Surveillance of Respirable Crystalline Silica Dust Using OSHA Compliance Data (1979–1995)

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Background *The objective of this work was to estimate the percentage of workers by industry that are exposed to defined concentrations of respirable crystalline silica dust.*
Methods *An algorithm was used to estimate the percentage of total workers exposed to crystalline silica in 1993 at concentrations of at least 1, 2, 5, and 10 times the National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL) of 0.05 mg/m^3. Respirable crystalline silica air sampling data from regulatory compliance inspections performed by the Occupational Safety and Health Administration (OSHA), for the years 1979–1995, and recorded in the Integrated Management Information System (IMIS) were used to estimate exposures. Therefore, this work does not include industries such as mining and agriculture that are not covered by OSHA. The estimates are stratified by Standard Industrial Classification (SIC) codes.*
Results *This work found that some of the highest respirable crystalline silica dust concentrations occurred in construction (masonry, heavy construction, and painting), iron and steel foundries (casting), and in metal services (sandblasting, grinding, or buffing of metal parts). It was found that 1.8% (13,800 workers) of the workers in SIC 174—Masonry, Stonework, Tile Setting, and Plastering—were exposed to at least 10 times the NIOSH REL. For SIC 162—Heavy Construction, Except Highway and Street Construction—this number is 1.3% (6,300 workers). SIC 172—Painting and Paper Hanging—which includes construction workers involved in sandblasting was found to have 1.9% (3,000 workers) exposed to at least 10 times the NIOSH REL. The industry that was found to have the highest percentage of workers (6%) exposed to at least the NIOSH REL was the cut stone and stone products industry.*
Conclusion *Not enough is being done to control exposure to respirable crystalline silica. Engineering controls should be instituted in the industries indicated by this work.* Am. J. Ind. Med. 34:547–558, 1998. *© 1998 Wiley-Liss, Inc.*[†]

KEY WORDS: crystalline silica; silica; quartz; dust; silicosis; lung disease; respiratory disease; pneumoconiosis; OSHA IMIS; hazard surveillance

"His lungs were hard as rock. I couldn't cut them with a scalpel."

Barbara Ducatman, NIOSH Pathologist, 1994, after examination of a deceased silicosis victim's lungs.

INTRODUCTION

As the twentieth century comes to a close, the National Institute for Occupational Safety and Health (NIOSH) continues to document egregious respirable crystalline silica dust exposures and tragic deaths due to silicosis in the United States [NIOSH, 1992a,b, 1996a,b]. NIOSH recently issued a report of a health hazard investigation in which concentrations of respirable crystalline silica of 300 to 540 times the NIOSH Recommended Exposure Limit (REL) were measured during sandblasting of a water tank [NIOSH, 1995a]. In another instance, NIOSH discovered a plumber

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working in a concentration of respirable crystalline silica dust 284 times the NIOSH REL while using only a disposable particulate filter respirator [NIOSH, 1996a].

Occupational exposure to crystalline silica dust and the resulting lung disease of silicosis have long been recognized as serious industrial health problems [Peacock, 1860; Greenhow, 1865; Greenhow, 1866; Trasko, 1956; NIOSH, 1974; Cherniack, 1986; Peters, 1986; Rosner and Markowitz, 1991; Rom, 1994]. The International Agency for Research on Cancer (IARC) recently designated crystalline silica in the form of quartz or cristobalite as a Group I Human Carcinogen, which adds to the concerns of occupational exposure [IARC, 1997].

Efforts to curb exposures and the disease continue, with both government and partners examining the issues surrounding silicosis, as evidenced by the recent conference ''1997 National Conference to Eliminate Silicosis'' held in Washington, DC, on March 25 and 26, 1997. NIOSH, OSHA, and the Mine Safety and Health Administration (MSHA) recently organized an interagency campaign to raise awareness of silicosis. On August 1, 1996, the Occupational Safety and Health Administration (OSHA) initiated a Special Emphasis Program (SEP) targeting silica exposures [Dear, 1996]. Between April 1, 1996 and April 1, 1997 Federal OSHA inspectors performed 332 silica inspections and found that approximately 30% of the air samples were over the OSHA Permissible Exposure Limit (PEL) [Galster, 1997].

Identification and measurement of crystalline silica exposures are very important in the prevention of silicosis. The task of determining which workers are at elevated risk of developing silicosis, is of utmost importance for a number of reasons including:

1. Ensuring an informed industrial management and worker population.
2. Establishing research and intervention priorities.
3. Encouraging compliance with accepted exposure limits.
4. Identifying occupations in which engineering controls need to be designed.

However, estimating the number and extent of workers' exposures to crystalline silica in the U.S. industrial workplace is a difficult task because comprehensive hazard surveillance data do not exist. For general industry, there are no specific legal requirements, such as those for lead and asbestos exposures, to monitor the air or the health of workers exposed to crystalline silica. The personal protective equipment regulations (29 CFR 1910.134) for respiratory protection require workers using respirators to be examined by a physician to determine if they are physically capable of doing the work while using the respirator assigned to them. Also, under this regulation OSHA may require air monitoring for workers using respiratory protection. Even so, there exists no routine systematic method of estimating with confidence the number of workers exposed, the number who develop silicosis each year (incidence), the number who are living with silicosis (prevalence), or the number who die as a result of silicosis (mortality).

The purpose of this work is to use currently available OSHA compliance data to provide an estimate of the percent of workers exposed at given concentration levels by industry so that prevention efforts may be prioritized. The estimates are stratified by Standard Industrial Classification (SIC) codes [U.S. Office of Management and Budget, 1987]. Since the largest source of exposure data for general industry in the United States is the OSHA Integrated Management Information System (IMIS), which compiles data from OSHA compliance inspections, it has been used in the development of this estimate. OSHA inspectors follow standard inspection procedures that are outlined in manuals [OSHA, 1995, 1996]. The OSHA IMIS has been previously investigated as a tool in assessing the risk of silicosis in U.S. industry, but has not been used to estimate the percentage of total workers exposed at defined concentrations [Froines et al., 1986a,b, 1989a,b; Freeman and Grossman, 1995].

In August 1997, OSHA sponsored a stakeholder's meeting in order to discuss ways in which the IMIS database could be improved. An additional purpose of this paper is to provide some insight into how changes could be applied in order to strengthen the estimates which are derived from IMIS.

