In-Depth Survey Report

Engineering Control of Silica Dust from Stone Countertop Fabrication and Installation

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Stone Systems of Minnesota
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DEPARTMENT OF HEALTH AND HUMAN SERVICES
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Site Surveyed:

Stone Systems of Minnesota
2425 Waters Dr.
Mendota Heights, MN 55120

NAICS Code:

327991 Cut Stone and Stone Product Manufacturing

Survey Dates:

August 25-26, 2015

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Abstract

Background

Workplace exposure to respirable crystalline silica can cause silicosis, a progressive lung disease marked by scarring and thickening of the lung tissue. Quartz is the most common form of crystalline silica. Crystalline silica is found in several materials, such as brick, block, mortar and concrete. Construction and manufacturing tasks that cut, break, grind, abrade, or drill those materials have been associated with overexposure to dust containing respirable crystalline silica. Stone countertop products can contain >90% crystalline silica, and working with this material during stone countertop fabrication and installation has been shown to cause excessive exposures to respirable crystalline silica. NIOSH scientists are conducting a study to develop engineering control recommendations for respirable crystalline silica from stone countertop fabrication and installation. This site visit was part of that study.

Assessment

NIOSH scientists visited Stone Systems of Minnesota, Mendota Heights, MN on August 25-26, 2015. During the site visit, they performed industrial hygiene sampling which measured the short term task-based exposures to respirable dust and respirable crystalline silica of six workers who used handheld tools in the stone countertop fabrication process. The evaluated work tasks predominantly included polishing (i.e. “Polishers”) and grinding (i.e. “Grinders”). An engineering control measure that supplied water to the tools to suppress the dust at its source was used throughout the fabrication process. Local exhaust ventilation was also in place for the Grinders. The NIOSH scientists recorded detailed survey notes about the work process to understand the conditions that led to the measured exposures.

Results

Air sampling for respirable crystalline silica showed that the short term respirable crystalline silica exposures ranged from 21.4 to 122.9 $\mu g/m^3$ for the Polishers, and from 114.8 to 583.2 $\mu g/m^3$ for the Grinders. The geometric mean short term respirable crystalline silica exposures were 65.7 and 223.3 $\mu g/m^3$ for Polishers and Grinders, respectively. The Grinders’ short term respirable crystalline silica exposures were significantly higher than the Polishers’ exposure ($p<0.0001$). The geometric mean silica contents of the respirable dusts samples were 38.1% and 62.2% for Polishers and Grinders, respectively. The Grinders’ respirable dust samples contained significantly more crystalline silica than the Polishers’ respirable dust samples ($P<0.0001$).

Conclusions and Recommendations

The results from the task-based samples in this survey revealed that wet grinding and wet polishing engineered quartz stone may still lead to overexposure to respirable crystalline silica. The exposure levels for wet grinding were especially concerning. Using a larger amount of water through a center water feed for the

grinders may be the first choice for a future test of control technologies. Additional and more effective engineering control measures will be needed for these tasks to reduce the exposure to levels consistently below the NIOSH Recommended Exposure Limit (REL). In the absence of sufficient dust controls, respirators should continue to be used to reduce exposures, and the employer needs to make sure that the respiratory protection program follows the OSHA standard.

Introduction

Background for Control Technology Studies

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Since 1976, EPHB has conducted a number of assessments of health hazard control technologies on the basis of industry, common industrial process, or specific control techniques. Examples of these completed studies include the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involve a number of steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concept techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

Background for this Study

Crystalline silica refers to a group of minerals composed of silicon and oxygen; a crystalline structure is one in which the atoms are arranged in a repeating three-dimensional pattern [Bureau of Mines 1992]. The three major forms of crystalline silica are quartz, cristobalite, and tridymite; quartz is the most common form [Bureau of Mines 1992]. Respirable crystalline silica refers to that portion of airborne crystalline silica dust that is capable of entering the gas-exchange regions of the lungs if inhaled; this includes particles with aerodynamic diameters less than approximately 10 micrometers (μm) [NIOSH 2002]. Silicosis, a fibrotic disease of the lungs, is an occupational respiratory disease caused by the inhalation and deposition of respirable crystalline silica dust [NIOSH 1986]. Silicosis is irreversible, often progressive (even after exposure has ceased), and potentially fatal. Because no effective treatment exists for silicosis, prevention through exposure control is essential.

Stone countertops became increasingly popular among consumers in recent years. Granite and engineered quartz stone are the two major stone countertop materials, respectively representing an estimated 27% and 8% market share (by sales) in a $74B global countertop market in 2012. Sales of engineered quartz stone countertops have especially been growing at a rapid pace, exhibiting a compounded annual growth rate of 15.8% between 1999 and 2012. In a report by Stone Update [2012], U.S. imports of engineered quartz slabs jumped 55.2% in May 2012 compared to the previous year. Thus, the size of the workforce performing fabrication and installation of stone countertops is expected to grow from a conservative estimate of 36,000 workers in the U.S. in 2012 [Phillips et al., 2012].

Unfortunately, a large amount of dust that contains crystalline silica can be produced during stone countertop fabrication and installation. On average, granite naturally contains 72% crystalline silica by weight [Blatt and Tracy 1997], and engineered quartz stone contains about 90% quartz grains by mass in a polymer matrix [Phillips et al., 2013]. An outbreak of silicosis was reported in Israel [Kramer et al., 2012], where 25 patients were identified who shared an exposure history of having worked with engineered quartz stone countertops without dust control or respiratory protection. In addition, 46 silicosis cases were recently reported in Spain among men working in the stone countertop cutting, shaping, and finishing industry [Pérez-Alonso et al., 2014]. Most recently, the first silicosis case in the US was reported for a worker who had worked with engineered quartz stone countertops [CDC, 2015]; and NIOSH and OSHA [2015] released a Hazard Alert on worker exposure to silica during countertop manufacturing, finishing and installation. A systematic evaluation, optimization, and improvement of task-based engineering control measures for processes involved in stone countertop fabrication and installation is needed to give stakeholders best-practice recommendations for consistently reducing respirable crystalline silica exposures below the NIOSH Recommended Exposure Limit (REL) of 0.05 mg/m^3.

