CONTROL TECHNOLOGY AND EXPOSURE ASSESSMENT FOR OCCUPATIONAL EXPOSURE TO CRYSTALLINE SILICA:
Stone Monument Manufacturing

PRINCIPAL AUTHORS:
Robert W. Kurimo
Leo M. Blade
William A. Heitbrink

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U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
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National Institute for Occupational Safety and Health
Division of Applied Research and Technology
Engineering and Physical Hazards Branch
4676 Columbia Parkway, Mail Stop R-5
Cincinnati, Ohio 45226

FACILITY STUDY SITE:	Hirons Memorial Works Mount Orab, Ohio
SIC CODE:	3281
STUDY DATES:	March 22-24, 29, 1999
STUDY CONDUCTED BY:	Leo M. Blade William A. Heitbrink Robert W. Kurimo
EMPLOYER REPRESENTATIVE:	No Union
ANALYTICAL SUPPORT:	Leroy May, NIOSH Donald Dollberg, NIOSH DataChem Laboratories, Salt Lake City, Utah
EDITORIAL REVIEW:	Jennifer Topmiller, EPHB

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ABSTRACT

Worker exposure to crystalline silica was monitored during an abrasive blasting operation where stone monuments were being manufactured. A stencil was placed over the stone, and then abrasive blasting was used to produce the engravings by removing stone not covered by the stencil. The primary engineering control in use at this site was an exhausted enclosure with a face velocity of 160 fpm. Area and personal samples were collected during the survey to measure how much respirable silica was produced by this process. The geometric mean was 0.0071 mg/m^3 in the breathing zone and 0.0026 mg/m^3 for the area samples. The low concentrations appear to result from relatively effective engineering controls for the blasting operation, and, in addition, the blasting operation was performed only during part of the workday which resulted in less dust being generated. Further reductions in workers' exposures can be affected by enclosing the abrasive agent recycle chute, providing a vacuum for the worker to clean his clothing instead of using compressed air, and using a vacuum and/or wet wipe or water to remove dust from the completed monument and enclosure.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH), working under an inter-agency agreement with the Office of Regulatory Analysis of the Occupational Safety and Health Administration (OSHA), is conducting a study to survey occupational exposures to crystalline silica and to document engineering controls and work practices affecting those exposures during abrasive blasting operations. The performance of a thorough industrial hygiene survey for a variety of individual employers provides valuable and useful information to the public and employers in the industries included in the work. NIOSH has conducted more than 30 case study assessments to document engineering controls and the associated worker exposures to crystalline silica. The principal objectives of these surveys are:

1. To identify and describe the control technology and work practices in use in operations associated with occupational exposures to crystalline silica, as well as determining additional controls, work practices, substitute materials, or technology that can further reduce occupational silica exposures.

2. To measure full-shift, personal breathing zone, respirable particulate exposures to crystalline silica. These samples provide examples of exposures to crystalline silica among workers across the many industries where silica is encountered. These exposure data, along with the control data described above, provide a picture of the conditions in the selected industries.

One of the industries selected for surveying was the production of stone monuments (SIC code 3281). Over 13,000 employees are employed in more than 1,000 of these facilities in the United States.

This facility engraves and finishes cemetery monuments and similar stone products, primarily using an automated abrasive blasting technique. This in-depth survey was the first of several planned by EPHB to document crystalline silica exposures and their associated, existing exposure control measures in abrasive blasting operations. These in-depth surveys are supplemental to the larger EPHB study of crystalline silica exposures and controls conducted in support of the planned OSHA rulemaking regarding crystalline silica exposures. The field studies for this project were directed by NIOSH research personnel.

The current OSHA Permissible Exposure Limit (PEL) for respirable dust containing quartz is calculated from the following formula and expressed in terms of milligrams per cubic meter of air:

$$PEL = \frac{10}{\%\ silica + 2} \qquad (1)$$

The current NIOSH Recommended Exposure Limit for quartz is 0.05 mg/m[1,3] while the current American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV®) is 0.1 mg/m [2,3]. A review of OSHA's Integrated Management Information System (IMIS) database shows that many workers are exposed to crystalline silica at concentrations exceeding the OSHA PEL, the NIOSH REL, and the ACGIH TLV. There is a need to understand the nature of these silica exposures, what is causing the exposures, and what steps are being taken or could be taken to reduce the exposures (e.g., engineering controls, work practices, and personal protective equipment).