The mining and agriculture industries are not addressed by OSHA compliance data. The Mine Safety and Health Administration (MSHA) has the responsibility of regulating the mining industry while OSHA regulates most other industry. The National Institute for Occupational Safety and Health (NIOSH) has the responsibility of doing research into occupational safety and health issues for all industry. A particularly difficult sector in which to obtain exposure information is the agricultural industry. Therefore, we have provided a brief overview of the agriculture literature in the Discussion section. Mining has long been recognized as an industry with substantial silicosis risks, as evidenced in 1700 by Bernardo Ramazzini in ''De Morbis Artificum Diatriba,'' and is an important industry anytime silicosis is discussed [U.S. Bureau of Mines, 1984; Watts, 1995; NIOSH, 1995b]. The number of workers in the mining industry is small, but with a much higher percentage of workers exposed to crystalline silica than general industry. NIOSH, in a study that collected bulk settled dust found at mines covering 66 different mineral commodities, estimated that all miners are potentially exposed to bulk dust containing at least 1% quartz (272,000 miners) [Greskevitch et al., 1992]. NIOSH further estimated that 29% of miners are potentially exposed to bulk dust containing an average of 12% quartz or more. For bituminous coal workers, who account for about half of the mining industry (135,000 coal workers), NIOSH estimated that they are potentially exposed to bulk dust containing 11% quartz. Because the mining industry is regulated by a separate agency (MSHA) with a different system of dust sampling and data recording, this effort will not address mining.

BACKGROUND

In 1974 NIOSH published detailed recommendations concerning occupational exposure to crystalline silica [NIOSH, 1974]. On page 17 of that document, NIOSH estimated that 1,200,000 workers are exposed to crystalline silica. That estimate did not include many occupations or industries in which it is reasonable to suspect a portion of the workers to have crystalline silica dust exposure. For example, the 1974 estimate did not include people employed in agriculture, the production of chemicals and allied products, or workers in heavy construction, many of whom are routinely exposed to crystalline silica. In 1980, using Bureau of Labor Statistics employment data, the U.S. Department of Labor presented an estimate of 1 million exposed [U.S. Department of Labor, 1980]. These estimates were based on numbers of total workers employed in certain industries well known to present a silicosis risk. However, the percent of workers exposed at a defined concentration of respirable crystalline silica by industry was not estimated.

Froines and colleagues investigated silica compliance inspections from the time when OSHA started recording the sampling data in 1979 through 1982 [Froines et al., 1986a]. They studied the appropriateness of using the IMIS as a hazard surveillance tool for silicosis prevention. That report, however, did not attempt to provide an estimate of the total number of workers exposed to crystalline silica. A major problem stated in the paper was that the IMIS had only recorded a few years of data.

The National Occupational Exposure Survey (NOES) is a survey of general industry that was conducted by NIOSH from 1982 to 1983 [NIOSH 1988a,b, 1990a]. This survey does not include mining, most of the agriculture industry, and parts of various industries such as retail trade. The NOES estimates that 3.2 million workers, of which 662,000 are female, at 156,000 places of employment are ‘‘potentially exposed’’ to one or more of the substances containing crystalline silica listed in Table I [NIOSH, 1990b]. This survey did not gather measurements of airborne crystalline silica; instead it collected information on materials to which workers may potentially be exposed through an inventory of materials or trade name products found at work sites.

In 1991, using the 1986 Bureau of the Census County Business Patterns, the NOES general industry survey, and a more restrictive list of crystalline silica materials (flint, quartz, sand, silica powder), NIOSH estimated that 1.7 million workers were potentially exposed to crystalline silica dust [NIOSH, 1991].

TABLE I. Crystalline Silica Synonyms Used to Search the NOES Database for Potential Exposures

Cristobalite
Granite
Granite, dust
Granite, ground
Sand
Sandstone
Sandstone, dust
Silica
Silica sand, powder
Silica, dust
Silica, fiber
Silica, gravel
Silica, powder
Tridymite
Volcanic ash
Quartz
Quartz, dust
Tripoli
Tripoli, dust
Tripoli, powder

The best estimates of exposure come from air sampling measurements. Since the OSHA IMIS contains a record of such measurements, we have used it as a hazard surveillance tool in an attempt to develop information on silica exposure by industry.

METHODS

This section describes the algorithm to estimate the percentage and number of workers exposed to crystalline silica in 1993 at concentrations of at least 1, 2, 5, and 10 times the NIOSH REL.

For the years 1979–1995, the IMIS database contains 15,400 silica samples from 3,800 inspections performed in Federal OSHA Plan States. These inspections contain information for sites in 189 three-digit SIC codes. These 8-hr Time Weighted Average (TWA) samples measure the respirable crystalline silica dust concentrations after engineering controls, but they are not adjusted for the effect of any respirator use. Therefore, for the purposes of this paper, the term ‘‘exposure’’ is defined as the concentration of respirable crystalline silica dust measured in the work environment. The information about the amount of time that the workers are exposed at the determined concentrations (i.e., the exposure frequency) in the IMIS database is difficult to summarize because it is specified by a written description. Regular entry of this information is not found in the IMIS data before 1984. After 1984, there continue to be blank entries and characterizations of exposure frequency which are indeterminate, such as ''Variable,'' ''Up to 8 hr/day,'' or ''Daily.'' When a systematic sample of 850 records after 1984 was visually inspected, it was found that about two-thirds of the records specified an exposure frequency of at least 35 hours per week. There are 300 area samples that are excluded from the analysis and, therefore, only personal samples are used in the calculations. Monitoring and inspections involving fatalities, follow-up inspections, and inspections due to complaints have also been excluded. When a site had multiple inspections, only the most recent inspection has been included. After these editing procedures, there are 1,795 or about half of the inspections remaining.

The methods of estimation presented differ considerably from those of previous papers, such as those by Froines et al. [1986a] or Freeman and Grossman [1995]. The most conspicuous difference is that those authors reported exposure levels in terms of median or mean severity levels, the severity being the ratio of exposure concentration to the exposure limit. However, they were well aware that, when sampling results show low exposure or no detectable exposure, an OSHA inspector may not submit the results to the IMIS database, thereby making interpretation of the results more difficult. An alternative measure of exposure is used in this paper. First, we count the number of workers who were exposed to at least a specified level of respirable crystalline silica dust. Any inspection results that would indicate exposures less than the specified level are simply not counted using this method, and so the absence of low exposure data should not, in general, bias the estimate. After obtaining the count of workers, we divide by the number of employees in the establishment to obtain a proportion. Although we may avoid the issue of bias resulting from missing negative results, it should be admitted that we place more emphasis on ancillary information in the inspection reports, which introduces an unknown degree of measurement error. The additional measurement error can, in turn, attenuate our estimates and lead us to underestimate the exposure. The ancillary information includes the number of workers similarly exposed, as determined by the inspector, and the number of workers in the establishment, as reported to the inspector by the facility.

