 to over 23 square feet per hour, which is approximately 50 percent greater than the jet piercing method. The water jet machine can use water located at a quarry site. Water is pumped to a settling tank, where the heavy solids are removed and filtered prior to use in the machine.

Power is supplied to the water jet machine motors by the electrical service existing onsite. This will permit quarry owners to operate without auxiliary generators.

Automatic controls are used to operate the water jet system. The machine is mounted on metal rails so that the lance can traverse the cut. The lance can also be lowered into the cut at a specified rate. Once the system is set up, a 20-foot long, 20-foot deep kerf can be cut into the stone with only occasional monitoring by workers.

According to local industry personnel at Site No. 4, advantages of the water piercing system over jet piercing are:

- A narrower kerf is made, thus reducing amount of material cut.
- Little or no dust is generated.
- Noise levels are significantly lower.
- Dependence on petroleum products is reduced.

Also, JRB has calculated that the cost to operate the water jet machine is approximately 70 percent less than for jet piercing. Table 1 presents the results of JRB's analysis, and Attachment A presents a complete set of assumptions and calculations.

After a rectangular section of granite (about 18 feet by 20 feet) has been completely kerfed on all sides by jet piercing, the block can be loosened from the bed of the quarry. This is accomplished by using a large pneumatic drill with long 1-1/2 inch steel bits that are fitted with extra-hard carbide-tipped ends. Three or more horizontal holes are spaced 7 to 8 inches apart and drilled at the bottom center of the block to be lifted.

The drilling operation is performed dry. At two quarries at Site No. 4, Atlas Copco fabric dust collectors were located in the quarries but were not operating during the visit. A dust collector made of fabric filter bags enclosed in an oil drum, similar to the Atlas Copco unit, was seen at one granite quarry. Although the unit was not in operation during the visit, the foreman of that quarry said that the dust collector was used during the drilling of both "riftback" (horizontal lift) holes and "hardway" (vertical wedge and shim) holes.

The Atlas Copco dust collectors and the unit designed by a granite quarry at Site No. 4 use compressed air to produce a negative pressure inside the chamber that houses the fabric bags. Long hoses are connected to the filter units. Rubber hemispherical dust encapsulation devices cover the drill hole. As many as 12 hoses can be attached to the Atlas Copco unit. Two hoses can be attached to the Site No. 4 unit. Since the quarry at Site No. 4 is a small operation, more dust collection hoses are not necessary.

Table 1. Cost comparison between jet piercing
and water jet machine.

	<u>Jet piercing</u>	<u>Water jet machine</u>
Cutting rate (per hour)	12 sq ft	Assumed 21 sq ft
Fuels used/rate consumed (per hour)		
Electricity	68 kWh	135 kWh
#2 fuel oil	12 to 16 gal	--
Fuel cost (per hour)		
Electricity	\$4	\$8
#2 fuel oil	\$18	--
Total	\$22	\$8
Labor cost (per hour)	\$7	\$7
Total cost to cut 20' long x 20' deep channel (400 sq ft)	\$967	\$286
Estimated cost reduction with use of water jet machine - <u>70%</u>		

The foreman stated that MSHA inspectors had measured dust levels at one Site No. 4 quarry during operation of the dust collector, and had determined that the quarry was in compliance. These sampling data were not available at the time of the visit.

Wet drilling had been tried at the four quarries that were visited, but had been discontinued. According to one quarry foreman, water that was pumped through the axial drill steel would splash over the pneumatic drill operator. During cold weather, the water would chill the drill operators, creating uncomfortable working conditions and increasing the number of employee illnesses. Even during warmer weather, wet clothing is not conducive to productivity. The dry drilling method with filter dust collection is preferred over wet drilling, because it reduces dust levels while causing only a small inconvenience to the workers.

The next step after drilling is to place small charges of black blasting powder in paper-wrapped containers in the holes underneath the block. Two small wires in each charge of powder are extended to a battery. When contact is made, an electrical spark sets off the charge. The resulting small explosion is just sufficient to "raise" and break the block loose from the quarry bed; therefore, the block is lifted, not blasted, free.

4

Workers are not present during blasting operations. After all the charges have been detonated, the workers can re-enter the area. Although we did not observe a blasting operation, the lifting action of the small blast should not generate much dust, because very little rock fragmentation is involved.

When the whole section (called a quarry block) is free on the sides and the bottom, jack hammers and plug drills are used to prepare smaller saw blocks of specific dimensions. Small vertical holes 3 to 5 inches deep are drilled along the large quarry block (commonly called "dotting the line"). Each hole requires approximately 10 seconds to drill. The distance measured between the small vertical holes ranges from 5 to 7 inches. Drill operators dot the line by drilling holes one shoe width apart along the chalkline.

Thus, the distance between holes depends upon the width of the operator's foot and the distance he places the drill bit from his foot. Since an average size block of rough granite is 10 feet long, 3 feet wide, and 3 feet high, the number of drill holes could be reduced from about 35 to 25 by maintaining a 7-inch spacing (a 28 percent reduction in drilling time). Although dotting the line does not take more than 10 minutes, drilling holes every 7 inches would require less time and less dust would be formed. Quarry foremen indicated that 7-inch spacing does not decrease the quality of the hardway cut.

Wedges and shims are inserted in all drilled holes. The wedge is a 3-inch piece of tapered steel placed between 2 shims. The quarry worker uses a sledge hammer to tap each wedge and force the pressure from the wedge to the shims, causing the granite to break evenly.

The entire dimension saw block is then free from the quarry block. Loops of heavy steel cable from a derrick boom located above the quarry are placed around the block. In an alternative method, large hooks connected to derrick cable are placed in holes drilled at each end of the block. These holes are also drilled dry. The holes are drilled only deep enough to permit the hooks to be securely attached. The fabric filter dust collectors mentioned previously are not used during this process step.

The derrick boom is slowly raised, tightening the cables around the block or securing the hooks, and the block is lifted from the quarry to be placed on a waiting flatbed truck for transport to the manufacturing plant.

Haulage roads to waste piles and onsite finishing mills were not paved at the four quarries visited. The road base is granite. However, all quarry roads were covered with granite dust and dried clay. At one granite quarry, watering trucks wet the haulage roads on a daily basis when the weather is dry.

Respirators or similar personal protective equipment are made available to all employees at no cost. However, during the site visit, JRB observed

that respirators were not worn by any of the quarry employees. A company foreman said that the shortage of available labor and low wages limit the amount of supervision that can be used to enforce respirator usage.

After careful examination, the granite selected for finishing is fed through various processes. The remainder, which is more than 60 percent of all granite quarried at Site No. 4, is discarded on grout or waste piles.

Finishing Operations

Facility A--

The Facility A granite operations are located approximately 1/4-mile from the quarry site. The sawing process transforms large blocks of rough granite into smaller pieces for building stone panels 7/8-inch thick. In monument production, slabs of granite are usually sawed into 6-, 8-, 10-, and 12-inch thicknesses.

Two types of saws were observed at this cutting facility. The diamond rotary saw in use at the plant is 9 feet in diameter. The steel blade has approximately 140 segments inserted on the blade cutting surface. Each segment consists of diamond grit particles molded with a metal bonding agent. Water is used to cool the saw blade while it is operating. The water flows out of one side of the saw cowl and wets the entire blade and the granite block that is being cut.

No dust was observed during the sawing operation. Airborne water mist was visible. The mist was generated from the high rotational speed of the saw.

Diamond rotary saws are fully automatic. Operators are not needed to control the sawing operation. Workers were present in the sawing operation building. These workers were not stationed in the immediate area of the diamond saw unless they were conducting maintenance work on the saw equipment or setting up a new block to be sawed.

Wire saws are also used to cut granite at the Facility A operation. A wire saw consists of continuous strands of twisted wire stretched between large wheels, which serve as pulleys. The wire is driven at a high speed by the rotating wheels and cuts into the granite blocks at the rate of 13 inches per hour.

Single-strand and multiple strand wire saws were observed at the operation. The wire saw is not fully automatic and requires periodic supervision for proper cutting of the granite. No operator was positioned near the wire sawing operation.

