In-Depth Survey Report

Field Evaluation of a Mobile Dust Control Booth for Stone Countertop Grinding

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Stone Systems of Houston
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Site Surveyed:

3700 S. Sam Houston Pkwy W.
Houston, TX 77053

NAICS Code:

327991 Cut Stone and Stone Product Manufacturing

Survey Dates:

June 28-30, 2016

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Abstract

Background

Workplace exposure to respirable crystalline silica (RCS) 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 RCS. 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 RCS exposures. NIOSH scientists are conducting a study to develop engineering control recommendations for RCS in the stone countertop fabrication and installation tasks. This site visit is part of that study.

Assessment

NIOSH scientists visited the company Stone Systems of Houston, TX on June 28-30, 2016. During the site visit, NIOSH scientists evaluated the effectiveness of a mobile dust control booth installed at the site. During the survey, researchers collected breathing zone air samples to assess the short-term respirable dust and RCS exposures of a worker who performed wet grinding inside the mobile dust control booth both with and without the booth's filtration unit running. Additionally, a handheld pneumatic wet grinder was used that featured a center-water-feed for suppressing dust at its source. NIOSH scientists recorded detailed survey notes about the work process to understand conditions leading to measured dust and RCS exposures.

Results

Respirable dust concentration monitored from an aerosol photometer was significantly higher when the exhaust air from the pneumatic grinder was in the opposite direction of the airflow in the booth ($P<0.01$). This result suggests that the orientation of the grinder's exhaust deflector can affect the exposure level when it is used in a dust control booth. Thus, subsequent tests were conducted with the deflector set to allow the exhaust air to flow along the same direction as the general booth airflow. Additionally, when the booth's filtration unit was running at an average airflow velocity of 133.6 ± 8.1 fpm, the worker's exposure was significantly reduced compared to values when the filtration unit wasn't running. The reduction of exposure on respirable dust from the aerosol photometer (75.9%) and air samples (73.5%) as well as that on RCS are in reasonable agreement (78.7%).

Conclusions and Recommendations

When grinding stone countertops in a dust control booth, it is a best practice to adjust the grinder's exhaust deflector to allow the exhaust air to flow in the same direction as the airflow in the booth. The aggregated results of the short-term task-

based time weighted average exposure to RCS from previous field surveys have a mean of 237.5 and 69.3 $\mu g/m^3$ for grinders and polishers, respectively, when working exclusively with engineered quartz stone. Therefore, it is likely that the dust control booth running at the evaluated airflow velocity would reduce RCS exposure below the NIOSH Recommended Exposure Limit (REL) of 0.05 mg/m^3 for polishers, but not for grinders. Additional engineering control measures are thus needed for the grinding process to consistently reduce exposures below the NIOSH REL. In the absence of sufficient dust controls, respirators should continue to be used to reduce exposures, and the employer needs to ensure that their respiratory protection program follows OSHA standards.

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 Field Studies and Engineering 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 (RCS) 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 RCS 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 RCS 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]. In 2015, 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 engineering control measures for processes involved in stone countertop fabrication and installation is needed to give stakeholders best-practice recommendations for consistently reducing RCS 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 RCS (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 the OSHA's Integrated Management Information System (IMIS) reveals that citations issued for exceeding the PEL for RCS 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 RCS [81 Fed. Reg. 16285, 2016], making it critical to address these overexposures.

This project aims at reducing 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, and a NIOSH Internet topic page. The long-term objective of this study is to provide practical recommendations for effective dust controls that will prevent overexposures to RCS during stone countertop fabrication and installation.

Background for this Survey

Previous studies suggest that among stone countertop fabrication and installation tasks, the task of grinding stone countertops led to the highest exposure to RCS. This is true even when applying water as a dust-control measure [Zwack et al., 2016; Qi and Echt, 2016; Qi and Lo, 2016]. Therefore, additional and more effective engineering control measures are needed for this task to further reduce exposures. In this survey, NIOSH researchers evaluated the effectiveness of a mobile dust control booth installed at Stone Systems of Houston in Houston, TX. This survey was performed on June 28-30, 2016 and consisted of collecting breathing zone air samples to assess the short-term respirable dust and RCS exposures of a worker who performed wet grinding inside a dust control both with and without the booth's filtration unit running.