METHODS

This field study was conducted in accordance with 42 CFR 85a, the NIOSH regulations governing the investigation of places of employment. An initial visit was made to the site on January 11, 1999 to observe the operation and schedule subsequent surveys. The sampling survey was conducted on March 22-24, and 29, 1999. Employees with the highest potential silica exposures in each process area or operation were the major focus of the site visit. Workers selected for sampling were briefed on the sampling procedures to be conducted. Because the goal of this study was to assess the effectiveness of engineering controls and work practices on crystalline silica exposures, samplers were placed outside of any respiratory protective equipment worn by the worker. Four days of sampling were conducted at this site, allowing workers to be monitored for up to four days.

Personal respirable particulate samples, ranging from three to over five hours, were collected for each silica process worker. Respirable particulate samples were collected at a flow rate of 1.7 liters/minute using a 10-mm nylon cyclone (a Dorr-Oliver cyclone) and a pre-weighed, 37-mm diameter, 5-µm pore-size polyvinyl chloride filter backed by a stainless steel filter support in a two-piece filter cassette sealed with tape or a cellulose shrink band, in accordance with NIOSH Method 0500 [2] for total respirable dust and NIOSH Method 7500 for crystalline silica.[3] Area samples, ranging from four to over six hours were collected for selected areas. Two bulk samples of settled dust were collected and analyzed in accordance with NIOSH Method 7500. All samples were analyzed by the DataChem Laboratory in Salt Lake City.

Velocity measurements were made using a velometer (Velocicalc, TSI, St. Paul, MN). Smoke tubes were used to observe the airflow patterns. In addition, Video Exposure Monitoring was also used to observe worker exposures as the worker moved around. An aerosol photometer (HAM, PPM inc., Knoxville, TN) was placed in the worker's breathing zone. Air was drawn through the sensing chamber of the HAM by a battery-operated pump at a flow rate of 2 lpm. In the sensing chamber, the dust scatters light emitted from a light-emitting diode. The scattered light is detected by a photomultiplier tube. The analog output of the aerosol photometer is proportional to the amount of light detected by the photomultiplier tube. Because the amount of light scattered by the aerosol varies with the particle size and optical properties, the analog output of the aerosol photometer is a measure of relative concentration. The HAMs were used with a one second time constant and their analog output was recorded every second by a data logger

(Metrosonics, DL3200, Rochester, NY). The worker's activities were recorded on videotape while the output of the HAM was recorded on the data logger. The videocamera and datalogger clocks were synchronized after which the video recordings and the exposure data were reviewed to evaluate the effect of work practices upon exposure.

Sample data sheets were filled out by the field survey team to document all of the samples collected. Information contained on the sample sheets included: facility name, facility location, process name, job title, worker (who were identified only by task performed), pump number, pump flow rate, start and stop times, and filter number. In addition, any unusual conditions, work practices, and use of personal protective equipment were also noted on the sampling sheets.

During the site visit, information pertinent to process operation and control effectiveness (e.g.. control methods, ventilation rates, work practices, use of personal protective equipment, etc.) was also collected. A thorough description of the process is essential to understanding the role of engineering controls and work practices. Information was obtained from conversations with workers to determine if the sampling day was a typical work day. This information helped place the sampling results in proper perspective. Plant and process layout diagrams were also obtained. Information about the facility and the industry were also obtained.

The summary of engineering control information includes such items as ventilation flow rates and distance measurements. The proximity of the control systems to open doors or windows, general ventilation intakes and exhausts, and other interacting equipment (i.e., pedestal fans) were also noted. The age and history of the control systems, cost of control installation, maintenance practices, and operation and maintenance costs were determined from facility management, when possible. Any silica sampling data collected by the company showing the effectiveness of the controls were also collected and evaluated (for example, sampling data from before and after the control was installed).

NIOSH researchers calculated the exposures from the analytical results. For each employee sampled, an eight-hour time-weighted average (TWA) exposure to respirable dust and respirable crystalline silica was calculated. The TWA was calculated assuming that exposure remained constant during the unsampled period. The TWA exposures were calculated using the following equation:

$$TWA = \frac{C_1T_1 + C_2T_2 + \ldots C_nT_n}{T_1 + T_2 + \ldots T_n} \qquad \textbf{(2)}$$

where C_1, C_2...C_n are the concentrations for time periods 1 to n, and T_1, T_2...T_n are the sample times for time periods 1 to n.

When the analysis of a sample results in a value less than the limit of detection (LOD) of the analytical method, the LOD was used to calculate the TWA, and the value(s) are reported as "at or below" the calculated value for individual samples (e.g., $\leq$0.05 mg/m^3).

FACILITY AND PROCESS DESCRIPTION

On March 22- 24, and 29, 1999, NIOSH researchers conducted surveys at a monument manufacturer hereafter referred to as Facility A. Facility A produces cemetery monuments and similar stone products.