Water and silicon carbide grit is used to facilitate efficient wire sawing and to cool the wire while it is in contact with the granite. Wires are extended to pulley towers located at distances of several hundred yards or more from the cutting operation to cool the wires and thus extend wire life.

During the wire sawing process, granite mud is carried on the wire and is thrown off the wire against a steel backstop as the wire changes direction in traveling around the return wheel. In hitting the back-stop, the granite mud disperses a fine aerosol, which dries out. Accumulations of dust were observed on wire-sawing equipment, beams, and the floor area around the equipment.

Cutting Facility B--

At the Facility B cutting operations, a Loffler diamond rotary saw and a Schlatter diamond rotary slant saw were operating. Water and an Amway detergent are used to cool the saws. Water mist was not visible around the saws. The use of the detergent may prevent mist formation. A high-speed GB520 Thibaut polisher was used to polish cut slabs of granite with diamond polishing bricks.

Cutting Facility C--

At Cutting Facility C, granite blocks are sawed and fabricated into granite memorials. Diamond and wire saws were observed in use. Manual

polishing operations were also conducted. A heavy, round, cast-iron wheel called a scroll wheel was used to remove ripples in granite surfaces. The wheel is operated at high speeds over wet granite surfaces, but no dust or water mist was observed near the operator. A buffing operation was also observed. The polishing buffer has many compressed felt pads inserted in the wheel. These soft pads are coated with a mixture of water and tin oxide or aluminum oxide powder and slowly guided over the entire slab until a highly polished surface is achieved.

The unpolished edges of the slabs are trimmed with hand chisels. Other hand tools, such as hammers and pneumatic tools, are also used to smooth surfaces and to apply special surface finishes.

This detailed work is done with the granite in a dry condition. Exhaust hoods are used to capture dust during the finishing process. These hoods are movable (because of flexible ductwork, counterbalances, and swivel points) and can be placed at the source of dust. Each hood has a rectangular face with a flared section to which the duct is connected, thus allowing a streamlined air flow. The hood is surrounded on all four sides by a 3-inch flange.

The ductwork is connected to a baghouse located outside the building. It appeared to be properly designed. No sharp bends were observed in the ductwork. Chip traps are cleaned out on a regular basis, and problems with clogged ductwork have not occurred.

Designs, letters, and intricate figures are formed on granite slab surfaces by sandblasting operations. Before the slab is sandblasted, rubber stencils are glued over the surface of the granite. The stencils are cut with the desired lettering and design. The exposed sections of granite are then sandblasted. The uncut rubber portions deflect the sand and protect the polished surfaces.

The sandblast operator stands outside the sandblast enclosure or booth during the sandblasting operations. An exhaust filtration system is used to provide negative pressure inside the sandblast enclosure. An opening in the

booth, which is covered with rubber strips, allows the operator to move a hose equipped with a ceramic nozzle horizontally or vertically as needed. A non-silica abrasive manufactured by Norton is used to blast the slab located in the enclosure.

The sides and top of monuments are sometimes polished. These operations are also performed wet.

After the sandblasting is completed, live steam is sprayed over the entire granite surface to remove the remaining glue and tiny particles of stencil. The monument is allowed to dry and is then wrapped and packed in a heavy crate for shipment.

A similar operation and process flow was observed at another local granite company. One piece of equipment seen at that company, the Hydra-split, was not used at the Facility C operation. This machine breaks slabs into the smaller sizes needed for monuments.

Granite Finishing Facility D--

The Facility D company was visited to observe a French-made polishing system. The polisher, which is fully automatic, runs on tracks. Up to nine slabs can be set up and polished at one time. The system is also equipped with eight sensor tubes into which air is continually blown. When four or more of the tubes on the grinding head run off the edge of a slab, the sensors relay a signal to the computerized controls and the grinding head is re-positioned on the slab surface. The sensors allow the system to polish slabs of any shape. The machine is also equipped with separate automatic controls for different types and colors of granites, so that the number of passes the polishing head makes over each slab can be individually programmed. An operator is needed to check the system only on a periodic basis. No visible dust or mist was observed from the polishing process.

Similar finishing operations are conducted at the six granite fabrication plants visited. Sawing and polishing of granite are wet operations. The cutting, carving, and lettering procedures are dry processes.

Because of the moderate Georgia climate, the buildings that house the finishing operations are wood and metal structures open on many or all sides. There is a great deal of dilution ventilation in the open buildings. Most of the operations visited also had low-speed fans to pull air through the buildings and exhaust it to the outside.

Personal respirable sampling data collected in 1979 by the Mine Safety and Health Administration (MSHA) were obtained for Quarry 1 (19 samples), Quarry 2 (5 samples), Quarry 3 (5 samples), and Quarry 4 (6 samples). Quarry 1 and Quarry 4 each had two samples that exceeded the PEL for respirable dust. Three samples collected at Quarry 3 exceeded the PEL. None of the samples taken at Quarry 2 exceeded the PEL.

With the exception of one sample collected during general laborer activities, the samples that exceeded the PEL were all collected during rotary and percussive drilling operations. The data records did not indicate whether the drills were supplied with water for dust suppression, if dry dust collection systems were used, or if no controls were in use.

From our observations, quarry operations generated more dust than fabrication processes. Jet piercing and drilling activities in the quarry generated the most dust. The dust from the jet piercing typically rose straight up out of the quarry, while dust generated from drilling was dispersed throughout the quarry. Because of the depths of the quarries, natural ventilation and wind currents do not have much effect in dispersing the airborne dust from drilling.

ATTACHMENT A

Assumptions - Fuel, Cutting Rate, and Size of Dimension Stone

JET PIERCING

REFERENCE

1. Burners use 12 to 16 gal/hr of #2 fuel oil (average = 14 gal/hr) (1)
2. Quarrying (cutting) rate is 12 to 16 ft²/hr (average = 12 ft²/hr) (1)
3. Compressor electricity requirement is approximately 80 Hp or 68 kW - compressed air power requirement is 68 kWh per hour (2)
4. Fuel costs - #2 fuel oil = \$1.25/gal (1)
- electricity - \$0.06/kWh JRB estimate
5. Hourly fuel cost = \$1.25/gal x 14 gal/hr + \$0.06/kWh x 68 kWh = \$22/hr JRB calculation
6. Labor cost = \$7/hr (1)
7. Cost of cutting per square foot = \$29/hr ÷ 12 ft²/hr = \$2.42 ft² JRB calculation

WATER JET MACHINE

1. Motors used to operate machine (3)

<u>Motors</u>	<u>Motor Efficiency</u>	<u>Full Load kW</u>
150 Hp	92%	122.0
7-1/2 Hp	85%	6.6
5 Hp	85%	4.4
TOTAL		133.0 kW

2. Fuel usage rate ≈ 135 kWh per hour JRB calculation
3. Quarrying rate is 20 to 23+ ft²/hr (average = 21 ft²/hr) (1)
4. Fuel costs - see JET PIERCING
5. Hourly fuel cost = \$0.06/kWh x 135 kWh = \$8/hr JRB calculation

ATTACHMENT A (Continued)

REFERENCE

6. Labor cost = \$7/hr
7. Cost of cutting per square foot = $\$15/\text{hr} \div 21 \text{ ft}^2/\text{hr}$
= $\$0.71/\text{ft}^2$ JRB calculation

COMPRESSED AIR DATA (Jet Piercing)