Survey Site and Process Description

Introduction

Stone Systems of Houston is a stone countertop fabrication shop. Its products include granite, engineered quartz, and occasionally, marble countertops. The shop building consists of a fabrication area and an attached office area. The fabrication area is on the ground floor, while the office area is split between the first and second stories. 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. Large stone countertop slabs are transported into the shop at one end of the building and the completed products are transported out of shop at the other end.

Control Technology

The handheld pneumatic wet grinder (GPW-216, Gison Machinery Co., Ltd., Taiwan) used in this survey runs a maximum speed of 7,000 revolutions per minute (RPM) at 90 pounds per square inch (PSI). It was equipped with a center-water-feed feature (illustrated in Figure 1) as a dust control measure. During operation, water was continuously supplied through a water hose connected at the end of the grinder handle, running through a metal water-delivery tube at the top of the grinder, and released from the center of the gear shaft where a coarse diamond grinding cup wheel (Cyclone 15008, DIAMAX, INC, Atlanta, GA) was mounted.

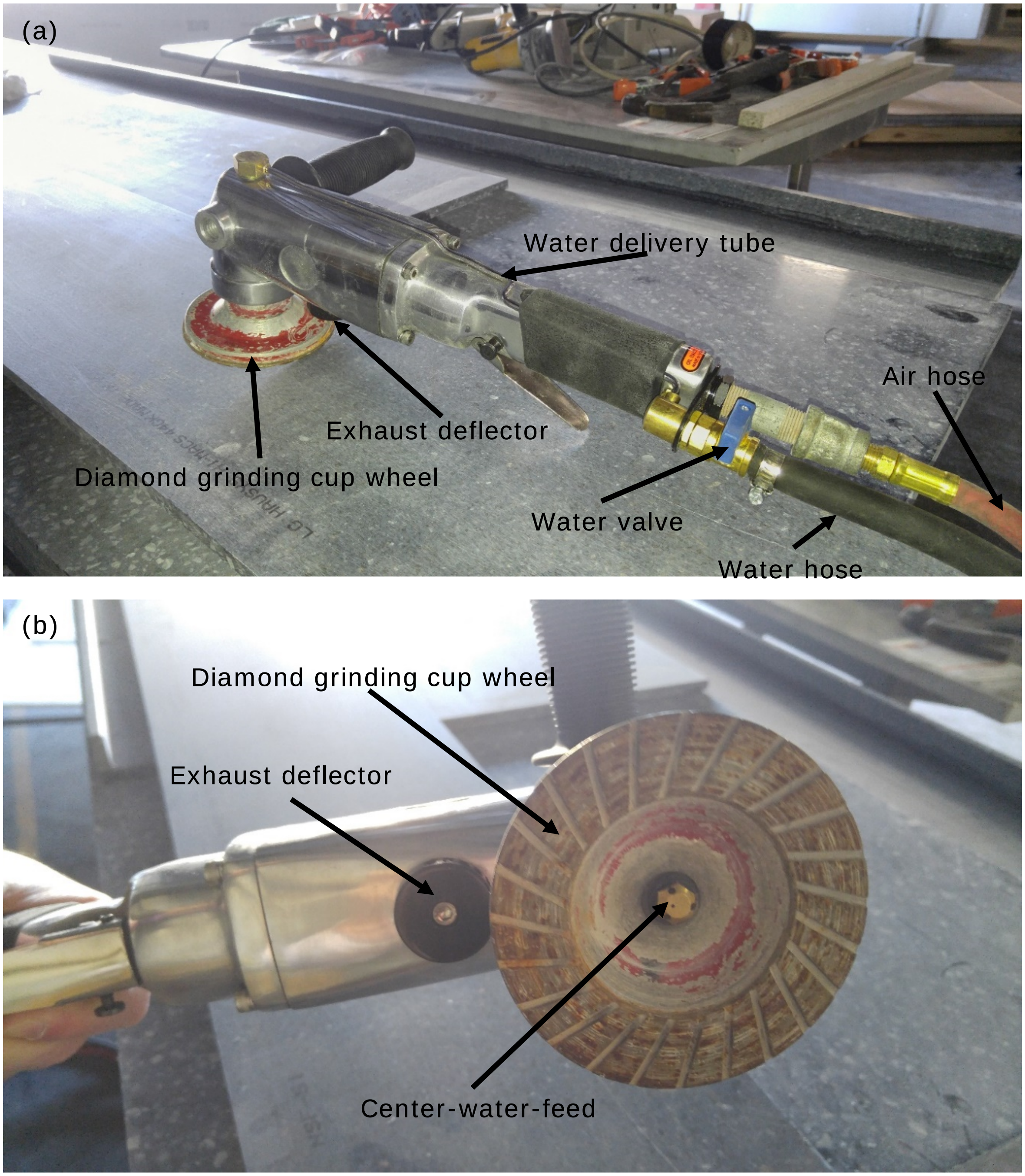

Figure 1 – (a) The handheld pneumatic wet grinder used in this survey; (b) holes for the center-water-feed feature of the grinder. Photo by NIOSH.

The mobile dust control booth (Duroair, Duroair Technologies, St. Catharines, Canada) was setup at a corner near the shop's entrance. Therefore, the area was isolated from other dust-generating processes. The enclosure of the booth is retractable with a fully extended dimension of 9.5 feet (') high (H), 14.0' wide (W), and 14.5' long (L). When not in use, it can be retracted to a much smaller footprint of 9.5’ H, 19’ W and 3’ L. Its DuroCap filtration unit is specified to have a flow capacity of 13,500 cubic foot per minute (CFM), and 3-stage dust filtration. The first stage of filtration was specifically added for this application in order to accommodate wet processing. This first stage consists of a washable metal panel screen for trapping moisture and wet dust in the air, thus extending the lives of the stage-2 panel filter and stage-3 pocket filter. The flow rate of the DuroCap filtration unit can be adjusted by a variable frequency drive.