The workshop building is a one-story building and consists of a preparation area, a showroom, an office, an abrasive blasting booth for automated blasting, and a manual blasting cabinet. The dimensions of the preparation room are 9.0 m (29.5 ft). by 9.0 m (29.5 ft.), and the dimensions of the blasting area are 8.8 m (29 ft.) by 5.3 m (19.75 ft.) The plant layout is presented in Fig. 1.

Abrasive blasting is performed using a MODEL J automatic sandblaster which is contained within an abrasive blasting enclosure. A viewing screen with a floodlight allows the operator to monitor the progress of the operation and slides open to obtain ready access for stencil repair. A rubber curtain mounted on the bottom half of the opening allows access for manual blasting or other work. This is shown in Fig. 2.

The granite stones, which are precut and polished, are received in the facility yard for display and storage. The color of the stone indicates the presence of trace elements and place of origin. A selected stone is masked with a 1/8" thick rubber stencil . The stencil is either pre-cut (determined by computer) or produced by hand. The edge of the stone is masked for protection against damage, and the stone is then ready for blasting.

Facility personnel generally work less than 40 hours per week and 8 hours per day. Four people are employed with one person doing the blasting and one assisting with the preparation at any given time.

CONTROL MEASURES

The primary engineering control was a booth to contain the automated blasting operation. The face velocity at the screen, measured with a velometer (TSI Velocicalc, TSI, St. Paul, Minnesota) was 160 fpm. The blasting nozzle apparatus moved along a slot 72" x 8", and the slot velocity (bottom slot) was 190 fpm. The manual blasting cabinet was contained within an enclosure which had a rubber curtain on the front face. This curtain consisted of vertical parallel strips which acted as a barrier to dust escaping from the cabinet while allowing the operator to reach inside to perform his work. The face velocity at the curtain during the manual blasting operation was approximately 100 fpm. This is shown in Fig. 3.

According to the owner, the manufacturer specified that the flow rate through the duct at the cyclonic air cleaner was 1500 cfm. Based upon measurements taken outdoors at the discharge of the dust collector, the flow rate appears to be at least equal to this value. It was not possible to obtain an accurate flow rate measurement because there was insufficient duct length.

Personal protective equipment included hearing protection, a full-face-shield air-purifying respirator with a dust/mist fume cartridge, and gloves.

RESULTS

Air Sampling

The results of the total respirable dust and crystalline silica measurements are listed in the table below:

Table 1. Sampling Results and Concentration Data

Date (1999)	Area	Job Title(PBZ) or Location (GA)	Sampling Time (HH:MM)	Total Respirable Dust (mg/m^3)	Total Dust PEL (mg/m^3)	Respirable Crystalline Silica (mg/m^3)	% Silica in Total Respirable Dust
3/22	Right of Blast Enclosure	Blasting (GA)	5:20	0.055	0.28	0.018*	33
3/22	Prep Room	(GA)	5:19	0.055	0.28	0.018	33
3/22	Blasting	Blasting (PBZ)	5:22	0.30	0.62	0.043**	14
3/23	Right of Blast Enclosure	Blasting (GA)	5:07	0.057	0.28	0.019	33
3/23	Prep Room	(GA)	5:08	0.057	0.28	0.019	33
3/23	Blasting	Blasting (PBZ)	5:09	0.12	0.45	0.024	20
3/24	Right of Blast Enclosure	Blasting (GA)	5:07	0.099	0.54	0.016	17
3/24	Prep Room	(GA)	5:57	0.049	0.28	0.016	33
3/24	Blasting	Blasting (PBZ)	5:57	0.13	0.61	0.019	14
3/29	Right of Blast Enclosure	Blasting (GA)	4:46	0.062**	0.28	0.021	33
3/29	Prep Room	(GA)	4:47	0.020**	0.096	0.020	100
3/29	Blasting	Blasting (PBZ)	4:47	0.091	0.28	0.030	33

GA = General Area Sample
PBZ = Personal Breathing Zone, taken outside of the respirator location in the worker's breathing zone.

* The amount on the filter is below this value which is the minimum detectable concentration (MDC).
** These values are between the MDC and minimum quantifiable concentration (MQC).

Two bulk samples of the settled dust were analyzed for quartz and cristobalite. The one which was collected at the air cleaner discharge had a silica concentration of 4.9% by weight. The other was collected at the recycle chute but did not contain detectable amounts of quartz. Neither sample contained detectable amounts of cristobalite. The LOD for both quartz and cristobalite was 0.8% and the LOQ was 2.0%.

Work Activities

The table below lists the amount of time spent in the blasting operations during the days of the site visits.

Table 2. Description of Work Activities

Date	Location	Job Description	Activities
03/22	In front of blasting booth	Blaster Operator	Performed automatic blasting for four hours.
03/23	In front of blasting booth	Laborer	Performed automatic blasting for four hours
03/24	In front of blasting booth	Laborer	Performed automatic blasting for five hours
03/29	In front of blasting booth	Laborer	Performed automatic blasting for one hour and thirty minutes. Performed manual blasting for thirteen minutes.