A review of workplace inspections conducted by the state of Washington’s Department of Labor and Industries found overexposures to respirable crystalline silica (above the OSHA Permissible Exposure Limit (PEL)) and violation of rules on engineering controls in 9 of 18 stone countertop shops inspected [Lofgren 2008]. Data from OSHA’s Integrated Management Information System (IMIS) reveals that citations issued for exceeding the PEL for respirable crystalline silica jumped from an average of 4 per year during 2000-2002 to an average of 59 per year during 2003-2011 at stone countertop fabrication shops and installation sites. These results indicate that knowledge and implementation of dust control methods does not appear to be well disseminated among shops in this industry. OSHA recently published a new PEL of 0.05 mg/m^3 as an 8-hr time weighted average (TWA) for respirable crystalline silica [81 Fed. Reg. 16285, 2016], making it critical to address these overexposures.

This project aims to reduce workers' exposures and risks in the stone countertop fabrication and installation industries by evaluating, optimizing, and improving engineering control measures, validating their effectiveness through field studies, and disseminating the results through NIOSH field survey reports, articles in professional and trade journals, a NIOSH Workplace Solutions document, and a NIOSH Internet topic page. The information will also be provided to OSHA to assist in the implementation of the new silica standard. The long-term objective of this study is to provide practical recommendations for effective dust controls that will prevent overexposures to respirable crystalline silica during stone countertop fabrication and installation.

Background for this Survey

Short term task-based sampling was planned for this survey. The aim was to investigate workers' respirable crystalline exposures when conducting the tasks during which higher exposures were likely to happen with the existing control technology. All the operations in the surveyed shop were conducted using wet methods. A recent study of exposures associated with countertop fabrication [Phillips et al., 2013] reported that wet sawing and wet polishing were the two tasks where water was used that led to the highest respirable quartz exposure levels. Exposures associated with other wet processes, such as the use of bridge saws and computer-controlled cutting (a.k.a. CNC) machines, were associated with lower full-shift TWA respirable quartz exposures, in a narrow range from 0.020 to 0.021 mg/m^3 [Phillips, et al., 2013]. At this facility, workers cutting countertop material with automated machinery, such as bridge saws, CNC machines, and water jet machines, operate the machinery while standing at a certain distance away from the process. Thus, during this survey, the task-based sampling was mainly focused on wet polishing and grinding, and occasional wet cutting using handheld tools. This survey was performed on August 25-26, 2015 at Stone Systems of Minnesota in Mendota Heights, MN. Air sampling was conducted to assess the respirable dust and crystalline silica exposures of five workers performing a variety of tasks.

Survey Site and Process Description

Introduction

Stone Systems of Minnesota is a stone countertop fabrication shop. Its products mainly include granite and engineered quartz countertops. The shop building consists of a fabrication area and an attached office area. The doors separating the office and fabrication areas were kept closed to prevent dust from entering the office area. There are signs beside these doors reminding personnel to wear their respirators and hearing protection before entering the fabrication area.

Process Description

The shop processes about 900 square feet of countertop surface per day, on average. The countertop fabrication process began at one end of the facility where the stone slabs were received and stored. The stone slabs were first cut into smaller pieces using bridge saws and water-jet cutters. Straight cuts were performed using both the bridge saws and water-jet cutters; while radial cuts were made using the water-jet cutters only. The bridge saws were all equipped with water sprays to suppress dust. After the initial cutting, some stones also went through a lamination process, depending upon the design requirements of the product. During the lamination process, workers cleaned and dried the stone surfaces, wet cut thin strips of stone using electric wet grinders (~8,300 RPM) with turbo blades, and glued these thin strips of stone to the larger countertop pieces to form countertop edges. Some initial grinding of the stone surfaces and edges was also conducted at this step using handheld pneumatic/electric wet grinders (~7,000-8,300 RPM) with coarse diamond grinding cup wheels. This abraded the surface and allowed the glue to adhere to the stone. After the glue cured, the stone assembly and stones without edge pieces went to CNC and other large machines that shaped, edged and profiled them. All of these machines were equipped with water sprays to suppress dust. After this process was completed, the stones were sent to the final grinding and polishing area. Workers used handheld tools equipped with water to manually grind and polish the edges of the stones. Three to four workers used pneumatic/electric wet grinders (~7,000-8,300 RPM) with diamond grinding cup wheels (both coarse and medium ratings) for final grinding of the stone edges, then five to six workers used pneumatic wet polishers (~4,500 RPM) with resin-bonded polishing discs for final polishing. The workers who used grinders were the same workers performing the lamination job in this shop. All the workers involved in the production process wore elastomeric, half-face air-purifying respirators with either P100 cartridges or combination P100 and organic vapor cartridges. Other personal protective equipment worn included hearing protection, eye protection, rubber safety shoes, and aprons.

Occupational Exposure Limits and Health Effects

As a guide to assessing hazards posed by workplace exposures, NIOSH investigators use mandatory and recommended Occupational Exposure Limits (OELs) to evaluate chemical, physical, and biological agents in the workplace. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit.

Combined effects are often not considered in the OEL. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus can increase the overall exposure. Finally, OELs may change over the years as new information on the toxic effects of an agent become available.