Figure 2 – Duroair dust control booth (a) fully extended; (b) retracted. Photo by NIOSH

During the survey, a workbench was set up in the center of the fully extended booth as shown in Figure 3. The worker participating in this survey performed the task of grinding engineered quartz stones on the two sides of the workbench along the airflow direction. The worker wore an elastomeric, half-face, air-purifying respirator with P100 cartridges. Other personal protective equipment worn included hearing protection, eye protection, rubber safety shoes, and an apron.

Figure 3 – A worker using a handheld pneumatic wet grinder with a diamond grinding cup wheel inside the dust control booth. Photo by NIOSH

Occupational Exposure Limits and Health Effects

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH investigators use mandatory and recommended Occupational Exposure Limits (OELs) when evaluating 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 2003] 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).

Respirable Crystalline Silica Exposure Limits

When dust controls are not used or maintained or proper practices are not followed, RCS exposures can exceed the NIOSH REL, the OSHA PEL, or the ACGIH TLV. NIOSH recommends an exposure limit for RCS 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].

$$\mu g S_i O_2/m^3 = \frac{\mu gQ + \mu gC + \mu gT + \mu gP}{V} \qquad (1)$$

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 RCS 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

The aim of this survey was to investigate the effectiveness of the dust control booth for wet grinding. Thus, during this survey multiple short-term air samples were taken near the worker performing wet grinding inside the dust control booth both with and without the DuroCap filtration unit running. Most of the time, the worker grinded continuously for only 1-2 minutes and spent the remainder of his time moving stone slabs and taking measurements on stone dimensions. Sampling was paused when the worker was not grinding so that the samples were taken only when grinding was performed. This sampling strategy allows evaluation of control effectiveness of the booth alone. However, it also means that these short-term, task-based sampling results should not be directly compared to occupational exposure limits such as the OSHA PEL or the NIOSH REL, which are for full-shift (8 hours or 10 hours) exposures.