1. Air required to burn 1 gal of #2 fuel oil
(stoichiometric) = 106 pounds (5)
2. Air weights = $0.0753 \text{ pounds}/\text{ft}^3$ (6)
3. Fuel combustion rate - 12 to 16 gal/hr (1)
4. Quantity of air used per hour = $106 \text{ pounds of air}/\text{gal} \div 0.0753 \text{ pounds of air}/\text{ft}^3 \times$
 $1728 \text{ in}^3/\text{ft}^3 \times 60 \text{ min}/\text{hr}$
 $\times (12 \text{ to } 16 \text{ gph})$ JRB calculation
5. Estimated excess air for complete combustion = 20% JRB estimate
6. Estimated $\text{in}^3/\text{min} = 584,000 \text{ to } 778,000$ JRB estimate
Estimated $\text{ft}^3/\text{min} = 338 \text{ to } 450$
7. Air pressure supplied to lance - 90 psig (8)
8. Estimated compressor size required to supply 584,000 to
778,000 cfm @ 90 psig $\approx$ 100 Hp Worthington Air
Compressor (7)
9. Estimated average hourly full load = $80\% \times 100 \text{ Hp} \div 88\%$
motor efficiency - 68 kW (4), (7), and
JRB estimate

REFERENCES

- (1) Site visit data, Site No. 4
- (2) Compressor Calculation Sheet
- (3) Equipment inspection by JRB Associates, May 1982
- (4) Baldor Stock Motor Performance Data

ATTACHMENT A (Continued)

- (5) ASHRAE Fundamentals 1981, p. F15.10, Table 13
- (6) Standard Handbook for Mechanical Engineers
- (7) Miller Distributors -- Personal communication, May 1982
- (8) Mr. Alton Smith -- Century Granite Company - Personal communication,
May 1982

TECHNOLOGICAL FEASIBILITY OF CONTROLLING
ASBESTOS AND SILICA AT MINES AND MILLS

Site Visit Report No. 5
Coal Mine, Northwestern U.S.

Personnel of JRB Associates and Science Applications, Inc. (SAI) conducted a site visit on April 28, 1982, at the mine at Site No. 5. The purpose of the visit was to observe dust control methods used in mining and milling processes.

The mine is a large strip mining operation producing 6 to 7 million tons of low sulfur coal per year. The majority of the coal produced is sold to a local power plant (2,000 megawatts). The mine currently has 523 full-time employees.

Before any actual mining may begin, all the topsoil is removed from the mining area by scrapers, which have enclosed cabs without air conditioning. The topsoil is directly reapplied to mined areas or stored for later application. After removal of the topsoil, the underlying 3 to 10 feet of soil may be salvaged and stored separately. The remaining overburden is arranged in a large spoil pile near the mined area while the coal is removed. After mining is completed, the mined-out area is refilled with the overburden and recontoured by track and rubber-tired bulldozers. The recontoured land is tilled by scrapers and conventional farm equipment and topsoil is reapplied and reseeded. All equipment used in reclamation is equipped with enclosed cabs. The cabs are not air conditioned.

Coal mining equipment used at the mine site includes:

EQUIPMENT TYPE:

QUANTITY

Stripping:

• Marion 8200 dragline, 75 cubic yard capacity	2
• Page 757 dragline, 60 cubic yard capacity	1
• Page 732 dragline, 20 cubic yard capacity	1
• Koehring backhoe, 8 and 16 cubic yard capacity	2
• Bucyrus-Erie 60-R blasthole drill	1

● WABCO 85C haul truck	6
● Ingersoll-Rand DM-7 blasthole drill	1
● Marion M-3 overburden drill	1
● Michigan 380 rubber-tired dozer	2

Coal mining:

● Bucyrus-Erie 195-B coal-loading shovels	2
● Ingersoll-Rand T-4 mobile drill	1
● Dart 600C front-end loader	2
● Michigan 380 rubber-tired dozer	3
● WABCO 75B water truck	3
● Cat 16G motor grader	3
● WABCO 75B/120CT tractor with 120-ton trailer	14

Ash haul from power plant:

● WABCO 75B ash hauler with trailer	4
● EJECT-ALL ash hauler with trailer	1

Reclamation and road maintenance:

● Komatsu 355A tractor with ripper	2
● Fiat-Allis 41B tractor	1
● Steiger 450 rubber-tired dozer	1
● Cat D9G dozer	4
● Cat 631 scraper	4
● Cat 633 scraper	1
● Cat 657 scraper	1

To avoid excessive rehandle (material that is handled more than once), the mine utilizes a two-pass stripping sequence for overburden removal. On the first pass, the upper portion of the overburden, which is a soft sandstone, is drilled on a 40- by 40-foot pattern with 12-1/4 inch diameter blastholes. The powder factor used on this pass is approximately 0.5:1 (lbs explosive/yard overburden) with bulk ammonium nitrate and fuel oil (ANFO) being used in dry holes and a packaged product used in wet holes. Water gel explosive is commonly used to boost the ANFO, especially where harder material is encountered. After the top portion of the overburden is shot, the overburden is removed by dragline in a conventional manner, then the lower portion of the overburden, which is a hard sandstone, is drilled on a 30- by 30-foot pattern and shot with a 0.85:1 powder factor. Here, the overburden is purposely cast as far as possible by the blast, since the dragline, which will remove this overburden, will be working from the spoil side of the pit. The

management is very pleased with the two-pass system and has noticed a decrease in the amount of rehandle as well as an increase in the digging efficiency of the dragline due to the varied patterns and powder factors used in drilling and blasting.

All the overburden is drilled with large track-mounted electric drills using 12-1/4 inch bits, and all the overburden drills are equipped with enclosed cabs, air conditioning, and American baghouse dust collection systems (an option that costs about \$50,000). The drills are equipped with skirts around the drill steel. All drills have multi-pass capability and are operated by a crew of one. Drilling at the mine is conducted dry.

The team visited one of the overburden drills, a Marion M-3. The baghouse on the drill was not operating due to a breakdown. The operator stated that the baghouse really did not reduce the dust in his work station, since the cab is enclosed, air conditioned, and pressurized. However, the baghouse does contain some of the dust generated during drilling and therefore controls the dust level exposures for people working outside and downwind of the drill.

The team observed the operator changing the drill steels on the drill. The entire process was performed from inside the operator's cab. The operator said the only time it was necessary to leave the cab was while moving the drill and while staking the drill pattern. The drill is equipped with a remote control unit to allow the operator to move the machine from outside the cab. A cable reel is used to handle the trail cable that supplies the power to the drill.

The blasting pattern is designed by the engineering department. Holes are stemmed with drill cuttings. Due to the large size of the holes, a rubber-tired dozer or skidder is used to place the stemming into holes. The dozer operator pushes the cuttings into the hole with the aid of one person directing the dozer and protecting the down line going to the explosive charge.

The mine currently has four walking draglines that are used for overburden removal. Two of the machines have 75 cubic yard buckets; one has a 60 cubic yard bucket and one a 20 cubic yard bucket. All of the draglines have a crew of three--an operator who operates the machine, an oiler who is responsible for lubrication, and a groundman who keeps the working pad of the dragline level with a track-mounted dozer. The operator's cab, where the crew members spend the majority of their time, is enclosed and air conditioned. The machinery house, which contains all the motors, cable reels, gears, and electrical components, is pressurized with a slight positive pressure of 0.01 psi greater than the outside pressure to prevent dust from entering. All of the air used for pressurization is filtered prior to entering the machinery house.

Once the overburden has been removed by the dragline and the coal is exposed, the coal is drilled, blasted, and loaded into trucks for transport to the power plant. Drilling in the coal is performed with diesel-powered, track-mounted rotary drills. The drills are equipped with enclosed cabs with air filtration systems. The coal, like the overburden, is drilled dry.

After blasting the coal, it is loaded into 120-ton WABCO bottom dump trucks equipped with cabs without air conditioning. The trucks are loaded either with electric shovels or with front-end loaders. The shovels have enclosed cabs that are air conditioned and, like the dragline, have a pressurized machinery house. The front-end loader has an enclosed cab without air conditioning. The shovel is operated by a crew of two. The front-end loader is operated by one worker.

The coal seam at Site No. 5 splits into two seams and has an innerburden of hard shale separating the seams. This shale must be drilled, blasted, and removed so that the second seam of coal can be mined.

Drilling is conducted on a 20- by 20-foot pattern using a 7-7/8 inch drill. The drills are all equipped with enclosed cabs with air filtration systems, and all drilling is done dry. Like the lower portion of the overburden, the innerburden is shot with a 0.75:1 powder factor.