Most OELs are expressed as a TWA exposure. A TWA exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have a recommended Short Term Exposure Limit (STEL) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

In the U.S., OELs have been established by Federal agencies, professional organizations, state and local governments, and other entities. The U.S. Department of Labor OSHA Permissible Exposure Limits (PELs) [29 CFR 1910.1000 2003a] are occupational exposure limits that are legally enforceable in covered workplaces under the Occupational Safety and Health Act. NIOSH recommendations are based on a critical review of the scientific and technical information available on the prevalence of health effects, the existence of safety and health risks, and the adequacy of methods to identify and control hazards [NIOSH 1992]. They have been developed using a weight of evidence approach and formal peer review process. Other OELs that are commonly used and cited in the U.S. include the Threshold Limit Values (TLVs®) recommended by American Conference of Governmental Industrial Hygienists (ACGIH®), a professional organization [ACGIH 2013]. ACGIH® TLVs are considered voluntary guidelines for use by industrial hygienists and others trained in this discipline “to assist in the control of health hazards.” Workplace Environmental Exposure Levels® (WEELs) are recommended OELs developed by the American Industrial Hygiene Association® (AIHA), another professional organization. WEELs have been established for some chemicals “when no other legal or authoritative limits exist” [AIHA 2007].

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91–596, sec. 5(a)(1)]. Thus, employers are required to comply with OSHA PELs. Some hazardous agents do not have PELs, however, and for others, the PELs do not reflect the most current health-based information. Thus, NIOSH investigators encourage employers to consider the other OELs in making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminating or minimizing identified workplace hazards. This includes, in preferential order, the use of: (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation) (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection).

Crystalline Silica Exposure Limits

When dust controls are not used or maintained or proper practices are not followed, respirable crystalline silica exposures can exceed the NIOSH REL, the OSHA PEL, or the ACGIH TLV. NIOSH recommends an exposure limit for respirable crystalline silica of 0.05 mg/m^3 as a TWA determined during a full-shift sample for up to a 10-hr workday during a 40-hr workweek to reduce the risk of developing silicosis, lung cancer, and other adverse health effects [NIOSH 2002]. When source controls cannot keep exposures below the NIOSH REL, NIOSH also recommends minimizing the risk of illness that remains for workers exposed at the REL by substituting less hazardous materials for crystalline silica when feasible, by using appropriate respiratory protection, and by making medical examinations available to exposed workers [NIOSH 2002]. In cases of simultaneous exposure to more than one form of crystalline silica, the concentration of free silica in air can be expressed as micrograms of free silica per cubic meter of air sampled (µg/m^3) [NIOSH 1975].

$$\mu gS_iO_2/m^3 = \frac{\mu gQ + \mu gC + \mu gT + \mu gP}{V} \qquad (1)$$

Where Q is quartz, C is cristobalite, and T is tridymite, P is “other polymorphs”, and V is sampled air volume.

The current OSHA PEL for respirable crystalline silica is 0.05 mg/m^3 as an 8-hr time weighted average (TWA) [81 Fed. Reg. 16285, 2016]. The ACGIH TLV for α-quartz (the most abundant toxic form of silica, stable below 573°C) and cristobalite (respirable fraction) is 0.025 mg/m^3 [ACGIH 2013]. The TLV is intended to mitigate the risk of pulmonary fibrosis and lung cancer.

Methodology

Sampling Strategy

Short term task-based sampling was planned for this survey. The aim was to investigate workers’ exposures when conducting the tasks where higher exposures were likely to happen. Thus, during this survey, the task-based sampling was focused on handheld tools. On all three sampling days, multiple short term task-based air samples were taken from two workers who mainly used pneumatic/electric wet grinders (referred to below as Grinder 1 and 2) and four workers who mainly used pneumatic wet polishers (referred to below as Polisher 1 and 2). As noted earlier, the two Grinders also performed the lamination and the initial grinding jobs in this shop. Figure 1 shows the sampled workers performing those tasks.

Figure 1 – (a) A worker using a handheld electric wet grinder with a diamond grinding cup wheel in the grinding process; (b) A worker using a handheld pneumatic wet polisher in the

final polishing process; (c) A worker using a handheld electric wet grinder with a turbo blade for cutting thin stone strips in the lamination process.

Sampling Procedures

Personal breathing zone air samples for respirable particulate were collected at a flow rate of 4.2 liters per minute (L/min) using a battery-operated sampling pump (Gilian GilAir Plus, Sensidyne LP, Clearwater, FL) calibrated before and after each day's use with a DryCal Primary Flow Calibrator (Bios Defender 510, Mesa Laboratories, Inc., Lakewood, CO). A sampling pump was clipped to the sampled worker's belt worn at his waist. The pump was connected via Tygon® tubing and a tapered Leur-type fitting to a pre-weighed, 37-mm diameter, 5- µm pore-size polyvinyl chloride (PVC) filter supported by a backup pad in a three-piece filter cassette sealed with a cellulose shrink band (in accordance with NIOSH Methods 0600 and 7500) [NIOSH 1998, NIOSH 2003]. The front portion of the cassette was removed and the cassette was attached to a respirable dust cyclone (model GK2.69, BGI Inc., Waltham, MA). At a flow rate of 4.2 L/min, the GK2.69 cyclone has a 50% cut point of (D_{50}) of 4.0 µm [BGI 2011]. D_{50} is the aerodynamic diameter of the particle at which penetration into the cyclone declines to 50% [Vincent 2007]. The cyclone was clipped to the sampled workers' shirts near their breathing zone. In addition to the personal breathing zone air samples, at least two field blank samples were taken on each sampling day. Bulk dust samples were also collected in accordance with NIOSH Method 7500 [NIOSH 2003].