Sampling Procedures

Personal breathing zone (PBZ) air samples for respirable particulate were collected at a flow rate of 9.0 liters per minute (L/min) using a battery-operated sampling pump (Leland Legacy sampling pump, SKC, Inc., Eighty-Four, PA) calibrated before and after each day's use using 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 to a pre-weighed, 47-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 cover of the cassette was removed and the cassette was attached to a respirable dust cyclone (BGI GK 4.162 cyclone, MesaLabs, Butler, NJ). At a flow rate of 9.0 L/min, the GK 4.162 cyclone has a 50% cut point of (D_{50}) of 3.91 µm, and conforms to the respirable sampling convention at flow rates between 8.5 and 9.5 liters per minute [HSL 2012]. 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 worker's shirts near his breathing zone. In addition to the personal breathing zone air samples, at least two field blank samples were taken on each sampling day. Two 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	30	4	5	10	0.3	0.3	0.5
LOQ	98	13	16	33	0.93	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 9.0 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 9 minutes would collect a quartz mass above the LOD of 4 µg/sample. Thus, each filter sample in this survey was collected with a cumulative sampling time greater than 9 minutes from multiple instances of grinding (each performance normally lasted about 1-2 minutes and the sampling pump was paused when one instance was completed). During this survey, the worker worked exclusively with engineered quartz stone.

Concurrent with the filter samples, real-time PBZ respirable dust samples were also taken using an aerosol photometer (SidePak AM510 aerosol monitor, TSI Inc., Shoreview, MN) with a 10-mm nylon respirable dust cyclone. The instrument's internal sampling pump was calibrated before and after each day's use to operate at a flow rate of 1.7 L/min. The SidePak was clipped to the worker's belt and the cyclone was clipped to his collar in the worker's breathing zone. A length of Tygon tubing connected the cyclone and the instrument. The SidePak was set to have a calibration factor of 1.0 and to log data every second during the sampling period. The average, minimum and maximum respirable dust concentrations of each sample were logged by the instrument in real-time.

During the first day of the survey, it was observed that the amount of air released from the grinder's exhaust deflector (shown in Figure 1) was could be felt by researchers and could therefore affect the dispersion of the dust plume generated from grinding. The manufacturer specifies the air consumption of the grinder of 26 CFM (0.74 m^3/min). The orientation of the exhaust deflector on the grinder can be adjusted so that the exhaust air is directed to different directions. Two cases were tested in this survey with the exhaust air from the grinder in the same and opposite direction of the airflow driven by the filtration unit of in the booth. The hypothesis is that when they are in the same direction, the exhaust air from the grinder may help move the dust away from the worker more quickly, reducing the exposure level; and when they are in the opposite direction, the exhaust air may result in the dust staying the worker's breathing zone longer, increasing the exposure level. For these tests, only the SidePak was used so that the results can be available in real-time.

Flow Measurement

A flow velocity matrix (Alnor® Electronic Balancing Tool 731, TSI Inc., Shoreview, MN) was used to measure the air flow velocity across an area of about 1 square foot. The measurement was taken on the workbench near the booth's entrance side and it logged data every second. The average flow velocity for 60 seconds of continuous measurement was recorded.

Results

The Effect of the Exhaust Deflector

As described earlier, the effect of the exhaust deflector of the grinder was evaluated by using the SidePak only. The real-time direct reading respirable dust results with the exhaust air in the same or opposite direction of the airflow in the booth are listed in Table 2. Six measurements were taken for each case. The average airflow velocity in the booth measured by the velocity matrix was 121 feet per minute (fpm) during these tests.

Respirable dust concentration was significantly higher when the exhaust air from the grinder is in the opposite direction of the airflow in the booth ($P<0.01$). This result verifies the hypothesis that the orientation of the exhaust deflector on the grinder can affect the exposure level when it is used in a dust control booth. Thus, it is desired to adjust the exhaust deflector to allow the exhaust air to flow along the same direction as the airflow in the dust control booth. Subsequent tests were conducted with this desirable setting.