The shot innerburden is loaded by either a front-end loader or a large backhoe loader into 85-ton end-dump trucks. The loaders both have enclosed cabs that are not air conditioned. The innerburden is hauled a short distance to a section of the mine where the lower seam has been removed. After the innerburden has been removed, the lower seam coal is mined in the same manner as the upper seam.

Dust on haul and access roads became a problem at the mine shortly after it opened in mid-1974. Due to the amount of dust, driving was hazardous for the two 120-ton coal haulers (moving at speeds up to 40 mph), four 85-ton ash trucks, and numerous standard vehicles used at that time.

Roads were originally surfaced with leucitite and scoria. The leucitite, or cooled lava flow, was extracted by an outside contractor from a nearby area and put down on the main haulroad to provide a 12- to 18-inch base. The scoria, which is superheated sandstone found above burned-out coal, was used as an economical means of surfacing the access and service roads with a 12- to 18-inch base.

Large quantities of water were applied continuously on the main haulroad, access road, and service roads by water spreader trucks. Because of the extremely low humidity at the site and common 30 to 40 mph wind velocities, the water evaporated within minutes of its application.

Finally, the decision was made to use Coherex®, a dust retardant, to control dust on the haulroads. For the first-time treatment of the roads, a 15 percent solution of Coherex to water was applied at a rate of one-half gallon per square yard. After the initial application, a 1:10 solution (agent to water) was applied every 4 to 6 weeks, with water alone used between these runs.

Both the leucitite and scoria surfaces were susceptible to rutting from vehicle wheels. To control the ruts, the roads were scarified to a depth of about 1 inch with steel spikes attached to a Caterpillar model 16H road grader every 2 to 3 months. Coherex was then added to the ripped-up surface at a

ratio of 1:10. Vehicular traffic packed the scarified road down to provide a smooth-running surface.

The initial application of the agent to a 70-foot-wide road (at a dilution rate of 15 percent) cost approximately \$3,500 per mile in 1974. Annual upkeep ran about \$2,000 per mile per year (at the maintenance dilution rate of 1:10). These figures represent the cost of the Coherex only.

A permanent tank was constructed to store the Coherex. To offset the effects of freezing weather, the 20,000-gallon tank was built into a small hill so that only the access end of the tank was exposed. Two 20,000-gallon tank trucks of Coherex were delivered per year at a cost of \$0.42 per gallon.

Three distributor trucks were used for the application of the dust retardant: an 11,000-gallon WABCO water truck, a 10,000-gallon Caterpillar 641, and an 8,000-gallon Caterpillar 631.

While the Coherex was superior to plain water, it was expensive and difficult to apply. In the summer of 1981, the decision was made to resurface the haulroads and use a different dust retardant.

Scoria is no longer used on roads because it weathers poorly and breaks down, which causes airborne dust. Currently, there are two basic types of service roads at Site No. 5. Approximately 20 miles of 20-yard wide haulroads connect the coal seam mining areas with the power plant. These roads are structurally designed to withstand the stress of heavy loads and to prevent airborne dust from vehicular traffic. The road base is a composite of leucitite (local volcanic rock) and smaller aggregate.

The second road type, which may change from day to day due to mining advances, is for smaller vehicles traveling between the haulroad and mining operation sites. They appear to be constructed from surface soil and are not treated with a dust suppressant. Water is the only dust control agent used.

The haulroad dust suppressant used presently is ammonium lignin sulfonate (ALS). This compound is a pulpwood waste product and is considered nontoxic. When properly mixed, rolled, and compacted with the leucitite and aggregate road materials to form a homogenous mixture, ALS is an effective dust suppressant.

The road base mixture can be prepared by batch process or at the location of the road surface to be treated. Effective dust control requires an initial application of 0.75 gallons of ALS per square yard of scarified road surface. The ALS must be applied to a depth of 4 inches. In subsequent applications for road dust control maintenance, 0.50 gallons of ALS are used per square yard of scarified road surface. Reapplication is done approximately once per year, because the initial treatment was found to be effective for a year. Treated roads are usually watered twice daily by WABCO 10,000-gallon water trucks. No applications of ALS or water are made during the winter months.

It was calculated by the site visit team that a 20-mile by 20-yard wide road has 70,400 square yards of road surface. Initial road treatment would cost \$147,500 for the ALS product and \$30,000 for ALS application, totalling \$177,500. This cost equals \$0.252 per square yard. Reapplication costs for the same area would be \$0.18 per square yard. These figures do not include costs of road base materials, road construction, or vehicle purchase and maintenance.

The management is very satisfied with ALS dust suppression results and has noticed an increase in tire life, as well as a decrease in the frequency of watering required to control the dust on the haulroad. The mine currently has three WABCO 10,000-gallon 75-B water trucks to apply water when needed.

During the site visit, main haulroads were observed to have a somewhat rough and rocky surface. The roads were in this condition because maintenance of road surface cannot be conducted during winter months. Alternating freeze-thaw cycles, which are common in the spring, also cause road damage. As soon as the weather becomes more clement, road maintenance will be resumed.

The mine safety department has established speed limits on the mine haulroads. The maximum speed for pickup trucks is 45 mph; for loaded coal haulers, it is 30 mph. With the long gentle grades and normally excellent condition of the roadway, these speeds are commonly achieved.

The coal is transported either to a hopper designed for the bottom dump trucks or placed into stockpile. With the low demand for electricity, the mine and power plant are stockpiling a large amount of coal. The power plant currently has a stockpile of 1.5 million tons of coal, and the mine has one stockpile of 130,000 tons, with another 120,000-ton stockpile under construction. For construction of the stockpile, the coal is dumped by the bottom dump trucks, graded with tracked and rubber-tired dozers, and compacted dry. It was pointed out by mine personnel that it is very important to compact and seal the coal pile edges to keep air and water from entering the stockpile, which may lead to spontaneous combustion of the stockpiled coal. This exothermic reaction results from the interaction between water and iron pyrite, a mineral present in the coal.

Coal that is not placed into the mine stockpile is dumped into a hopper, where it becomes the property of the power plant. While the team did not visit the power plant, a mechanical drop sock was observed on an intermediate coal stockpile. The drop sock is controlled by an operator and is telescopic to allow for decreased drop distances at various stockpile heights. It was mentioned that last year the operator did not retract the sock as the coal pile grew, and the sock became plugged with coal. As the stockpile was depleted, it ceased supporting the plugged sock. The additional weight of the coal in the sock caused structural damage to the conveyor structure leading to the drop sock.

Another dust source present at Site No. 5 is ash produced from the power plant. This ash is hauled back to the mine where it is eventually buried. The ash is dumped, graded, and compacted to avoid excessive dust generation. Occasionally, water will be applied to hold the dust levels down.

Results of MSHA Dust Monitoring--

The safety department collects breathing-zone respirable dust samples of seven MSHA designated job categories, which represent high risk exposures. The samples are analyzed by MSHA. The results and status of compliance are reported to the mine.

Table 1 lists the results of respirable coal dust monitoring obtained from the safety department. The data in Table 1 show nearly complete MSHA compliance with the respirable coal dust standard and for other dusts of unknown silica content.

The refuse/backfill operator, working without dust controls, had the highest level and widest range of dust exposures. This would be expected, because his job is to move overburden.

The coal hauler had no cab dust controls, but the treated roads should reduce non-coal type dust exposures. The dust levels recorded might have accumulated during loading and unloading operations. His exposures were well within allowable limits.

The shovel operator can be expected to be exposed to respirable dust because he is moving overburden and coal throughout the shift. However, even without dust controls, his exposures were well within the allowable limits. It is important to note that while the coal seam area is not wetted, there are no surface winds in the excavated seam area. Winds would potentially stir up dust and present exposure problems to the operator.

The oiler, who is responsible for proper shovel function, is in an open environment and would appear to be subject to more dust from mining operations and moving machinery. However, his dust exposures were low and similar to the shovel operator.

The coal drill operator, even with dust controls, had high dust exposures compared to most other jobs surveyed. It is possible that the operator spends

Table 1. Coal dust exposures per job category (mg/m³).