The filter samples were analyzed for respirable particulates according to NIOSH Method 0600 [NIOSH 1998]. The filters were allowed to equilibrate for a minimum of two hours before weighing. A static neutralizer was placed in front of the balance (model AT201, Mettler-Toledo, Columbus, OH) and each filter was passed over the neutralizer before weighing. The limit of detection (LOD) and the limit of quantitation (LOQ) of the respirable dust analysis are listed in Table 1.

Table 1 – The limit of detection (LOD) and the limit of quantitation (LOQ) for all the sample analysis.

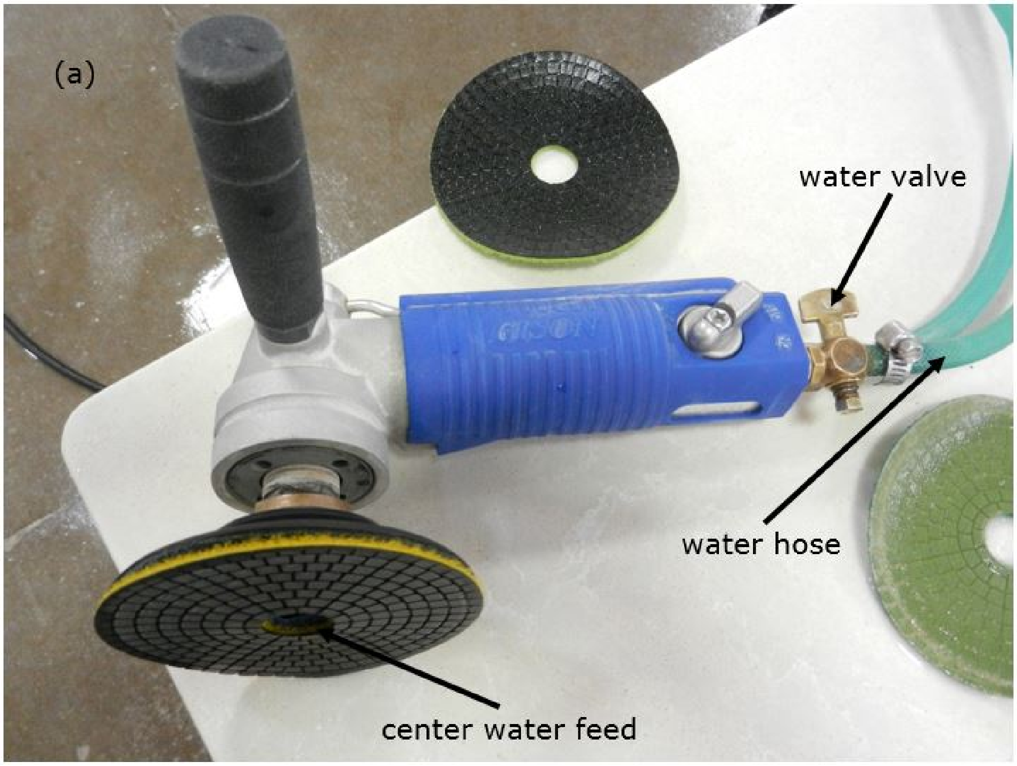
	Air Samples (µg/sample)				Bulk Samples (%)		
	respirable dust	quartz	cristobalite	tridymite	quartz	cristobalite	tridymite
LOD	20	5	5	10	0.3	0.3	0.5
LOQ	82	17	17	33	0.83	0.83	1.7

Crystalline silica analysis of filter and bulk samples was performed using X-ray diffraction according to NIOSH Method 7500 [NIOSH 2003]. The LODs and LOQs for quartz, cristobalite, and tridymite in both air samples and bulk samples are also listed in Table 1.

Based on the sampling flow rate of 4.2 L/min, it was estimated that sampling an aerosol containing an average quartz concentration at the level of the NIOSH REL (0.05 mg/m^3) for 24 minutes would collect a quartz mass above the LOD of 5 µg/sample. Thus, all the task-based samples in this survey were collected with a sampling time greater than 24 minutes. For each air sample, the corresponding worker's activity during the sampling period was recorded. During this survey, all the workers worked exclusively with engineered stone.

Control Technology

As described earlier, water suppled to the tools was used throughout the fabrication process as a control measure for silica dust. For the automated machines, the water delivery and the amount of water used was set in accordance to the manufacturers' specifications. All the polishers and some grinders used in this shop were equipped with a center water feed feature, as illustrated in Figure 2(a). During operation, water was continuously supplied through a water hose connected at the end of the tool's handle and released from the center of the grinding/polishing disc. A water valve was used to adjust the amount of water used so the workers may use different water flow rates for their tools per their own preferences. Therefore, the water flow rate in the tools was not monitored in this survey. The grinders used with turbo blades to cut thin stone strips, as illustrated in Figure 2(b), did not have a center water feed feature. Instead, water was released from a water hose that discharged at the edge of the turbo blade (also shown in Figure 1(c)).