Table 2 – Real-Time Direct-Reading Respirable Dust Results (mg/m^3)

Flow Direction	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Average
Same	0.057	0.066	0.059	0.065	0.111	0.158	0.086
Opposite	0.511	0.293	0.374	0.389	0.413	0.359	0.390

The Effectiveness of the Dust Control Booth

Table 3 reports the short-term exposures to respirable dust and RCS for the worker with and without the filtration unit running. The respirable dust exposures from the concurrent SidePak sampling are also listed in the table.

When the filtration unit was running, the airflow velocity was 133.6 ± 8.1 (average ± standard deviation) feet per minute (fpm). Overall, the short-term respirable dust exposures ranged from 0.456 to 3.248 mg/m^3 with a mean of 1.568 mg/m^3 when the filtration unit was not running, and from 0.172 to 0.852 mg/m^3 with a mean of 0.416 mg/m^3 when the filtration unit was running. The mean short-term respirable dust exposure reduced 73.5% with the running filtration unit. The short-term RCS exposures ranged from 0.173 to 2.016 mg/m^3 with a mean of 0.788 mg/m^3 when the filtration was not running, and from 0.024 to 0.371 mg/m^3 with a mean of 0.168 mg/m^3 when the filtration unit was running. The mean short-term RCS exposure reduced 78.7% with the running filtration unit. The SidePak data also demonstrated a 75.9% reduction of exposure to respirable dust when the filtration was running.

Table 3 – Respirable Dust and RCS Results.

Date	Sample Period	Air Flow Velocity (fpm)	Volume (L)	Duration (min)	Short-term Exposure to Respirable Dust (mg/m^3)	Real-Time Direct-Reading Respirable Dust Exposure (mg/m^3)	Short-term RCS Exposure (mg/m^3)	Silica content (%)
6/28/2016	1	0	247.8	27.4	3.148	n/a	1.534	48.7
6/28/2016	2	0	185.0	20.4	1.892	0.450	0.919	48.6
6/28/2016	3	121	245.6	27.1	0.570	0.078	0.305	53.6
6/28/2016	4	0	89.3	9.9	3.248	1.093	2.016	62.1
6/28/2016	5	138	234.8	25.9	0.852	0.173	0.371	43.5
6/29/2016	1	0	185.4	20.5	1.348	0.518	0.593	44.0
6/29/2016	2	140	268.4	29.7	0.447	0.088	0.156	35.0
6/29/2016	3	0	174.7	19.3	0.916	0.329	0.435	47.5

Date	Sample Period	Air Flow Velocity (fpm)	Volume (L)	Duration (min)	Short-term Exposure to Respirable Dust (mg/m^3)	Real-Time Direct-Reading Respirable Dust Exposure (mg/m^3)	Short-term RCS Exposure (mg/m^3)	Silica content (%)
6/29/2016	4	123	266.8	29.5	0.172	0.088	0.131	76.1
6/29/2016	5	0	194.5	21.5	0.977	0.489	0.463	47.4
6/29/2016	6	137	269.8	29.8	0.356	0.152	0.126	35.4
6/30/2016	1	0	144.7	16.0	0.456	0.432	0.173	37.9
6/30/2016	2	140	240.4	26.5	0.191	0.127	0.024*	12.6
6/30/2016	3	0	154.1	17.0	0.558	0.254	0.175	31.4
6/30/2016	4	136	174.0	19.2	0.322	0.152	0.063	19.6

Notes: n/a means not available; data with a * indicates the sampled data was below the LOQ but above the LOD.

Two blank samples were collected each day. No respirable dust or crystalline silica were detected on any of the blank samples. Two bulk samples were collected from surfaces near the workbench, and they both contained 44% quartz. No cristobalite or tridymite were detected in the bulk or air samples. Thus, only the quartz results were used in the calculation of the crystalline silica content of the air samples. The respirable dust and RCS data in Table 3 were used to calculate crystalline silica content in these samples, and it averaged 39.4% and 45.9% with and without the dust control running, respectively.