The NIOSH Recommended Exposure Limit (REL) for respirable crystalline silica is 0.05 mg/m^3 regardless of whether it is in the form of quartz, cristobalite, or tridymite. The NIOSH severity is defined as a multiple of this recommended limit. For instance, a NIOSH severity of two or greater indicates an exposure of at least twice the NIOSH REL. The essential strategy for estimation is to use the IMIS inspection data to estimate the proportion of all workers (including the white-collar workers) in each SIC code who have a silica exposure of at least a specified NIOSH severity. Results will be presented separately for NIOSH severities of 1, 2, 5, and 10. The number of workers (including the white-collar workers) employed in each SIC category is obtained from the 1993 County Business Pattern (CBP) data [U.S. Dept of Commerce, 1993] and is then multiplied by the proportion estimate in order to obtain an estimate of the number of workers in each SIC who are exposed at, or above, the given severity.

The IMIS database was not designed to be a surveillance tool; it is a record of compliance data maintained for OSHA's management. In order to provide estimates of the number of workers exposed at the specified levels, it is first necessary to recognize the limitations of the data and to give special considerations to both the patterns of the samples within inspections, and to the patterns of the inspections within the SIC categories. The methods are restricted not only by the structure and shortcomings of the IMIS data, but also by the limitations of any ancillary information, such as the CBP database.

When samples within inspections are examined, one learns that, although each sample provides an estimate of NIOSH severity, there are about 20% of the samples where the number of workers similarly exposed, $n_{exposed}$, is coded as zero. The variable $n_{exposed}$ has been coded as zero whenever this entry is left blank on the sampling form. For personal samples, we expect this number to be at least one, counting the worker wearing the sampler. The usual explanation for a missing entry for $n_{exposed}$ is that an inspector obtained silica air samples for a group of workers in an area of the inspection site, and then entered the total number of workers similarly exposed (summing over the group of samples) on only the first sampling form. In a small number of inspections, all of the $n_{exposed}$ entries are missing. This would occur if this information was entered on another type of air sample (e.g., a sample for lead) that was obtained at the same time. In general, there is no correspondence or linkage within an inspection between air samples with zero and non-zero entries for $n_{exposed}$. Also, for unknown reasons, some information in the IMIS database is replicated. However, the replication does not impact the analysis.

Of the 1,795 inspections, 206 are discarded because, for unknown reasons, the number of personal silica samples exceeds the total number of workers who were sampled. The remaining 1,589 inspections are classified into two categories of inspections for the purposes of estimation. For each category a different method is used to estimate the quantity $exposure_{site}$, the proportion of workers at a site with exposure greater than or equal to the specified NIOSH severity. The first method is applied to the 1,214 inspections where $n_{exposed}$, the number of workers similarly exposed, is positive for all the samples within an inspection. For these inspections the formula for $exposure_{site}$ is given by

$$exposure_{site} = \frac{\sum_{severity \geq S_0} n_{exposed}}{n_{site}} \tag{1}$$

where the summation of $n_{exposed}$ is performed over all the samples where the NIOSH severity is greater than some fixed value S_0. The variable n_{site} is the total number of workers at the site.

The second method is applied to the 375 inspections where there is at least one sample with a zero entry for $n_{exposed}$. We define a given sample as ''positive'' if its NIOSH severity is greater than or equal to the specified level. In the following formula the quantity (N_{pos} / N_{total}) is the proportion of the samples that are positive. This proportion is regarded as a surrogate for the proportion of the workers sampled who have exposures equal to, or greater than, the specified NIOSH severity. This proportion is then multiplied by a summation, which represents the total number of workers sampled, and then divided by n_{site}, the number of workers at the site. The formula for $exposure_{site}$ is now given by

$$exposure_{site} = \frac{(N_{pos}/N_{total})\ \Sigma\ n_{exposed}}{n_{site}} \qquad (2)$$

where N_{pos} is the number of positive samples in an inspection and N_{total} is the total number of samples in an inspection. It should be admitted that the estimates that result from equation (2) will tend to be biased upwards. In fact, its construct is similar to one found in Froines et al. [1986a]. The introduction of equation (2) represents a compromise which is made in order to retain a significant portion of the data.

After $exposure_{site}$ is calculated for each of the 1,589 inspections using either equation, we can then use all of the resulting estimates for inspections in a given SIC category to provide an overall estimate of the proportion of workers for that three-digit SIC who are exposed to at least the specified NIOSH severity. It should be noted that there are many inspections where the proportion exposed is zero, or, in other words, where all of the samples in the inspection indicated an exposure that was below the specified severity. In spite of this, one could still estimate the proportion exposed for an SIC category by simply calculating the mean of its estimates of $exposure_{site}$. However, this is not done here, because it will be necessary in the following to differentiate between the positive and zero estimates of $exposure_{site}$. An alternative estimate for the proportion exposed in an SIC is given by the product of a_{SIC}, the mean of the positive estimates of $exposure_{site}$, and q_{SIC}, the proportion of all of the inspections with positive estimates of $exposure_{site}$. That is, the proportion of workers exposed in an SIC category is estimated by

$$EXP_{SIC} = q_{SIC} \cdot a_{SIC} \qquad (3)$$

In the calculation of q_{SIC}, we need to take account of the many inspections in the IMIS database, other than the 3,800 inspections with which we started, which have no silica samples. In fact, the SIC codes that contain the most information on silica exposure have silica samples in only about 10% of the inspections performed. For the purposes of estimation we assume that, when inspectors gathered no silica samples, there was zero exposure to silica. Therefore, the calculation for the denominator of q_{SIC} will allow for the additional inspections that contain no silica samples.

A further complication occurs because a portion of the data has been lost due to editing procedures that are apparently unrelated to silica exposure, such as the deletion of the 206 inspections where the number of samples exceeded the total number of workers sampled. It should then be assumed that a corresponding portion of the inspections without silica samples would also be lost. Let r be the proportion of the inspections with silica samples which are retained after the editing procedures. In addition, for a given SIC category, let I_{pos} be the number of inspections that yield a positive estimate of $exposure_{site}$, and let I_{total} be the total number of inspections (including those without silica samples). Hence, the proportion of all inspections with positive $exposure_{site}$ is estimated by $q_{SIC} = I_{pos} / (r \cdot I_{total})$.