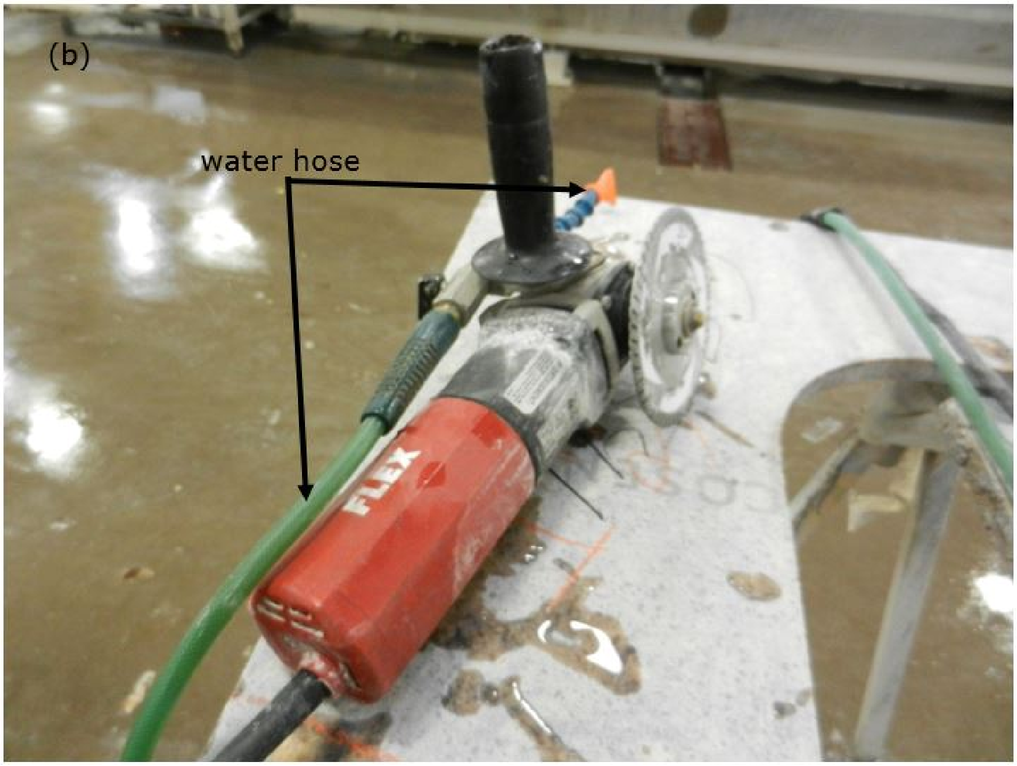


Figure 2 – (a) A handheld pneumatic wet polisher with a center water feed feature; (b) A handheld electric wet grinder without a center water feed feature.

In addition to using water to control dust, the shop was equipped with two air cleaners (Model F122, Airflow Systems Inc., Dallas, Texas) suspended from the shop's ceiling to provide local exhaust ventilation as shown in Figure 3. Each air cleaner had two 14-foot long E-Z Arm® High Flow Extractors that could be positioned near the source of the dust. In this shop, the extractors were primarily used by the Grinders working with different blades as shown in Figure 1 (a) and (c). The four arms were able to reach most of the Grinders' working area. The air cleaner had a manufacturer-rated capacity of 2,200 cubic feet per minute (CFM) and was equipped with high efficiency particulate air (HEPA) filters. The air cleaners were operated throughout the survey. Unfortunately, air flow measurement equipment was not available during the survey to monitor the actual flow rate and velocity provided by the air cleaners. It was noted that the Grinders always used the extractors for cutting thin stone strips, as shown in Figure 1(c). However, they did not always use them during the grinding process as shown in Figure 1(a), possibly because moving and adjusting the extractor arm during grinding could slow down the process.

Figure 3. Two air cleaners, each equipped with two E-Z Arm® High Flow Extractors.

Results

Silica Content in Air and Bulk Samples

Three bulk samples were collected from surfaces near the workbenches of the sampled workers. They contained 74%, 53%, and 57% quartz, respectively, resulting in a mean of 61.3% quartz and a standard deviation of 11.2%. In addition, the bulk samples also contained 1.5%, 3.4%, and 2.9% cristobalite, resulting in a mean of 2.6% cristobalite and a standard deviation of 1.0%. No tridymite was detected in the bulk or air samples. Thus, only the quartz and cristobalite results were used in the calculation of the crystalline silica content of the air samples.

Table 2 presents the respirable dust and respirable crystalline silica masses reported for every task-based air sample collected during this survey. There were 25 air samples collected from the four Polishers, and 14 air samples collected from the two Grinders. The respirable dust and respirable crystalline silica data in Table 2 were used to calculate crystalline silica content in these samples. The table in the Appendix provides the sampling data used to calculate the results provided in Tables 2–3.

All the air samples contained respirable dust and quartz in amounts that exceeded their respective LODs listed in Table 1. However, cristobalite was detected in only four air samples. Those four samples also had a higher quartz content than most of the other air samples. Cristobalite in the bulk dust samples represented only 4.1% of all the crystalline silica (i.e., the three bulk dust samples contained an average of 2.6% cristobalite and 61.3% quartz), and cristobalite represented 8.4±1.0% of the crystalline silica in the four air samples that contained cristobalite. Considering the amount of quartz in most of the air samples listed in Table 2, the amount of cristobalite in these samples would be expected to be below the LOD of cristobalite (5 µg/sample). The value of LOD/SQRT(2) is often suggested as a substitute with fairly modest bias for non-detectable samples results [Hewett and Ganser, 2007]. However, this approach may not be applicable to this survey. These air samples clearly have very different amounts of quartz. Using the value of LOD/SQRT(2) for cristobalite (3.54 µg/sample) would overestimate the cristobalite content in most of these samples considering the amount of quartz they contain. Since the percentage of cristobalite in crystalline silica of the four samples with detectable amounts of cristobalite is quite consistent (8.4±1.0%), this percentage was applied to the other air samples to derive the estimated cristobalite masses in those samples.

Table 2 – Respirable Silica Masses, Respirable Dust Masses, and Percent Silica.