Survey dates	Refuse/backfill*	Dozer operator*	Coal drillers*	Shovel operators*	Shovel oiler*	Coal hauler
June 1981	1.0	2.1	2.2	0.4	0.4	1.0
July	---	0.4, 0.5, 0.4 0.4, 0.7	0.8, 0.4, 1.1, 0.4, 1.2	---	---	---
August	3.3, 0.7	1.1	2.0	1.0	0.7	3.3, 0.7
September	0.7, 0.2 0.4, 1.0	---	---	---	---	0.7, 0.2, 0.4 1.0
October	0.4	0.7	0.4	0.4	---	0.4
November	---	---	---	---	---	---
December	---	2.2	1.7	0.7	0.7	---
January 1982	---	---	---	---	---	---
February	---	---	---	---	---	---
March	0.5	1.0	1.7	0.1	0.1	0.5

NOTE: The Shop Welder was omitted from this table.

*No dust controls on equipment.

time away from his protected environment, on the equipment platform or on the ground near the drill.

Observations made during the site visit review of the dust exposure data indicate that this surface mining operation does not present extreme dust problems. There are few pieces of high-speed operating machinery, and there is a great deal of air to dilute and disperse dust.

TECHNOLOGICAL FEASIBILITY OF CONTROLLING
ASBESTOS AND SILICA AT MINES AND MILLS

Site Visit Report No. 6
Potash Mine, Southwestern U.S.

A potash mine at Site No. 6 was observed on March 24, 1982, by JRB and SAI staff. The purpose of the visit was to observe dust control methods used in mining and milling processes.

Access to the mine is by vertical shafts. The mining is done at two levels, which are 600 feet and 800 feet below ground. The overall ore recovery is approximately 72 percent. The mining is done using a conventional room and pillar system (see Figure 1). Seven panels with 11 entries are currently being mined.

The mining sequence consists of the following steps: undercutting the face, drilling and loading holes with explosives, blasting, loading the ore, and roof bolting. The working areas underground are all operated in essentially the same manner and use the same type of equipment. This standardization facilitates transfer of mine crews from area to area with the least possible interruption to production caused by different equipment or methods.

The standard production crew size is six workers: one undercutter operator, one drill operator, one powder machine operator, one loading machine operator, and two shuttle car drivers. The loading machine cleans up the blasted ore, and the undercutter, drill, and powder machine operators follow in sequence to prepare more ore.

The production equipment in each section consisted of the following:

- 2 Joy 15RU or 17RU undercutters
- 1 CD43 or CD73 Joy jumbo drill
- 2 14BU - 10 Joy loading machines
- 2 Jeffrey diesel powered ramcars

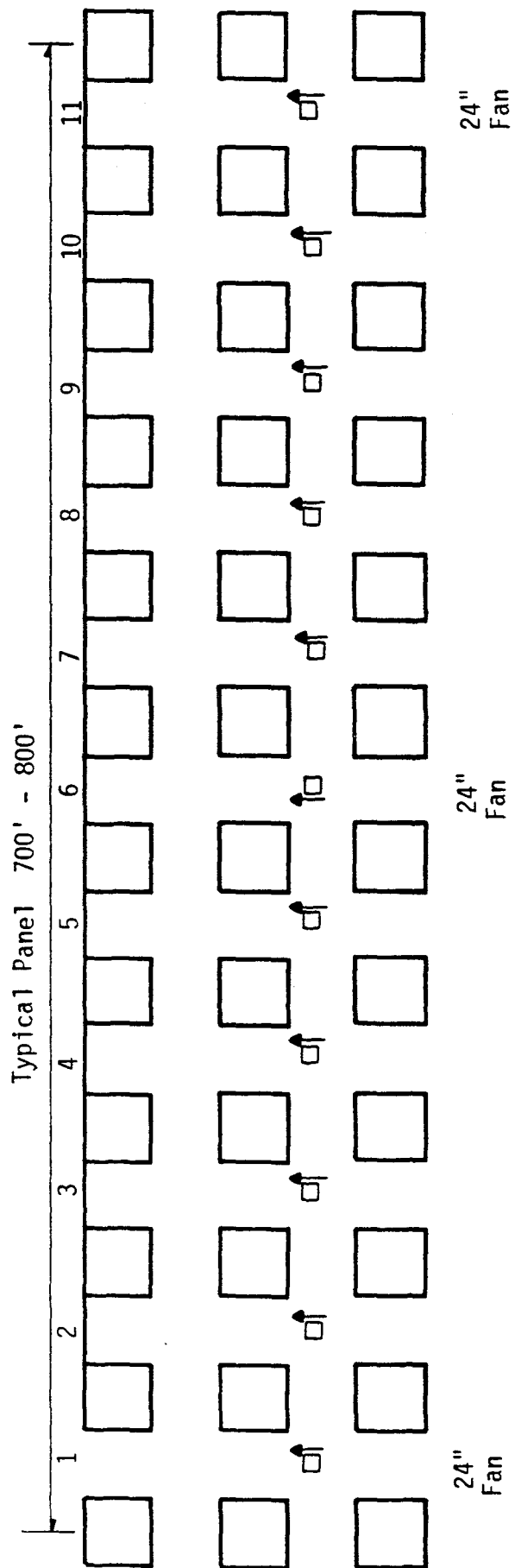


Figure 1. Room and pillar system for potash mining.

- 1 Getman powder machine
- 1 Gallis roofbolter
- 1 Sien grease rig.

All of the production equipment, excluding the hauling system, is operated by a 550 volt, 3-phase AC system. Haulage is accomplished using diesel-powered ram cars.

Pillar sizes are 30 feet by 40 feet, or 30 feet by 50 feet with 32-foot wide rooms. Headings measure 8 feet high by 36 feet wide, and are advanced 12 feet with each blast.

Face areas are not wet down because the ore materials are highly soluble in water. Working area haulageways are sprayed with water twice weekly. Once monthly, or more as needed, main haulageways are wetted down.

The face is undercut before drilling to control the size of blasted headings. Water sprays are used on the bottom side of the cutter bar near the chainfeed to control dust during cutting operations.

In a standard round, 16 holes are drilled by twin-boom jumbo drills. Water spray nozzles are located 3 inches from the bit of each boom. The spray nozzles are hollow cone. Sprays are manually controlled. It was observed that little dust was generated during the drilling process when sprays were used.

All blasting is done with an ammonium nitrate fuel oil (ANFO) blasting agent. The holes are primed with one stick of gel explosive and an electric blasting cap, and are then pneumatically loaded with the ANFO. The drillhole pattern optimizes ore recovery but may not be the most effective pattern for reducing dust generation. No attempt is made to wet the area to reduce dust or fumes after blasting. Blasting is generally done between shifts. The time between shifts is adequate to reduce dust and fumes to acceptable limits.

The loading machines are each equipped with a hollow cone spray nozzle located above the gathering arms. Diesel-powered ram cars are loaded by the gathering arm machines, and ore is transported by the ram cars to conveyor feeders. The ram cars are equipped with manually operated water sprays at the conveyor discharge end. Ore from the ram cars is dumped into feeders. The feeders crush and transport the ore to a belt conveyor system situated within 300 feet of the face. Water sprays are located at the transfer point between feeder belts. These sprays are manually operated.

Spray nozzles on the mine equipment were manufactured by Binks, Inc. The nozzles are made of brass, which prevents corrosion. Each nozzle contains a slotted strainer to trap water impurities and prevent nozzle clogging.

Water lines at 35-40 psi run the length of the working area. Equipment operators can easily connect hoses to the lines and obtain water for mining machine water spray systems.

When operating properly, the spray nozzles produce a very fine spray. Occasionally, problems have occurred because operators modify and enlarge the nozzle orifices with hack saws until they can see the spray. After the modification, sprays are visible because they are coarser. However, the dust suppression effectiveness of the sprays is greatly reduced.

At each face, 24-inch fans exhaust air into the main drift of the panel. For each panel main drift, three 48-inch fans exhaust air out of the panel and into the main exhaust system. This ventilation system was effective in reducing visible airborne dust.