If a 3-digit SIC category has at least two inspections with ten silica samples, its positive estimates of $exposure_{site}$ are included in the linear modelling to calculate a_{SIC}. There is a notable negative correlation between the positive estimates of $exposure_{site}$ and n_{site}, the number of workers at a site. In other words, the IMIS database indicates that sites with a larger work force generally have a smaller proportion of workers exposed. Changes in the proportion of workers exposed are related to the relative sizes of n_{site} and, therefore, an explanatory variable enters into the model as the natural logarithm of n_{site}. A cube-root transformation is used to normalize the response and the final model also includes the explanatory variables of the three-digit SIC category of an inspection and the year of the inspection. Also, to account for residual curvature in the relation between the cube root of the proportion of workers exposed and the logarithm of n_{site}, the square of the log-transformed n_{site} also enters the model as a suppressor variable. Therefore, the expected value of the proportion of workers exposed at a site is related to the effects by

$$Expected\,(\sqrt[3]{exposure_{site}}) = SIC + year + \ln(n_{site}) + \ln^2(n_{site}). \qquad (4)$$

Employing this model, the 1993 mean responses are estimated for the average worker population for sites in each SIC category. This average population of workers is obtained from the 1993 County Business Pattern (CBP) database. Because the mean estimates for each SIC are based upon a cube-root transformation, the results are then back-transformed to produce the estimates of a_{SIC} for each of the SIC codes. These estimates of a_{SIC} are then inserted into equation (3) and multiplied by the corresponding estimates of q_{SIC} in order to produce the estimates of EXP_{SIC}. The estimates of q_{SIC} and a_{SIC} had low correlation over the SIC codes. By assuming zero covariance for two estimators μ_1

and μ_2, the variance of their product is derived as

$$VAR\,(\mu_1\mu_2) = \sigma^2_{\mu_1}\sigma^2_{\mu_2} + \mu^2_1\sigma^2_{\mu_2} + \mu^2_2\sigma^2_{\mu_1}. \qquad (5)$$

The variance estimate of EXP_{SIC}, the product of the estimators q_{SIC} and a_{SIC}, is calculated by inserting the estimates of q_{SIC}, a_{SIC}, and their respective variance estimates into (5). An estimate of EXP_{SIC} was retained if its 90% confidence interval does not include zero.

Finally, each estimate given by equation (3) is multiplied by the number of workers in the SIC, as given by the CBP data, and the result is rounded to the nearest hundred workers to provide an estimate of the number of workers in a SIC who are exposed to at least the specified severity. These quantities are then summed over the SIC codes to produce the estimated total number of workers exposed for the remaining SIC categories.

RESULTS

Estimates are given for populations of workers in 1993 because we have relied on information in the 1993 County Business Pattern (CBP) database. The algorithm described in Methods is used to estimate the number of workers in 1993 exposed to at least 1, 2, 5, and 10 times the NIOSH REL (without taking into account the use of respirators). This resulted in estimates for 64, 54, 48, and 38 SIC codes, for the respective exposure levels. In order to provide estimates for only the SIC codes that have comparable levels of information, only estimates with a 90% confidence interval, which excludes zero, were retained and listed in Tables II–V. These tables contain the estimated number and percent of workers in 1993 exposed to at least 1, 2, 5, and 10 times the NIOSH REL for 21, 20, 16, and 5 SIC codes, respectively. Tables II–V also show the number of inspections which were included in the estimation for each of the SIC codes.

Table II indicates that the SIC codes with the largest number of workers exposed include research and testing services, masonry, heavy construction (excluding highway construction), and iron and steel foundries. There are other SIC codes that involve much fewer workers but which may present a risk for a relatively larger percentage of workers. These SIC codes include painting and paper hanging (which can include sandblasting), structural clay products, and cut stone.

For some SIC codes, the residual variation and the low number of inspections available make its 90% confidence interval too wide for inclusion in Tables II–V. In other words, the database contains insufficient or low information for these SIC categories. Estimates are shown in Table VI for five SIC codes, for which the database contains low information, but that are associated with relatively large estimates of the number of workers exposed. The SIC code 599, listed as ‘‘Retail Stores, Not Elsewhere Classified’’ includes the monument-finishing industry. These SIC codes include working environments in which sandblasting, grinding, buffing, mixing, and bagging occur. If we dropped the requirement that the 90% confidence interval exclude zero, then the estimates for the five SIC codes in Table VI would add an additional 54,000 workers to the total of workers exposed in Table II, and about 32,000 workers to the total in Table III. Other industries, which the data suggest could present a substantial exposure to workers but whose estimates have very low information, include the iron scrap industry, bean and grain elevators, the cleaning or repairing of railroad equipment, and metallurgical testing. Other operations with high exposures include rock drilling and the

TABLE II. Estimates of the Number and Percent of Workers in 1993 Exposed to at Least the NIOSH Recommended Exposure Limit for Selected SIC Categories in the IMIS Database*

SIC category/description	Number of inspections[a]	Workers exposed[b]	Percent of workers	90% Conf. int.[c]
873/Research, testing services	9	46,200	5.4	1.7–9.2
174/Masonry, plastering	13	20,400	2.7	0.9–4.5
162/Heavy construction[d]	33	12,200	2.5	1.5–3.6
332/Iron and steel foundries	375	8,600	3.5	2.9–4.1
154/Nonresidential construction	11	6,000	1.3	0.3–2.4
172/Painting, paper hanging	18	5,100	3.2	1.5–5.0
179/Special trade contractors	28	4,500	0.5	0.2–0.8
327/Concrete, plaster products	62	4,000	1.2	0.6–1.7
356/Gen. industrial machinery	22	2,300	0.5	0.2–0.8
326/Pottery, related products	52	2,200	3.0	1.9–4.0
325/Structural clay products	74	2,100	3.4	2.4–4.4
329/Nonmetallic mineral products	45	1,300	1.0	0.5–1.5
347/Metal services	38	1,300	0.6	0.3–0.9
336/Nonferrous foundries	146	1,000	0.7	0.4–0.9
344/Fabricated metal products	37	1,000	0.1	0.1–0.2
328/Cut stone, stone products	23	700	6.0	3.4–8.6
331/Blast furnace, steel products	25	600	0.1	0.0–0.2
295/Paving, roofing materials	22	500	1.0	0.3–1.8
322/Glassware, pressed or blown	37	400	0.3	0.1–0.6
373/Ship, boat building and repair	14	400	0.1	0.0–0.3
353/Construction machinery	20	300	0.1	0.0–0.2
Total		121,100		

*This does not account for respirator use.
[a]Includes only inspections with silica samples.
[b]Rounded to the nearest hundred workers.
[c]Rounded to the nearest one-tenth percent.
[d]Excepting highway construction.