Data analyses

Table 4 lists a summary of the statistics of data analyses for the exposure data. The analysis results suggest that the grinder's exposure was significantly reduced when the filtration unit of the control booth was running (*P* =0.02 for respirable dust exposure from filter samples; *P* =0.01 for respirable dust exposure from SidePak; and *P* =0.03 for RCS exposure). The silica content is not statistically different between the two test conditions (*P*=0.47).

Table 4 – Summary Statistics of Data Analyses

Variable	Airflow velocity near the operation zone (fpm)	Respirable Dust Exposure (µg/m^3)		RCS Exposure (µg/m^3)	Quartz Content (%)
		SidePak	Filter Sample		
Filtration Unit off	0	509.1 ± 273.3	1567.9 ± 1102.0	788.4 ± 665.8	45.9 ± 8.9
Filtration Unit on	133.6 ± 8.1	122.6 ± 38.0	415.8 ± 237.0	168.1 ± 125.7	39.4 ± 21.2

Although the control booth demonstrated significant reduction of RCS exposure (78.7%) at the evaluated airflow velocity, it is uncertain whether it would reduce the RCS exposure below the NIOSH REL. Table 5 lists the aggregated results of the short-term task-based TWA exposure to RCS for grinders and polishers from three previous field surveys [Zwack et al., 2016; Qi and Echt, 2016; Qi and Lo, 2016]. Assuming the 78.7% RCS exposure reduction from the control booth is fully translated, the polishers would have the RCS exposure reduced to 14.8 ± 6.2 µg/m^3 and 7.9 ± 5.0 µg/m^3 when working with quartz stone only and mixed types of stones, respective. They are both below the NIOSH REL of 50 µg/m^3. However, the grinders would have the RCS exposure reduced to 58.3 ± 25.9 µg/m^3 and 31.6 ± 20.8 µg/m^3 when working with quartz stone only and mixed types of stones, respective. Therefore, it is still questionable whether the dust control booth running at the evaluated airflow velocity would reduce the grinders' RCS exposure consistently below the NIOSH REL.

Table 5 – Short-term task-based TWA exposure to RCS from Previous Surveys (µg/m^3)

Factor		Number of Samples	Mean	Standard Deviation	Maximum	Minimum
Stone Type: Quartz	Grinder	13	237.5	121.4	583.2	114.8
	Polisher	35	69.3	29.3	142.6	21.4
Stone Type: Mixed	Grinder	23	148.2	97.5	450.8	50.4
	Polisher	23	37.1	23.5	99.3	7.1

Note: "Mixed" stone type means the worker worked with both engineered quartz and granite during the sampling.

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 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 respirable dust concentration was significantly higher when the exhaust air from the pneumatic grinder is in the opposite direction of the air flow in the booth ($P<0.01$). Therefore, it is desirable to adjust the exhaust deflector to allow the exhaust air to flow along the same direction as the airflow in the dust control booth. At the average airflow velocity of the filtration unit (133.6 ± 8.1 fpm), the grinder's exposure was significantly reduced ($P = 0.02$ for respirable dust exposure from filter samples; $P = 0.01$ for respirable dust exposure from SidePak; and $P = 0.03$ for RCS exposure). The reduction of exposure for respirable dust according to SidePak data (75.9% reduction) and air sample data (73.5% reduction) as well as that on RCS are in reasonable agreement (78.7% reduction). Compared to the aggregated results of the short-term task-based TWA exposure to RCS for grinders and polishers from previous field surveys, it is likely that if the dust control booth were running at the evaluated airflow velocity, the RCS exposure would fall below the NIOSH REL for polishers, but not for grinders. Additional engineering control measures are thus needed for grinders to reduce the exposure of RCS consistently below the NIOSH REL.

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]. Note that the short-term sampling results in this study were obtained only when the grinding task was conducted. Therefore, these sampling results should not be directly compared with the NIOSH REL, which is for full-shift (10-hour) exposures. Previous field surveys under similar conditions 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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