Exposures Related to Activities

The time periods, activities, and related exposures are listed in the tables below. The exposures were obtained from HAM measurements. They do not represent actual concentrations such as milligrams per cubic meter but relative amounts which can be used for comparison purposes. The percent of activity exposure was obtained by dividing the exposure for that particular activity by the total of all activity exposures and multiplying by 100. The percent of time exposure was obtained by dividing the particular activity time by the total exposure times and multiplying by 100. Graphical representations can be seen in Figs. 4 - 7.

Table 3. Worker Exposures Related to Activity.

Date	Activity	Time Period (min and sec)	Exposure (Relative Units)	% Activity Exposure to Total Exposure	% Activity Time to Total Time
3/23	Preparation of Stone for Blasting	5:54	19.6	7.79	29
3/23	Adjusting Rubber Curtain	0:28	1.99	0.79	2.3
3/23	Automated Blasting	12:16	219	86.7	61
3/23	Shutdown	0:19	2.32	1.28	1.6
3/23	Exiting and Outside of Booth	1:19	8.66	3.44	6.5
	Totals	20:16	252.1	100	100
3/24	Placing Pumps on Worker	0:49	2.26	1.05	5 0
3/24	Automated Blasting	15:13	159	90.4	94
3/24	Exiting Booth	0:11	14.9	8.44	1.1
3/24	Outside of Booth	0:03	0.277	0.16	0.3
	Totals	16:16	176.4	100	100
3/24	Exiting Booth	0:13	0.246	0.1	0.94
3/24	Outside of Booth	3:18	10.1	4.9	14.3
3/24	Stone Preparation	13:41	13.4	6.5	59.3
3/24	Lifting Curtain, Putting Gloves on.	0:52	5.50	2.7	3.75
3/24	Automated Blasting	3:56	141	69	17.0
3/24	Taking Compressed Air Hose	0:14	9.20	4.5	1.01
3/24	Cleaning with Compressed Air Hose	0:22	22.7	11	1.59
3/24	Putting Hose Back	0:03	.908	0.4	0.22
3/24	Using Compressed Air to Clean Stone	0:26	2.08	1.0	1.88
	Totals	23:05	205	100	100
3/29	Manual Blasting	2:23	64.2	67.1	61
3/29	Getting Compressed Air Hose	0:15	7.72	8.1	6.4
3/29	Cleaning with Compressed Air	0:23	12.4	12.9	9.8
3/29	Exiting Booth	0:55	11.4	11.9	23
3/29	Totals	3:56	95.7	100	100

CONCLUSIONS AND RECOMMENDATIONS

A review of the sampling results showed that air concentrations of both respirable silica and total dust were higher in the personal breathing samples than in the area samples; however, neither the concentrations of crystalline silica nor the concentrations of total respirable dust (as calculated from Equation 1) exceeded the OSHA PEL. Also, personal respirable silica exposures did not exceed the NIOSH REL.

In the personal breathing zone, air concentrations of crystalline silica ranged from 0.019 to 0.043 mg/m^3, and concentrations of total respirable dust ranged from 0.091 to 0.30 mg/m^3. In the two areas sampled, concentrations of crystalline silica ranged from 0.016 to 0.021 mg/m^3, and concentrations of total respirable dust ranged from 0.02 to 0.099 mg/m^3.

The per cent of silica in the samples was obtained by dividing the weight of crystalline silica by the total amount of respirable dust and multiplying by 100. This value was then put into the equation to obtain the PEL for that sample.

These well-controlled exposures can be attributed to good work practices, relatively clean environment, and also to the fact that the operation is performed on a part-time basis with time in between blasting operations allotted to cleanup and maintenance. If work were to be done on a full-time basis, worker exposures could possibly be higher due to the greater amount of dust being generated.

Based on video exposure monitoring, automated blasting is a primary source of exposure. This is shown in Figures 3, 5a, and 5b. The results of the analysis of the air samples show that the enclosure is an effective engineering control. A second means to reduce worker exposure may be effected if the worker uses a vacuum for cleaning instead of using compressed air. This can reduce "bounce back" of large particles through the screen and rubber flaps of the blast enclosure. The movements of these larger particles may cause respirable dust to be entrained and transported into the worker's personal breathing zone.

Further reductions in worker's exposures to respirable dust may also be accomplished by using a vacuum and/or wet wipe or water to dust off the completed monument and to clean up the enclosure. It is also recommended that the chute returning the blasting agent from the automatic blaster to the blasting pot be enclosed.

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