Two intake shafts supply air to the mine at a rate in excess of 300,000 cubic feet per minute. Two separate series ventilation circuits are used to control dust and fumes. The circuits are separated by air doors and bulkheads. Dust contamination from panels located near the intakes is diluted to low levels before the air reaches panels away from the intake. The dilution effect is due to the large volumes of air used to ventilate the mine.

Mixed ore (sylvite and langbeinite) is hoisted from the mine. The mixed ore is crushed dry in a closed circuit. After crushing, saturated brine is added for scrubbing and mechanical desliming operations that remove the mud from the ore. Visible airborne dust was present in the crusher building. Conveyors were enclosed, but dust leakage was observed from cracks and openings at several points along the conveyor belts. Much dust dispersion was noticed at conveyor head and tail pulleys. Access doors and openings were provided along the enclosures for inspection and maintenance. Some doors were left open, and openings were not covered. Gaps were also seen between lower enclosure edges and belt surfaces; these gaps resulted in dust leakage.

Coarse crushed ore is conveyed to a heavy media separator section and is split into an upgraded sylvite fraction, an upgraded langbienite fraction, and a waste halite fraction.

The upgraded sylvite fraction from the heavy media separator is recombined with the fine mixed ore fraction and reduced by wet milling to a size that is optimum for flotation. A separate flotation circuit is used for langbeinite concentration. Visible dust was not observed in these areas because the processes are wet. The sylvite and langbeinite concentrates are dewatered, dried in rotary gas-fired dryers, and separated by screens into the desired sizes. The air was visibly dusty in the dryer area. Dry cyclones and wet scrubbers are used to control dust from the drying process; however, because of problems with dust buildup in the ductwork, the fans exhaust insufficient air for dust control at their designed velocities. Ductwork is frequently inspected for dust buildup problems. Due to the amount of dust generated during dry processing, many ducts are clogged.

The three scrubbers used for dust control in the plant were designed in-house. With the scrubbers, the mining company has been able to comply with the Federal Clean Air Act, as amended, of 1977. The scrubbers require frequent maintenance because the material processed in the plant cakes easily, which causes clogging of ductwork and internal parts. During the visit, it was noted that one scrubber system was inoperative because of a plugged duct line.

A high parafinic weight oil is added to finished products by spray bars, which are located approximately 12 inches above the conveyors transferring the material to storage and warehouse areas. The oil is added to prevent setup and caking of the material during storage; it also suppresses dust generation and dispersion during conveying, transfer, and storage of the finished product.

TECHNOLOGICAL FEASIBILITY OF CONTROLLING
ASBESTOS AND SILICA AT MINES AND MILLS

Site Visit No. 7
Molybdenum/Copper Mine, Southwestern U.S.

A site visit was conducted on March 29, 1982, at Site No. 7 by JRB and SAI personnel. The purpose of the visit was to obtain information on the types of dust control methods used in mining and milling operations.

The open pit mine produces approximately 20,000 metric tons of ore and 80,000 metric tons of waste rock per day. The following facilities are located at the mine site: molybdenum and copper concentrator facilities; waste disposal areas; and various auxiliary facilities including offices, storage buildings, roads, and power distribution lines.

Haul roads are the major source of dust in the open pit mine. With the very dry climate (approximately 4 inches of precipitation per year), haul road dust control must be conducted on a year-round basis.

The operation uses three 14,000-gallon water trucks (modified WABCO's) to wet haulageways. All haulageways are wet down at least daily in the pit. Some haulageways are wet down more frequently, depending on the amount of traffic. While surface water is scarce, subsurface water is abundant. However, water conservation remains a significant concern because of the high cost of operating the water pumps.

While no road dust suppressants have been tried in the mine itself, several compounds have been used in the shop/warehouse area and on access roads between temporary housing locations and the construction site. Waste oil is being used around the shop and warehouse to control dust. Permission was given by the State to use the oil for this purpose. Lignin sulfonate was used previously as a water additive on the access road from the housing site to the construction site. Although lignin sulfonate helped control dust on straight sections of the road, it adversely affected curved sections, where the roadway broke up very badly. The lignin sulfonate was applied without

first scarifying the road surfaces, which may have been the reason for the premature deterioration of the road on the curved sections. Future tests of magnesium chloride as a dust suppressant on road surfaces are planned. This wetting agent has been used satisfactorily at company mining operations in Montana.

The ore body is drilled using 45R Bucyrus-Erie rotary drills. These machines are equipped with hollow drill steels, which are supplied with water during the drilling process. The drills are equipped with controllable skirts around the drill stem. These skirts isolate drill cuttings from air currents, and thus reduce entrainment and dispersion of dust. Experience of JRB personnel has shown that these skirts are prone to damage as the drill moves.

Ore is blasted during shifts and loaded into 120-ton WABCO mechanical end-dump trucks by 18-cubic-yard mining shovels. The ore is hauled out of the pit area on unpaved haulage roads. Some spillage was observed on the haulroads.

To assist in dust control, a high-pressure nozzle mounted on a water truck is used to wet the muckpile where the mining shovel is working. The nozzle was primarily installed for firefighting purposes. The effectiveness of this practice is questionable. The amount of dust suppressed by water applied to the working face may not be equivalent to the dust that would be suppressed if the truck was used to water haul roads.

Because the operation at Site No. 7 is relatively new (it was constructed in 1980), dust controls were included in the construction design. Retrofitting at a later date was not required.

Flat spray pneumatic atomizing nozzles manufactured by Spraying Systems Company are used at the crusher dump pocket, the stacker conveyor discharge point, and the conveyor transfer point. The nozzle system consists of a fluid nozzle (No. 100150) and an air nozzle (No. 189351), which are capable of spraying 9.5 gal/hr with 6.35 ft³/min of air at an air pressure of 40 psi and water pressure of 30 psi. According to the manufacturer, this system provides a highly-atomized flat spray that is effective for airborne dust suppression

at a distance up to 14 feet. The total cost of installing the spray systems at the dump pocket was approximately \$1,500, which included \$800 for labor. These costs do not include costs for maintenance.

The primary crusher is a large gyratory crusher. The crusher dump pocket was fitted with water sprays located below the actual dumping level (see Figure 1). The water sprays were designed to contain the dust in the crusher area rather than to wet ore as it was fed into the crusher, since wet ore tends to clog the crusher.

The crusher operator, who works in an enclosed, air-conditioned control room, is responsible for activating the water sprays each time a truck load is dumped. Several problems were noted. Excessive water from the sprays may clog the crusher. If the crusher becomes clogged, it must be shut down, which decreases productivity. The other major problem is that the piping and spray nozzles are located so that they are susceptible to damage from falling rocks. JRB observed that one nozzle was broken, which allowed water to run directly into the crusher.

Several possible solutions are being considered for redesigning the water spray system at the crusher dump pocket. One solution involves moving the spray nozzles to a point above the dump level and spraying water down onto dust as it rises during a dump (see Figure 1). The major problem with this alternative is that water lines may freeze and ice may form on the crusher building. Another solution is to reroute piping so that it cannot be damaged by falling rock.

Dust from the crusher is collected by a vacuum system, which exhausts into a wet scrubber. A similar system is also used on a belt feeder located below the crusher. Company policy prohibits operating the crusher without the vacuum/scrubber system. The crusher operator reported that the vacuum system works well after modifications were made to correct problems with system flooding.