TABLE III. Estimates of the Number and Percent of Workers in 1993 Exposed to at Least *Twice* the NIOSH Recommended Exposure Limit for Selected SIC Categories in the IMIS Database*

SIC category/description	Number of inspections[a]	Workers exposed[b]	Percent of workers	90% Conf. int.[c]
873/Research, testing services	9	41,700	4.9	1.3–8.5
174/Masonry, plastering	13	19,900	2.6	1.0–4.3
162/Heavy construction[d]	33	10,100	2.1	1.1–3.1
154/Nonresidential construction	11	6,000	1.3	0.2–2.5
172/Painting, paper hanging	18	5,000	3.1	1.5–4.8
332/Iron and steel foundries	375	4,100	1.7	1.3–2.1
327/Concrete, plaster products	62	3,200	0.9	0.4–1.4
179/Special trade contractors	28	3,100	0.3	0.1–0.6
325/Structural clay products	74	1,500	2.4	1.6–3.2
356/Gen. industrial machinery	22	1,300	0.3	0.1–0.5
326/Pottery, related products	52	1,200	1.6	0.9–2.4
347/Metal services	38	1,000	0.5	0.2–0.7
329/Nonmetallic mineral products	45	800	0.6	0.2–1.0
344/Fabricated metal products	37	800	0.1	0.0–0.2
328/Cut stone, stone products	23	500	3.8	1.7–5.9
336/Nonferrous foundries	146	500	0.3	0.2–0.5
295/Paving, roofing materials	22	300	0.6	0.0–1.1
322/Glassware, pressed or blown	37	300	0.3	0.0–0.5
353/Construction, related machinery	20	300	0.1	0.0–0.2
373/Ship, boat building and repair	14	300	0.1	0.0–0.2
Total		101,900		

*This does not account for respirator use.
[a]Includes only inspections with silica samples.
[b]Rounded to the nearest hundred workers.
[c]Rounded to the nearest one-tenth percent.
[d]Excepting highway construction.

TABLE IV. Estimates of the Number and Percent of Workers in 1993 Exposed to at Least *Five* Times the NIOSH Recommended Exposure Limit for Selected SIC Categories in the IMIS Database*

SIC category/description	Number of inspections[a]	Workers exposed[b]	Percent of workers	90% Conf. int.[c]
174/Masonry, plastering	13	17,400	2.3	0.6–4.0
873/Research, testing services	9	12,300	1.4	0.2–2.7
162/Heavy construction[d]	33	7,800	1.6	0.8–2.4
172/Painting, paper hanging	18	4,400	2.8	1.1–4.4
154/Nonresidential construction	11	4,200	0.9	0.1–1.8
179/Special trade contractors	28	1,800	0.2	0.0–0.4
332/Iron and steel foundries	375	1,500	0.6	0.4–0.8
327/Concrete, plaster products	62	1,200	0.3	0.1–0.6
347/Metal services	38	800	0.3	0.1–0.6
356/Industrial machinery	22	700	0.1	0.0–0.3
325/Structural clay products	74	600	1.0	0.5–1.4
344/Fabricated metal products	37	500	0.1	0.0–0.1
326/Pottery, related products	52	500	0.6	0.2–1.0
329/Nonmetallic mineral products	45	400	0.3	0.0–0.5
328/Cut stone, stone products	23	300	2.0	0.7–3.4
336/Nonferrous foundries	146	200	0.2	0.0–0.3
Total		54,600		

*This does not account for respirator use.
[a]Includes only inspections with silica samples.
[b]Rounded to the nearest hundred workers.
[c]Rounded to the nearest one-tenth percent.
[d]Excepting highway construction.

cleaning or repairing operations in foundries. For comparison purposes, Table VII lists the first sixteen 3-digit SICs from Table II with the corresponding NOES estimate of the number of potentially exposed, with the exception of SIC 873 which was not available in the NOES data [NIOSH, 1990b]. The nine inspections available for SIC 873 all came from the four-digit SIC 8734, which includes metallurgical and other testing laboratories.

DISCUSSION

We have presented a method of using OSHA inspection data to identify and compare industries as to the total number and the percent of workers exposed to respirable crystalline silica dust. However, the limitations of the data used must be kept in mind while considering the results. The OSHA compliance program and the OSHA IMIS were not designed to be surveillance tools. Therefore, there are limitations in the use of the IMIS data for surveillance [Mendeloff, 1984; Froines et al., 1986a, 1989b; Pollack and Keimig, 1987; Baker et al., 1988].

General Limitations

- It should be understood that the SIC coding system may introduce error into occupational health and safety estimates since the SIC system was not designed to classify industry into similar occupational exposures. Workers within a given SIC may do a variety of work and, therefore, cannot be seen as completely homogeneous. This problem increased when we chose to use 3-digit SIC codes instead of the more industry specific 4-digit codes in order to have enough sampling data by coded industry. Also, OSHA inspectors may not be consis-

TABLE V. Estimates of the Number and Percent of Workers in 1993 Exposed to at Least *Ten* Times the NIOSH Recommended Exposure Limit for Selected SIC Categories in the IMIS Database*

SIC category/description	Number of inspections[a]	Workers exposed[b]	Percent of workers	90% Conf. int.[c]
174/Masonry, plastering	13	13,800	1.8	0.3–3.3
162/Heavy construction[d]	33	6,300	1.3	0.6–2.0
172/Painting, paper hanging	18	3,000	1.9	0.5–3.3
332/Iron and steel foundries	375	800	0.3	0.2–0.5
347/Metal services	38	400	0.2	0.0–0.3
Total		24,300		

*This does not account for respirator use.
[a]Includes only inspections with silica samples.
[b]Rounded to the nearest hundred workers.
[c]Rounded to the nearest one-tenth percent.
[d]Excepting highway construction.

TABLE VI. Some SIC Codes in the IMIS Database With Low Information But Large Estimates of Workers Exposed in 1993 to at Least One or Two Times the NIOSH Recommended Exposure Limit*

SIC category/description	Number of inspections[a]	Workers exposed (1 × REL)[b]	Workers exposed (2 × REL)[b]
599/Retail stores, not classified[c]	8	26,200	16,500
177/Concrete work	5	17,500	7,600
384/Medical and dental supplies	5	6,200	4,000
359/Misc. industrial machinery	9	2,300	1,800
399/Misc. manufacturing	6	1,900	1,700
Total		54,100	31,600

*This does not account for respirator use.
[a]Includes only inspections with silica samples.
[b]Rounded to the nearest hundred workers.
[c]Includes gravestones and monument co.