Date	Worker	Sample period	Respirable dust (µg/sample)	Respirable quartz (µg/sample)	Respirable cristobalite (µg/sample)	Respirable crystalline silica content (%)
8/25/2015	Polisher 1	1	40.0	11.0	0.85*	29.6
8/25/2015	Polisher 1	2	40.0	14.0	1.09*	37.7
8/25/2015	Polisher 1	3	60.0	20.0	1.55*	35.9
8/25/2015	Polisher 1	4	50.0	20.0	1.55*	43.1
8/25/2015	Polisher 1	5	40.0	21.0	1.63*	56.8
8/25/2015	Polisher 2	1	80.0	29.0	2.25*	39.1
8/25/2015	Polisher 2	2	100.0	29.0	2.25*	31.3
8/25/2015	Polisher 2	3	50.0	17.0	1.32*	36.6
8/25/2015	Polisher 2	4	70.0	19.0	1.48*	29.3
8/25/2015	Polisher 2	5	30.0	14.0	1.09*	50.3
8/25/2015	Polisher 3	1	50.0	19.0	1.48*	41.0
8/25/2015	Polisher 3	2	120.0	30.0	2.33*	26.9
8/25/2015	Polisher 3	3	50.0	18.0	1.40*	38.8
8/25/2015	Grinder 1	1	240.0	140.0	14.0	64.2
8/25/2015	Grinder 2	1	50.0	35.0	2.72*	75.4
8/25/2015	Grinder 2	2	110.0	71.0	5.52*	69.6
8/25/2015	Grinder 2	3	50.0	43.0	3.34*	92.7
8/25/2015	Grinder 2	4	130.0	65.0	6.6	55.1
8/25/2015	Grinder 2	5	50.0	59.0	5.4	100.0**
8/26/2015	Polisher 1	1	20.0	5.5	0.43*	29.6
8/26/2015	Polisher 1	2	30.0	24.0	1.86*	86.2
8/26/2015	Polisher 1	3	50.0	16.0	1.24*	34.5
8/26/2015	Polisher 1	4	40.0	15.0	1.17*	40.4
8/26/2015	Polisher 2	1	20.0	19.0	1.48*	100.0**

Date	Worker	Sample period	Respirable dust (µg/sample)	Respirable quartz (µg/sample)	Respirable cristobalite (µg/sample)	Respirable crystalline silica content (%)
8/26/2015	Polisher 2	2	50.0	12.0	0.93*	25.9
8/26/2015	Polisher 2	3	40.0	18.0	1.40*	48.5
8/26/2015	Polisher 2	4	20.0	10.0	0.78*	53.9
8/26/2015	Polisher 4	1	50.0	7.8	0.61*	16.8
8/26/2015	Polisher 4	2	40.0	20.0	1.55*	53.9
8/26/2015	Polisher 4	3	40.0	15.0	1.17*	40.4
8/26/2015	Polisher 4	4	40.0	13.0	1.01*	35.0
8/26/2015	Grinder 1	1	110.0	54.0	4.20*	52.9
8/26/2015	Grinder 1	2	130.0	73.0	5.5	60.4
8/26/2015	Grinder 1	3	60.0	47.0	3.65*	84.4
8/26/2015	Grinder 1	4	70.0	32.0	2.49*	49.3
8/26/2015	Grinder 2	1	100.0	55.0	4.27*	59.3
8/26/2015	Grinder 2	2	80.0	40.0	3.11*	53.9
8/26/2015	Grinder 2	3	60.0	24.0	1.86*	43.1
8/26/2015	Grinder 2	4	70.0	43.0	3.34*	66.2

Notes: Data with a * indicates the sampled data was below the LOD and a value derived from the mass of quartz in the corresponding sample and the assumption that cristobalite represents 8.4% of crystalline silica in these air samples; ** indicates the data were outliers with higher than 100% silica content.

It should be noted that there were two air samples with respirable crystalline silica mass greater than their respirable dust masses. This is not uncommon when the amount of respirable dust is close to the dust LOD and the percentage of crystalline silica is high in the dust samples, due to the greater sensitivity of the silica analysis (i.e., a quartz LOD of 5 µg/sample versus a dust LOD of 20 µg/sample). However, they are still considered to be outliers for silica content analysis as it is not realistic to have more than 100.0% crystalline silica in the respirable dust in those air samples. Excluding those two outliers, the other 37 air samples contained from 16.8 to 92.7% crystalline silica, with a mean of 48.3% and a standard deviation of 17.8%. The air samples from the Polishers have a mean silica content of 40.1% with a standard deviation of 13.8%; and the samples from the Grinders have a mean silica content of 63.6% with a standard deviation of 14.1%. Two blank samples were collected each day and no respirable dust or crystalline silica were detected on any of the blank samples.

Respirable Dust and Respirable Crystalline Silica Results

Table 3 reports the short term task-based exposures to respirable dust and respirable crystalline silica. Overall, the short term respirable dust exposures ranged from 68.0 to 295.9 µg/m^3 for the Polishers, and from 200.4 to 908.9 µg/m^3 for the Grinders; the short term respirable crystalline silica exposures ranged from 21.4 to 122.9 µg/m^3 for the Polishers, and from 114.8 to 583.2 µg/m^3 for the Grinders. The mean short term respirable dust exposure was 176.7 and 368.8 µg/m^3 for Polishers and Grinders, respectively; and the mean short term respirable crystalline silica exposure was 70.0 and 245.3 µg/m^3 for Polishers and Grinders, respectively. It is apparent that the Grinders experienced considerably higher exposure than the Polishers.

These short term task-based sampling results should not be directly compared to the occupational exposure limits such as the OSHA PEL and the NIOSH REL as these limits are for full shift (8 hours or 10 hours) exposures. However, it may be worth reporting that most of the air samples, especially those from the Grinders, show exposure to respirable crystalline silica higher than the NIOSH REL of 0.05 mg/m^3, which suggests that additional engineering control measures may be needed for these workers.

Table 3 – Respirable Dust and Respirable Crystalline Silica Results.