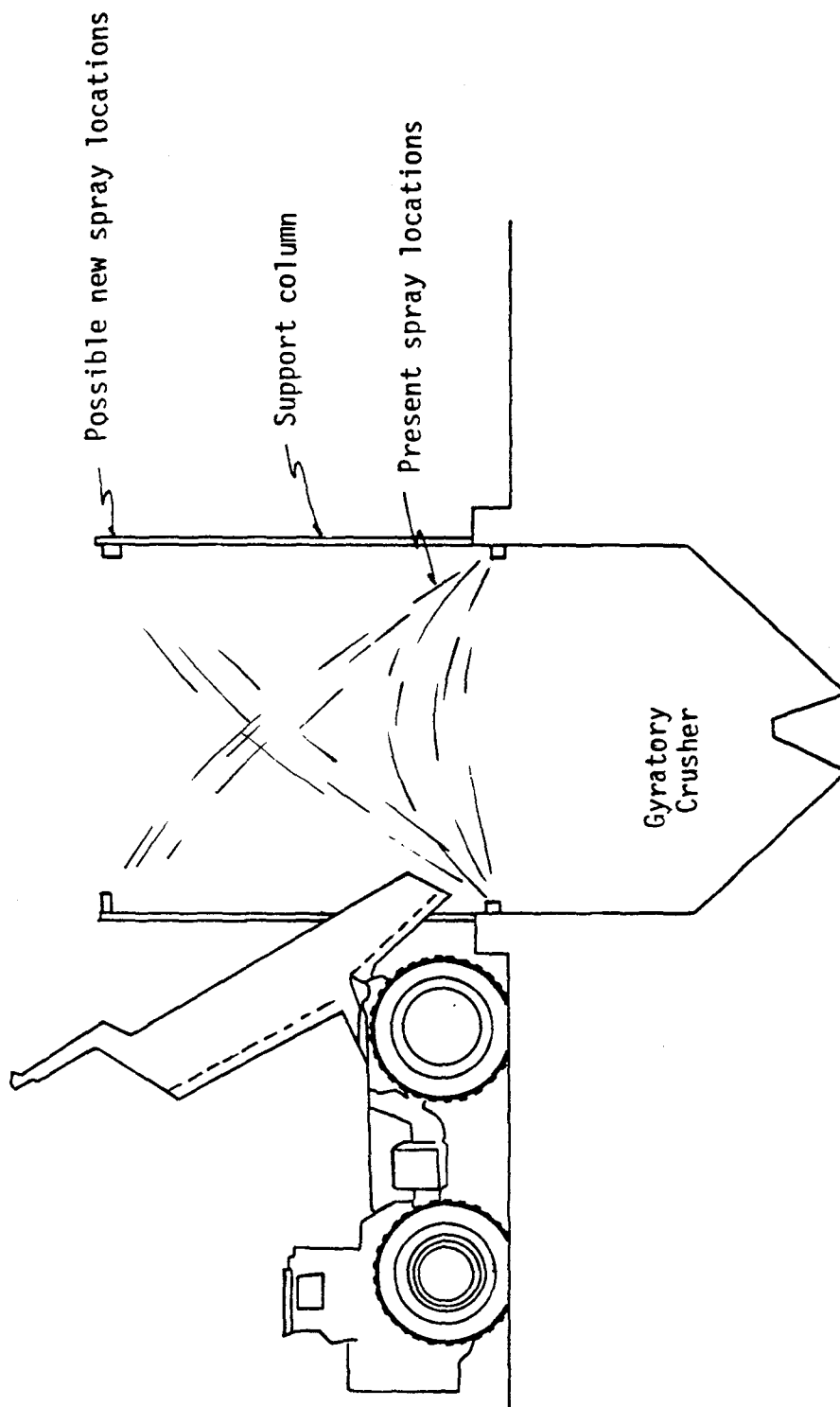


Figure 1. Existing and future dust controls.

Crushed ore is discharged from the primary gyratory crusher and conveyed to the coarse ore storage pile. Eight spray nozzles are located at the transfer point from the stacker conveyor to the storage pile. The spray nozzles were not operating at the time of the site visit. JRB observed that many of the nozzles were missing or had been damaged by falling rock. The company is considering redesigning the transfer point dust control system.

The stacker conveyors are partially enclosed to block cross drafts. One side is left open to facilitate maintenance of the conveyor belts. Belt scrapers are located on the underside of the belts. JRB observed spillage from the conveyors; however, housekeeping practices were adequate to prevent major dust buildups.

The ore is transported from the coarse ore pile by underground conveyor to semi-autogenous (SAG) grinders. Water sprays are used to suppress dust on the belts of the crusher discharge conveyor. To control the sprays, nozzles had been moved near the housing that contained the feeder belt. However, the sprays have not been effective in this location, because moisture and dust clog the ductwork leading to the scrubber. Coarse material from the grinding circuit is screened by vibrating screens and conveyed back through the SAG grinding mills. The screened ore is wet, and no dust was observed around these conveyors.

In the SAG mills, ore is ground and mixed with water to form a slurry. The slurry is transported to the flotation and concentration system. Ore is wet during these processes, and little dust was observed.

After the flotation process, ore concentrates are separated from the process medium by filtration. The copper concentrates are then transported by an enclosed conveyor to an outside storage pile. The ore remains wet during the filtration process, and no airborne dust was observed.

The molybdenite concentrate is dried by electric heat lamps as the wet concentrate passes through a drying chamber on a screw conveyor. The lamps are located directly above the screw conveyor. JRB observed airborne dust in

the screw conveyor enclosure. The drying chamber is vented by a vacuum/scrubber system similar to the one used on the crusher, with the addition of a mist eliminator.

Because the ductwork leading from the dryer to the scrubber system is only 3 inches in diameter, it can become clogged with molybdenite dust. There have also been clogging problems in the mist eliminator pad. Mine personnel at Site No. 7 are currently investigating ways to correct the problem with the ductwork. A weekly inspection program has been implemented to ensure that the mist eliminator pad remains clear.

The molybdenite concentrate is loaded into 55-gallon drums for shipment. The loading operation was not observed during the survey. Copper concentrate is shipped in bulk from an outside storage pile. Waste material produced by both the mining operation and the concentrator facility is stored in a 1,343 acre tailings containment area. The waste material is wet, and no dust was observed around the tailings. Additional dust suppressants are not used on the tailings.

Large quantities of lime are used in processing to control pH. A small baghouse is used at the lime storage silo and appears to be effective in controlling lime dust.

The crushing, milling, and concentrating operations are equipped with four Du-Con scrubbers for dust control (Dynamic scrubber type UW-4, Model IV's). Each unit incorporates heavy radial-blade wheel fans, which operate at a speed that gives the required gas flow against a specified system resistance. Inlet ducts from exhausted locations work best when they slope upward toward the scrubber. Material in an upward inclined duct can fall back into the process, which decreases clogging problems. Three of the scrubbers had upward sloping ducts. The scrubber used for dust control from the dryer was designed with a downward sloping duct, which may contribute to clogging problems in the dryer.

All scrubbers are inspected weekly. Inspection ports are easily accessible, with the exception of the scrubber that exhausts the dryer. The major maintenance problem is filter and spray nozzle clogging. Plugged spray nozzles can cause excessive water use rates and higher brake horsepower (BHP) requirements for fans. The weekly inspection and cleaning program practiced at Site No. 7 prevents material that can corrode and abrade internal parts from accumulating in the scrubbers.

TECHNOLOGICAL FEASIBILITY OF CONTROLLING
ASBESTOS AND SILICA AT MINES AND MILLS

Site Visit No. 8
Crushed Stone Quarry, Southwestern U.S.

Personnel of JRB Associates and Science Applications, Inc. (SAI), conducted a site visit on April 23, 1982, at the quarry at Site No. 8. The purpose of the visit was to observe dust control methods used in mining and crushing operations.

Coarse-grained igneous granitic rock composed chiefly of quartz, feldspar, and mica is mined at the quarry. The quarry operates six and one-half days per week with 18 or 19 full time personnel. The operation produces 500 tons of crushed stone per hour or 1.5 million tons per year. The quarry has a mineral reserve that can be mined for approximately 50 years.

The open quarry is worked in benches by earth-moving equipment. All drilling is dry, but dry cyclone air cleaners are used with skirting around the drill steel to control dust emissions at the drill hole. Each drill hole is 43 feet deep and 5-1/2 inches in diameter.

The primary blasting agent used is ANFO. Approximately 12 feet of stemming are used per hole. Unlike most operations, drill cuttings are not used for the stemming. Stone crushed at the quarry is used for the stemming material. This stone is coarser and much more angular than cutting material and forms a better plug. The crushed stone stemming prevents any rifling effect and contains the energy of the blast in the ore. The rock is fragmented into sizes that require a minimum of secondary breakage and can be readily handled by loading and hauling equipment. Blasting is done on shift approximately every third day.