TABLE VII. SIC Codes Appearing in Table II That Also Have a NOES Estimate of Potentially Exposed Workers*

SIC category/description	Plants	Total employees	Female employees
154/Nonresidential building construction	7,275	132,502	1,256
162/Heavy construction, except highway	3,123	59,151	8,544
172/Painting, paper hanging, decorating	774	32,135	159
174/Masonry, stonework, and plastering	6,778	132,146	—
177/Concrete work	1,496	18,039	—
179/Miscellaneous special trade contractors	4,594	56,609	562
295/Paving and roofing materials	151	4,584	—
325/Structural clay products	653	27,940	3,626
326/Pottery and related products	152	7,745	2,223
327/Concrete, gypsum, and plaster products	5,226	72,142	1,035
328/Cut stone and stone products	569	8,082	1,001
329/Miscellaneous nonmetallic mineral products	471	26,678	4,116
332/Iron and steel foundries	857	47,409	782
336/Nonferrous foundries	395	4,989	716
344/Fabricated structural metal products	3,377	64,813	2,795
347/Metal services, NEC	1,686	14,331	1,241
356/General industrial machinery	1,670	40,840	5,551

*The terms listed in Table I were used to define crystalline silica when the NOES database was searched.

tent in assigning the SIC codes to companies. If the company is large, the code assigned may only reflect what the sampled workers were doing and not the company as a whole.

- In addition, the method of choosing inspection sites changes over time as does the amount of emphasis given to silica exposures.

Biases Toward Higher Estimation

- The job of the OSHA inspector is to identify and sample maximum risk employees, not to determine the distribution of exposures. OSHA samples occupations in which silica dust is thought to be a problem and, therefore, the samples recorded in the IMIS database do not represent a random sample of exposure levels. Since we only counted workers with a minimum exposure of the NIOSH REL, any workers exposed at a lower concentration would not have been counted anyway. Measurement error may have contributed to the variability of our estimates, but there is no reason to believe that this error would systemically elevate our estimates.
- The levels of exposure in this report do not take into consideration the use of respirators. This information is not provided by the IMIS data; therefore, we must define the workers' exposures in terms of the ambient readings of exposure. Actual exposures for some workers may be much less.

Biases Toward Lower Estimation

There are several reasons for believing that this data underestimate the true number of workers exposed. The following considerations indicate that these estimates should be regarded as conservative.

- The data in the IMIS are Time Weighted Averages (TWA). The OSHA practice is to assume zero exposure during unsampled periods [OSHA, 1996]. Thus, if a job stopped, which is typical in construction, a high-exposure job may result in a low TWA since the non-exposure time is averaged into the TWA calculation.
- In addition, individual workers may change their activity due to their fear of a repercussion from the company management if they are found to be overexposed.
- The sampling scheme is not necessarily comprehensive for surveillance purposes. As stated, we have little information for numerous potentially important SIC categories. It is also possible that certain sectors of industry with substantial exposures are simply not represented in the IMIS database. For example, a few industries (3-digit SICs) that are either known to have silicosis risk or may reasonably be believed to have some risk have been excluded from this analysis because of insufficient data. Notably, flat glass manufacturing, agriculture, and oil and natural gas well drilling are not included.
- There may be differences between different parts of the country (State-plan OSHA States vs. Federal, or among the 10 OSHA regions) in stressing the importance of reporting this data to the IMIS. Some of the data, such as that from State-plan States may not be reported [Froines et al., 1986a, 1989a].
- We have required that the 90% confidence interval for each estimate of EXP_{SIC} exclude zero. Researchers could argue that this criterion is too strict. If one sample in the IMIS database shows that one worker in a SIC had exposures above the NIOSH REL, it is not necessary to do a test of significance to know that the percent of workers exposed above the recommended limit is greater than zero. For this study, it is more natural to regard the width of the confidence interval as indicating the degree of information that is available for a SIC code, rather than as a test of the hypothesis of no exposure in an industry.
- An important assumption for this estimation method is that inspectors are able to identify and sample all the workers at an inspection site who are potentially exposed to silica, which is unlikely to be true in all cases. Limitations of resources at OSHA and the size of some inspection sites may prevent inspectors from observing some exposures. Depending on the expertise of the OSHA inspector and whether the entire facility was included in the inspection, silica exposures may go unnoticed and unsampled. Also, some crystalline silica exposures are not of a continuous nature. For example, during different phases of construction work, activities that can produce crystalline silica may occur; however, if the OSHA inspection does not occur at that particular time, the dust concentration is not documented. During complex industrial processes, the presence of crystalline silica may not be obvious to the OHSA inspector. For example, silica flour (finely ground crystalline silica) is used in making numerous products such as cosmetics, pharmaceuticals, food supplements, cleaning agents, and paints.
- We excluded area samples and those samples involving complaints. Complaints, in particular, may be well founded and indicative of substantial concentrations of respirable crystalline silica. This exclusion may have diverted the analysis from SICs, which, if routinely monitored for personal exposures, would have contributed more workers to the estimates.

While this work may not include estimates for all workers at workplaces where there are levels of respirable crystalline silica significant to health, and there are several limitations associated with the data, it points out areas in which prevention efforts should be focused. In general, the results presented here are similar to those of Froines and coworkers [Froines et al., 1986a]. If 2-digit SICs from Table II are compared with those found in Table I of the Froines paper a great similarity exists. In fact, seven out of the nine 2-digit SICs that Froines lists are among the ten 2-digit SICs in Table II (16, 17, 32, 33, 34, 35, 37). Considering Table II in a broader sense, the SICs listed can be grouped into three divisions according to the SIC manual [U.S. Office of Management and Budget, 1987]. These divisions are Division C, Construction (15, 16, 17); Division D, Manufacturing (29, 32, 33, 34, 35, 37); and Division I, Services (87). The present analysis (see Table V) also provides numbers and percentages of workers in five 3-digit SICs in which workers are shown to be exposed to at least 10 times the NIOSH REL. Three of the SICs in this group (174, 162, 172) are in the construction industry and make up 95% of the workers in this table. Abrasive blasting or ''sandblasting'' and grinding or buffing of metal parts are thought to be major reasons for exposures in a number of the industries which appear in Tables II to VI. The large number of workers exposed in SIC 873 - Research, Development, and Testing Services, was unexpected. Activities in this SIC include mineral assaying, agricultural research, engineering laboratories, archeological expeditions, and various testing laboratories. These activities should be particularly amenable to dust control since most exposures are in a static laboratory type setting.

The OSHA IMIS data for crystalline silica indicate a possible decline over time in the concentration (% samples $>$ PEL) to which workers are exposed [NIOSH, 1996b]. However the OSHA Special Emphasis Program data discussed in the introduction indicate there may have been little change over this time period. As more of the Special Emphasis Program data become available, it will be interesting to see if this holds true.