Date	Worker	Sample period	Short term task-based exposure to respirable dust (µg/m^3)	Short term task- based exposure to respirable crystalline silica (µg/m^3)
8/25/2015	Polisher 1	1	153.3	45.4
8/25/2015	Polisher 1	2	154.7	58.3
8/25/2015	Polisher 1	3	205.1	73.7
8/25/2015	Polisher 1	4	197.9	85.3
8/25/2015	Polisher 1	5	170.8	96.6
8/25/2015	Polisher 2	1	238.0	93.0
8/25/2015	Polisher 2	2	239.9	75.0
8/25/2015	Polisher 2	3	225.2	82.5
8/25/2015	Polisher 2	4	245.0	71.7
8/25/2015	Polisher 2	5	145.6	73.2
8/25/2015	Polisher 3	1	183.0	74.9
8/25/2015	Polisher 3	2	295.9	79.1
8/25/2015	Polisher 3	3	255.9	99.3
8/25/2015	Grinder 1	1	908.9	583.2
8/25/2015	Grinder 2	1	387.8	292.6
8/25/2015	Grinder 2	2	427.9	297.6
8/25/2015	Grinder 2	3	200.4	185.7
8/25/2015	Grinder 2	4	341.6	188.1
8/25/2015	Grinder 2	5	269.6	347.2
8/26/2015	Polisher 1	1	72.3	21.4
8/26/2015	Polisher 1	2	142.5	122.9
8/26/2015	Polisher 1	3	200.8	69.2
8/26/2015	Polisher 1	4	205.4	83.0
8/26/2015	Polisher 2	1	68.0	69.6
8/26/2015	Polisher 2	2	180.2	46.6
8/26/2015	Polisher 2	3	130.2	63.1
8/26/2015	Polisher 2	4	75.8	40.9
8/26/2015	Polisher 4	1	172.8	29.0
8/26/2015	Polisher 4	2	157.0	84.6
8/26/2015	Polisher 4	3	143.5	58.0

Date	Worker	Sample period	Short term task-based exposure to respirable dust (µg/m³)	Short term task- based exposure to respirable crystalline silica (µg/m³)
8/26/2015	Polisher 4	4	148.7	52.0
8/26/2015	Grinder 1	1	401.4	212.3
8/26/2015	Grinder 1	2	493.9	298.2
8/26/2015	Grinder 1	3	277.3	234.1
8/26/2015	Grinder 1	4	233.0	114.8
8/26/2015	Grinder 2	1	405.8	240.5
8/26/2015	Grinder 2	2	305.3	164.5
8/26/2015	Grinder 2	3	269.9	116.3
8/26/2015	Grinder 2	4	240.6	159.3

Data analyses

Statistical analyses were performed using SAS v12.1 (SAS Institute Inc., Cary, NC). An ANOVA F-test was conducted for the crystalline silica content as well as the short term respirable crystalline silica exposure considering the job types, i.e., Polisher and Grinder. For the analyses of the crystalline silica content, the two outlier samples were also excluded. Therefore, there were 39 samples for the analyses of the short term exposure to respirable crystalline silica, and 37 samples for the analyses of the crystalline silica content. Worker exposures to air contaminants are typically log-normally distributed. Therefore, the geometric mean and geometric standard deviation were used in the data analyses.

The details of the statistical results are listed in Table 4. The short term task-based exposure to respirable crystalline silica for the Grinders was significantly higher than that of the Polishers ($P<0.0001$). The grinders were operated at a higher speed than the polishers (~7,000-8,300 RPM VS ~4,500 RPM), and the force between the stone and the diamond grinding cup wheels used in the grinders was certainly more aggressive than that between stone and the resin-bonded discs used in the polishers. Thus, a larger amount of stone materials, including respirable dusts, was expected to be aerosolized from using the grinders, leading to higher exposure among the Grinders. In addition, some grinders used in this survey did not have a center water feed feature, while all the polishers did. Releasing water from the center of the disc may help apply water more uniformly and suppress more dust during polishing. The release of water from a water hose at the edge of the turbo blade may result in some dry parts of the blade.

The silica content in the samples from the Grinders was also significantly higher than that in the samples of the Polishers ($P<0.0001$). Phillips et al. [2013] collected 61 partial-shift air samples from workers in four stone countertop fabrication shops. They found crystalline silica content ranges of 8-27% during fabrication with granite and 14-67% during fabrication of engineered stone, which were largely in agreement with the results of this survey. They did not analyze how job types affect the silica content in the air samples. The reason for higher silica content found in the samples of Grinders in this survey is unknown. Turbo blades and diamond grinding cup wheels used in the grinders are likely to generate larger dust particles than the resin-bonded polishing discs do during final polishing. Although all the samples were respirable fractions of the exposed dusts, the mass median aerodynamic diameters (MMAD) of the dusts from the Grinders' samples were likely to be larger than those from the Polishers' samples. A study by Chen et al. [2014] found that the XRD analyses of crystalline silica was sensitive to particle size, with the XRD intensity increasing with the MMAD of the dust. Elton et al. [1992] found that there is an amorphous layer approximately 0.03 µm thick surrounding crystalline silica particles. Thus, for smaller particles, the mass of crystalline silica is less than that of larger particles. These results help explain the higher silica content found in the air samples from the Grinders. Another possible explanation is that the smaller dust from stone countertop fabrication indeed contains lower amounts of crystalline silica. Additional research would be needed to verify that hypothesis.

Table 4 –Summary Statistics of Data Analyses

Variable	Factor		Number of Samples	Geometric Mean	Geometric Standard Deviation	Maximum	Minimum
Short term task-based exposure to respirable crystalline silica (µg/m^3)	Job Type	Grinder	25	223.3	1.55	583.2	114.8
		Polisher	14	65.7	1.48	122.9	21.4
Crystalline silica content (%)	Job Type	Grinder	24	62.2	1.24	92.7	43.1
		Polisher	13	38.1	1.38	86.2	16.8

Conclusions and Recommendations

Controlling exposures to occupational hazards is the fundamental method of protecting workers. Traditionally, a hierarchy of controls has been used as a means of determining how to implement feasible and effective controls. One representation of the hierarchy of controls can be summarized as follows:

- Elimination
- Substitution
- Engineering Controls (e.g. ventilation)
- Administrative Controls (e.g. reduced work schedules)
- Personal Protective Equipment (PPE, e.g. respirators)

The idea behind this hierarchy is that the control methods at the top of the list are potentially more effective, protective, and economical (in the long run) than those at the bottom. Following the hierarchy normally leads to the implementation of inherently safer systems, ones where the risk of illness or injury has been substantially reduced.