The blasted ore is loaded by a front-end loader. The loader is equipped with an enclosed cab without air conditioning or filter systems. At the time of the site visit, the operator was working with the doors of the loader open and was wearing a respirator, which was furnished by the company. The loading face was dusty and the ore was not being wetted prior to loading. The ore is

loaded into 35- and 50-ton end-dump haul trucks. The trucks are equipped with enclosed cabs, but like the loader are not equipped with air conditioning or air filtration systems. The operators had the windows open during the visit and were not wearing respirators; however, management will provide them with respirators if requested.

To control particulate emissions from the stone crushing and sizing operation, a combination of wet dust-suppression and dry collection techniques is used. Wet dust-suppression techniques are used to control emissions at the primary crushing stage and at subsequent screens, transfer points, and crusher feeds. Dry dust collection is used at the finishing screens.

Loaded material is hauled over unpaved roads to be crushed in a primary gyratory crusher. The crusher dump pocket is equipped with spray nozzles located on the side opposite the truck dump location. The sprays are manually controlled by a crusher operator who controls the amount of water applied to avoid excessive wetting of the ore, which can plug the crusher.

All the water used for dust suppression at the plant is mixed with a surfactant manufactured by Johnson-March Corporation called Compound MR. This compound reduces the surface tension of water and improves its wetting efficiency so that dust may be suppressed with a minimum of added moisture. A small building located near the unloading operation houses drums of Compound MR, water supply lines, pumps, and a proportioner that automatically mixes the compound and water in a 1:1000 ratio. The proportioner is equipped with a positive displacement pump that uses a spring bellows to meter the two liquids.

Few maintenance problems have occurred with the automatic proportioner and pumps. During 9 years of operation, only one pump has been replaced. Occasionally, nozzles clog from water impurities. During cold periods (less than 28°F), the piping system must be drained after the day shift to prevent frozen and damaged pipes. Insulation and heating of pipes has been found ineffective.

Approximately \$150 per month is spent for pump electricity costs. On an annual basis, six 55-gallon drums of Compound MR are used. Each drum costs \$4,000.

The four spray nozzles at the crusher dump pocket deliver a fine mist with a 30-degree spray angle at 24 gallons per hour. This application rate compares to a 500-ton per hour production rate.

Rock that passes through the primary crusher is 4 inches or less in diameter. It is fed to a conveyor belt for transport to a surge pile, which feeds a second set of crushers by means of a tunnel conveyor belt. Two sets of three sprays using 24 gallons per hour with a 30-degree spray angle, cover the material as it is fed to the conveyor belt. This material is then transported to a 5.5 standard (secondary) crusher and reduced to 1-1/2 inches or less. A short-head (tertiary) crusher further reduces the rock to 3/4-inch or less. There are three sprays at each crusher conveyor belt feedpoint. These sprays deliver 15 gallons per hour, with a 30-degree spray angle. Rock material is thoroughly wetted by the water sprays and no visible dust was observed during these crushing operations. The crushed ore is wetted again at the crusher discharge to a belt conveyor.

Spray nozzles are set up at all locations where dry material changes its direction of travel, such as conveyor transfer points, or where new rock surfaces are created. Sprays are equipped with an on-off controller that is interlocked with a sensing mechanism so that they operate only when material is on the belts. This conserves water and prevents excessive water buildup. After tertiary crushing, the rock is transferred by conveyor belt to storage piles or directly to screens for size separation. With the exception of one enclosed conveyor belt that carries granite sand, all conveyor belts are open.

Baghouse dry dust collection systems are used for dust control at screening operations. One baghouse system was manufactured by American Air Filter; the other system was designed by Fuller Company. Dusty air exhausted from the completely enclosed screens enters the collectors through inlets

located near the top of the baghouses. Both systems are single compartment, continuous, automatic self-cleaning cloth collectors. The dust collection system is designed in such a way that any failure at the baghouse will automatically shut down the entire plant.

JRB noticed sharp bends and 90-degree angles in ductwork leading to baghouses. Potentially, dust can be trapped in these bends. However, problems with clogged ductwork have not occurred at Site No. 8.

The baghouses exhaust only the area inside the enclosures. As the air passes through the filter medium, dust is deposited on the outside of individual filter bags, which are made of synthetic felt. Filtered air exhausted through the baghouse outlets was observed to be free of visible dust.

The filter bags are periodically cleaned by bursts of compressed air that are injected down inside the bags to dislodge dust. Because only a few of the bags are cleaned at one time, the units remain in continuous operation.

The baghouses are checked on a weekly basis for motor wear and fabric condition. The filters are in good condition and none have been replaced in 3 years of operation.

Each baghouse cost approximately \$15,000 when purchased in 1978. It is estimated that \$200 per month is spent on electricity to operate the baghouses for two shifts a day, six and one-half days per week.

As material of selected size is produced, it is transported to stockpiles by conveyor. The stacking conveyors are adjustable to allow control of the fall distance. The material is wetted as it enters the stacking conveyor.

Belt cleaning is accomplished by using ribbed rollers on the return roller assembly. The ribbed roller simply "beats" the belt and adhering wet and dry material falls off, where it can be cleaned up easily. The ribbed

rollers are not enclosed. Housekeeping around the plant was very good with no excessive dust accumulations on equipment or floor areas.

The unpaved haul road, which is approximately 1/2 mile in length, is well maintained by motor graders and frequently treated with water. During the visit, the road was damp with very little dust present. Magnesium chloride will be tried as an additive to the haul road water in the near future to improve the dust control. Access roads to the mining area are treated with water on an as-needed basis and were in very good condition.

Water is applied to the haul roads by water truck. The truck has a 2,700 gallon tank and two upright nozzles that can supply water at a rate of 380 gallons per hour. The nozzles consist of 3-1/2 inch metal tubing flattened into a slot. Depending on weather conditions and the amount of traffic on the roads, the water truck may wet down all haulage roads 3 to 4 times per day.

Daily operating costs to wet down roadways include \$14 per hour for operator wages, or \$126 for an 8-hour day. Approximately \$140 per week is spent on fuel, oil, and tires, and \$100 per month is required for truck maintenance.

Crushed stone is distributed directly from the quarry to the user with no intermediary involved. All of the inventory is stockpiled at the quarry location. Customers transport the products by trucks to desired locations. Trucks are loaded by front-end loaders from storage piles or they can be filled from storage bins. No dust control methods are used when loading from the storage piles. These piles are not wetted down because the water will segregate the material. It is important to maintain the homogeneity of these materials so that size specifications can be met. Visible dust was observed during loading operations.

Water sprays are located at bin exit points. No dust was observed during truck filling operations from the bins. Water hoses are located near the loading area, and customers are encouraged to wet down their loads before leaving the company property.

There was very little dust exposure information available to JRB at the time of the site visit. The only survey information was from a 1978 survey of a small driller. There were no dust controls in use at the time of the survey. Respirable dust exposure of the drill operator was 0.92 mg/m^3 . The silica content of the dust was equal to or greater than 8.9 percent.

At the time of the site visit, the plant site and air looked exceptionally clean for an industrial activity. The production operator station, which is situated above the primary crusher, is completely enclosed and was free of visible dust. The enclosure was not equipped with an air filtration system.

The drill operators generally sit in their trucks, parked to one side of their drills. Their dust exposure appeared to be equivalent to that of a person standing in a dirt parking lot with light traffic.

The maintenance operators probably were exposed to the greatest amount of dust when they attended machinery and equipment, including the screens and baghouse change-outs. Without supportive environmental data, it appeared that exposures would be below the MSHA PEL.

Personnel assigned to the site operations office and to the security-scale house were fairly well removed from the dusty areas.

It appeared that the exposures of the loader operators and the haul truck drivers would be below the MSHA PEL. The actual silica content of the dust would be an important factor in determining whether the existing respirable dust concentrations were acceptable.