As part of the silicosis awareness activities for the interagency campaign between the Department of Labor and NIOSH, a pamphlet titled ‘‘A Guide to Working Safely With Silica’’ has been distributed. In this pamphlet an estimate of 1 million workers exposed to crystalline silica is stated. A minimum level of exposure is not stated with this estimate. Considering we have used much more stringent criteria that eliminated industries such as the oil and natural gas industry, and with the addition of workers exposed in the mining and agriculture industries, one can see that an estimate of 1 million workers exposed at some level is not out of the question.

Table VIII presents death certificate data collected from 25 states for the years 1985–1993 [NIOSH, 1996b]. When the SICs contained in Table II are compared to the death certificate data, an agreement appears between industries with respirable crystalline silica dust concentrations equal to or greater than the NIOSH REL, and those with reported silicosis deaths. Tables IV and V, representing higher levels of exposure, agree with Table VIII to a greater degree, with 12 of the 16 SICs in Table IV being directly comparable to those in Table VIII and all of the SICs in Table V being comparable to Table VIII.

TABLE VIII. Silicosis: Most Frequently Recorded Non-Mining Industries on Death Certificates and PMRs, Selected States, U.S. Residents 15 Years and Older*

CIC category/description[a]	PMR 1985–1992[b]	Number of deaths 1985–1993	Comparative SIC codes
060/Construction	1.82	115	15, 16, 17
270/Blast furnace, steel rolling	6.49	74	331
262/Misc. non-metallic mineral products	55.31	61	328, 329
271/Iron and steel foundries	31.15	51	332
392/Non-specific manufacturing	2.67	40	392
331/General industrial machinery	3.96	27	356
010/Agricultural production, crops	<1.00	25	01
261/Pottery and related products	30.73	23	326
252/Structural clay products	27.82	22	325
300/Misc. fabricated metal products	5.87	20	347
All other industries		313	
Total		771	

*Information from 25 states reporting industry and occupation to the National Center for Health Statistics; see NIOSH [1996b].
[a]CIC codes from 1980 Census Population Index of Industry and Occupations.
[b]Proportionate mortality ratio; see NIOSH [1996b].

Crystalline Silica Exposure of Agriculture Workers

Since it is obvious that farmers work with soils that may contain crystalline silica, some discussion of the literature is appropriate. An undetermined portion of the more than three million agriculture workers [U.S. Bureau of the Census, 1993] in the United States is exposed to crystalline silica. Since OSHA does not regulate crystalline silica dust exposure on farms [Code of Federal Regulations, 1996], we did not estimate the number of farm workers exposed.

The literature suggests a wide range of crystalline silica exposure levels in the agriculture industry [Farant and Moore, 1978; Green et al., 1990; Norboo et al., 1991; Popendorf et al., 1982; Stopford and Stopford, 1995a,b]. The degree of exposure in the agriculture industry is dependent on factors such as:

1. The amount and size distribution of crystalline silica particles in the farm soil [Popendorf et al., 1982; Green et al., 1990; Stopford and Stopford, 1995a].
2. The geographic location of the farm (a drier climate can be inducive of more dust; coastal farms can have sandy soil, sandy soil may drain more efficiently leaving the soil drier) [Green et al., 1990; Stopford and Stopford, 1995b].
3. Farming methods, including: the use of irrigation versus water spray to grow crops in dry climates (lack of rain allows dust to build up on plant material); the amount of land that is bare and, therefore, available to produce dust; the frequency of ground disturbance either from machinery or from farm animals; the methods of harvesting plant material [Popendorf et al., 1982].
4. The amount of time the worker performs the dusty task.
5. The proper usage of dust controls, worker isolation, and respiratory protection.

Such factors and the lack of exposure data make it difficult to estimate the number of exposed agriculture workers. However, from the available literature, it is apparent that some agriculture workers are exposed to dust containing a significant percentage of crystalline silica.

RECOMMENDATIONS

We have presented a method of using the IMIS to provide much needed hazard surveillance information about crystalline silica exposures. The authors invite investigators to use this method to analyze other exposure data in the IMIS.

This information indicates the need for improved prevention efforts at manufacturing work places that sandblast and finish metal parts and in the construction and foundry industries. Also, SIC 873—Research, Development and Testing Services—should be investigated to determine what tasks are being performed that involve silica exposure and controls instituted. Research to clarify silica exposures and the risk of silicosis in the agriculture industry is needed. While this paper did not address the mining industry, mine work remains an important silicosis concern.

Prediction of exposure and the resulting disease depends on the quality of the surveillance data available. Therefore, care must be taken with the largest source of workplace environmental data: OSHA inspections. OSHA is committed to improving the IMIS as evidenced by a stakeholder's meeting that was held on August 27, 1997, and by their new project, the ''Health Data Project'' (OSHA, 1997, unpublished data). In order to make the most out of this valuable resource, an ongoing effort is needed to make sure that the data in the IMIS are complete, accurate, and easily accessible. We encourage others to investigate the validity of the data contained in the IMIS.

Interventions such as engineering controls, occupational health education and training of managers and workers, and adherence to regulations are needed to prevent exposure in the industries identified here. Medical screening is needed in some cases to identify workers and operations in which a high risk of silicosis exists. Silicosis diagnosis and reporting are also very important surveillance tools in silicosis prevention. NIOSH has published recommendations for reporting of silicosis [NIOSH, 1974, 1992a,b, 1996a]. Ultimately, prevention of silicosis depends on preventing exposures. In 1940, the U.S. Department of Labor Secretary Frances Perkins made a statement that still applies today: ''Our job is one of applying [preventive] techniques and principles to every known silica dust hazard in American industry. We know the methods of control; let us put them into practice'' [Rosner and Markowitz, 1991].

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REFERENCES

Baker EL, Melius JM, Millar DJ (1988): Surveillance of occupational illness and injury in the United States: Current perspectives and future directions. J Public Health Policy, 9:198–221.

Code of Federal Regulations (1996): 29 CFR 1928. Office of the Federal Register National Archives and Records Administration U.S. Government Printing Office, Washington, D.C.

Cherniack M (1986): ''The Hawk's Nest Incident America's Worst Industrial Disaster.'' New Haven: Yale University Press.

Dear JA (1996): ''Memorandum for Regional Administrators, Special Emphasis Program (SEP) for Silicosis.'' Washington, DC: Occupational Safety and Health Administration.

Farant JP, Moore CF (1978): Dust exposures in the Canadian grain industry. Am Ind Hyg Assoc J 39:177–194.

Freeman CA, Grossman EA (1995): Silica exposures in workplaces in the United States between 1980 and 1992. Scand J Work Environ Health 1995;21(Suppl 2): 47–49.

Froines J (1989): Worksite inspection and the control of occupational disease, The OSHA experience. NY Acad Sci 572:177–183.

Froines JR, Wegman D, Dellenbaugh C (1986a): An approach to the characterization of silica exposure in U.S. industry. Am J Ind Med 10:345–361.