The results from the short term task-based samples in this survey reveal that wet grinding and wet polishing engineered quartz stone may still lead to overexposure to respirable crystalline silica. The exposure levels associated with the Grinder job title, where local exhaust ventilation was used with water to control dust, were especially concerning. Using a larger amount of water through a center water feed for the grinders may be a priority consideration for a future test of engineering controls. Additional and more effective engineering control measures are needed to consistently reduce the exposure consistently below the NIOSH REL. In the absence of sufficient dust controls, respirators should continue to be used to reduce exposures.

A review of the respiratory protection program was beyond the scope of this survey. NIOSH recommends (and it is mandated by OSHA where the use of respirators is required) that respirators in the workplace be used as part of a comprehensive respiratory protection program following the OSHA standard (29 CFR 1910.134 2003b). If half-facepiece particulate respirators with N95 or better filters are worn properly and used in accordance with good practices, they may be used to reduce respirable crystalline silica exposures to acceptable levels when exposures do not exceed 10 times the NIOSH REL [NIOSH 2008]. The measured short term exposure results in this survey suggested that the 10-hour TWA exposure for these workers would not exceed 10 times the NIOSH REL for respirable crystalline silica. All the workers involved in the production process of this site wore elastomeric, half-face air-purifying respirators with either P100 cartridges or combination P100 and organic vapor cartridges. Therefore, NIOSH recommends that these respirators should continue to be used before sufficient dust control is implemented, and the employer needs to make sure that the respiratory protection program follows the OSHA standard.

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Appendix

Table A1 - Respirable Dust and Silica Sampling Results

Date	Worker	Sample period	Duration (min)	Volume (L)	Respirable dust (µg/sample)	Respirable quartz (µg/sample)	Respirable cristobalite (µg/sample)
8/25/2015	Polisher 1	1	62	260.9	40.0	11.0	0.85*
8/25/2015	Polisher 1	2	62	258.6	40.0	14.0	1.09*
8/25/2015	Polisher 1	3	70	292.6	60.0	20.0	1.55*
8/25/2015	Polisher 1	4	60	252.7	50.0	20.0	1.55*
8/25/2015	Polisher 1	5	56	234.2	40.0	21.0	1.63*
8/25/2015	Polisher 2	1	81	336.1	80.0	29.0	2.25*
8/25/2015	Polisher 2	2	100	416.8	100.0	29.0	2.25*
8/25/2015	Polisher 2	3	53	222.0	50.0	17.0	1.32*
8/25/2015	Polisher 2	4	69	285.7	70.0	19.0	1.48*
8/25/2015	Polisher 2	5	50	206.0	30.0	14.0	1.09*
8/25/2015	Polisher 3	1	65	273.3	50.0	19.0	1.48*
8/25/2015	Polisher 3	2	97	405.6	120.0	30.0	2.33*
8/25/2015	Polisher 3	3	47	195.4	50.0	18.0	1.40*
8/25/2015	Grinder 1	1	63	264.1	240.0	140.0	14.0
8/25/2015	Grinder 2	1	31	128.9	50.0	35.0	2.72*
8/25/2015	Grinder 2	2	62	257.1	110.0	71.0	5.52*
8/25/2015	Grinder 2	3	60	249.5	50.0	43.0	3.34*
8/25/2015	Grinder 2	4	91	380.6	130.0	65.0	6.6
8/25/2015	Grinder 2	5	45	185.5	50.0	59.0	5.4
8/26/2015	Polisher 1	1	66	276.5	20.0	5.5	0.43*
8/26/2015	Polisher 1	2	50	210.5	30.0	24.0	1.86*
8/26/2015	Polisher 1	3	59	249.0	50.0	16.0	1.24*
8/26/2015	Polisher 1	4	46	194.8	40.0	15.0	1.17*
8/26/2015	Polisher 2	1	70	294.1	20.0	19.0	1.48*
8/26/2015	Polisher 2	2	66	277.5	50.0	12.0	0.93*
8/26/2015	Polisher 2	3	73	307.3	40.0	18.0	1.40*
8/26/2015	Polisher 2	4	63	263.8	20.0	10.0	0.78*
8/26/2015	Polisher 4	1	69	289.4	50.0	7.8	0.61*
8/26/2015	Polisher 4	2	61	254.8	40.0	20.0	1.55*
8/26/2015	Polisher 4	3	66	278.7	40.0	15.0	1.17*
8/26/2015	Polisher 4	4	64	269.0	40.0	13.0	1.01*
8/26/2015	Grinder 1	1	65	274.1	110.0	54.0	4.20*
8/26/2015	Grinder 1	2	63	263.2	130.0	73.0	5.5
8/26/2015	Grinder 1	3	52	216.4	60.0	47.0	3.65*
8/26/2015	Grinder 1	4	72	300.5	70.0	32.0	2.49*
8/26/2015	Grinder 2	1	59	246.4	100.0	55.0	4.27*
8/26/2015	Grinder 2	2	63	262.1	80.0	40.0	3.11*
8/26/2015	Grinder 2	3	53	222.3	60.0	24.0	1.86*
8/26/2015	Grinder 2	4	70	290.9	70.0	43.0	3.34*

Notes: data with a * indicates the sampled data was below the LOD and a value of LOD/SQRT(2) was used in the calculation

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