Froines JR, Cornelia DA, Wegman DH (1986b): Occupational health surveillance: A means to identify work-related risks. Am J Public Health 76:1089–1096.

Froines J, Wegman D, Eisen E (1989): VI. Hazard surveillance in occupational disease AJPH 79:1089–1096.

Galster C (1997): A significant workplace exposure to crystalline silica. Appl Occup Environ Hyg 12:522–523.

Green FHY, Yoshida K, Green FHY, Yoshida K, Fick G, Paul J, Hugh A, Green WF (1990): Characterization of airborne mineral dusts associated with farming activities in rural Alberta, Canada. Int Arch Occup Environ Health 62:423–430.

Greenhow EH (1865): Specimen of diseased lung from a case of grinder's asthma. Trans Path Soc London 16:59.

Greenhow EH (1866): Specimen of potter's lung. Trans Path Soc Lond 17:36–38.

Greskevitch M, Turk A, Dieffenbach A, Roman J, Groce D, and Hearl F (1992): Quartz analyses of the bulk dust samples collected by the National Occupational Health Survey of Mining. Appl Occup Environ Hyg 7:527–531.

IARC (1997): ''Evaluation of the Carcinogenic Risk of Chemicals to Humans: Silica, Some Silicates, Dusts, and Organic Fibres,'' Vol. 68. Lyon: International Agency for Research on Cancer (IARC).

Mendeloff J (1984): An analysis of OSHA health inspection data. In U.S. Office of Technology Assessment. ''Health and Safety Control Technologies in the Workplace: Background Studies.'' Washington, DC: Government Printing Office.

NIOSH (1974): ''Criteria for a Recommended Standard: Occupational Exposure to Crystalline Silica.'' NIOSH HEW Pub No 75–120. Cincinnati, OH.

NIOSH (1988a): ''National Occupational Exposure Survey, Volume I.'' DHHS (NIOSH) Pub No 88-106. Cincinnati, OH

NIOSH (1988b): ''National Occupational Exposure Survey, Volume III.'' DHHS (NIOSH) Pub No 89–103. Cincinnati, OH

NIOSH (1990a): ''National Occupational Exposure Survey, Volume II.'' DHHS (NIOSH) Pub No 89–102. Cincinnati, OH

NIOSH (1990b): National Occupational Exposure Survey (1981–1983). Unpublished Provisional Data as of 7/1/90. Cincinnati, OH: NIOSH Division of Surveillance, Hazard Evaluations and Field Studies, Surveillance Branch, Hazard Section. Cincinnati, OH

NIOSH (1991): ''Work-Related Lung Disease Surveillance Report.'' DHHS (NIOSH) Pub No 91–113. Cincinnati, OH

NIOSH (1992a): ''ALERT, Request for Assistance in Preventing Silicosis and Deaths from Sandblasting.'' DHHS (NIOSH) Pub No 92–102. Cincinnati, OH

NIOSH (1992b): ''ALERT, Request for Assistance in Preventing Silicosis and Deaths in Rock Drillers.'' DHHS (NIOSH) Pub No 92–107. Cincinnati, OH

NIOSH (1995a): ''NIOSH Health Hazard Evaluation Report HETA 93–1037–2541, Johnson Brothers Company, Pittsburgh, Pennsylvania.'' DHHS, PHS, CDC, NIOSH. Cincinnati, OH

NIOSH (1995b): ''Criteria for a Recommended Standard Occupational Exposure to Respirable Coal Mine Dust.'' DHHS (NIOSH) Pub No 95–106. Cincinnati, OH

NIOSH (1996a): ''ALERT, Request for Assistance in Preventing Silicosis and Deaths in Construction Workers.'' DHHS (NIOSH) Pub No 96–112. Cincinnati, OH

NIOSH (1996b): ''Work-Related Lung Disease Surveillance Report 1996.'' DHHS (NIOSH) Pub No 96–134. Cincinnati, OH

Norboo T, Angchuk PT, Yahya M, Kamat SR, Pooley FD, Corrin B, Kerr IH, Bruce N, Ball KP (1991): Silicosis in a Himalayan village population: Role of environmental dust. Thorax 46:341–343.

OSHA (1995): ''OSHA Field Inspection Reference Manual.'' Rockville, MD: Government Institutes, Inc.

OSHA (1996): ''OSHA Technical Manual TED 1.15,'' 4th edition. Rockville, MD: Government Institutes, Inc.

Peacock, TB (1860): On French millstone makers phthisis. Br Foreign Med Chir Rev 25:214.

Peters JM (1986): Silicosis. In Merchant JA, Boehlecke BA, Taylor G, Pickett-Harner M (eds): ''Occupational Respiratory Diseases.'' DHHS (NIOSH) Publication No. 86–102:219–237.

Pollack ES, Keimig DG (1987): ''Counting Injuries and Illnesses in the Workplace: Proposals for a Better System.'' Washington, DC: National Academy Press, 3:27–28.

Popendorf W, Pryor A, Wenk HR (1982): Mineral dust in manual harvest operations. Ann Am Conf Gov Ind Hyg Vol 2. pp. 101–115.

Rom WN (1994) ''Environmental and Occupational Medicine.'' Boston: Little, Brown.

Rosner D, Markowitz G (1991): ''Deadly Dust: Silicosis and the Politics of Occupational Disease in Twentieth-Century America.'' Princeton: Princeton University Press.

Stopford CM, Stopford W (1995a): Respirable quartz content of farm soils. Appl Occup Environ Hyg 10(3).

Stopford CM, Stopford W (1995b): Potential for respirable quartz exposure from North Carolina farm soils. Scand J Work Environ Health 1995; 21(Suppl 2):44–46.

Trasko V (1956): Some facts on the prevalence of silicosis in the United States. AMA Arch Ind Health 14:379–386.

U.S. Bureau of Mines (1984): ''Analysis of Data on Respirable Quartz Dust Samples Collected in Metal and Nonmetal Mines and Mills.'' Bureau of Mines Information Circular, U.S. Department of the Interior, Report IC 8967.

U.S. Department of Commerce (1993): County Business Patterns (state files and public use data tapes). Washington, DC: Bureau of the Census, 1993.

U.S. Department of Labor (1980): ''An Interim Report To Congress On Occupational Diseases.'' Washington, DC: U.S. Dept. of Labor.

U.S. Office of Management and Budget: ''Standard Industrial Classification Manual.'' Washington, DC: Government Printing Office, 1987.

Watts W (1995): ''Quartz Exposure Trends in Metal and Nonmetal Mining.'' Appl Occup Environ Hyg 10:1009–1018.