Comprehensive Report

Engineering Control of Silica Dust from Stone Countertop Fabrication and Installation – Evaluation of Wetting Methods for Grinding

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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 during stone countertop fabrication and installation tasks. The site visits described in this report are part of that study.

Assessment

NIOSH scientists conducted three site visits to evaluate the effectiveness of three wetting methods in reducing occupational exposure to RCS for the grinding task at a stone countertop fabrication shop. The evaluated wetting methods included a water spray from a nozzle on a grinder, a center-feed feature that is built into a grinder, and a combination of water spray and a sheet-wetting method.

During the field evaluation, the NIOSH scientist collected personal breathing zone (PBZ) air samples to assess the short-term task-based time weighted average (TWA) exposures to respirable dust and RCS for a worker who performed the grinding task using one of the three wetting methods in the final grinding and polishing area of the site. Additionally, two area samples were collected each day during the first site visit to assess the TWA background respirable dust and RCS concentrations in this area. The NIOSH scientists recorded detailed field notes about the work process to understand conditions leading to measured dust and RCS exposures. PBZ samples from the first site visit were taken only during active grinding to allow for direct comparison of the two wetting methods (water spray and center-feed) on worker exposure. The following two site visits focused on the evaluation of the wetting method of combining water spray and sheet-wetting, with the PBZ samples taken continuously while working in the final grinding and polishing area.

Results

The short-term task-based respirable dust and RCS exposures were 354.3 ± 60.7 and 190.4 ± 105.4 μg/m^3 when using water spray, and they were 354.9 ± 149.6 and 195.3 ± 168.4 μg/m^3 when using center-feed. Area samples from the two sampling locations have RCS concentrations of 50.1 ± 29.0 and 44.5 ± 12.6 μg/m^3, respectively. The respirable dust in the area samples have concentrations of 161.2 ± 82.5 and 182.3 ± 28.5 μg/m^3 at the two locations.

When using the wetting method of combining water spray and sheet-wetting, the short-term task-based exposure was 33.2 ± 11.4 µg/m^3 and 123.4 ± 27.5 µg/m^3 for RCS and respirable dust, respectively. Due to the difference on the sampling strategies used, the exposure data with the wetting method of combining water spray and sheet-wetting is not directly comparable to those with the other two wetting methods evaluated in this study. However, compared to the exposure data from a previous study when only water spray was used as the wetting method for grinding, the exposures to respirable dust (P = 0.026) and RCS (P = 0.002) are both significantly reduced with the addition of sheet-wetting. The average RCS exposure with the addition of sheet-wetting was only 27.5% of the level reported when only water spray was used.

Conclusions and Recommendations

Although the short-term PBZ exposures or concentrations from area samples for RCS are not to be directly compared with the Permissible Exposure Limit (PEL) by Occupational Safety and Health Administration (OSHA) and NIOSH Recommended Exposure Limit (REL) of 50 µg/m^3, the background RCS concentrations observed in the final grinding and polishing area of the site suggest that workers in this area are likely to be overexposed to RCS without additional control measures. Both wetting methods of water spray and center-feed performed equally poor in terms of wetting the grinding spot and reducing the worker's RCS exposure during grinding, despite having very different water flowrates.

The significantly reduced respirable dust and RCS exposures by adding the sheet-wetting is evidence that this wetting method helps wet the active grinding area effectively, thus successfully suppressing the dust formation. With this new wetting method of combining water spray and sheet-wetting, the TWA RCS exposure for grinding can now be reduced to levels below the OSHA PEL and NIOSH REL of 50 µg/m^3. With some improvements, sheet-wetting could become a promising and practical engineering control solution for reducing RCS exposures during grinding.. Additional field surveys will be needed to further validate that this engineering control solution can reduce the workers RCS exposure consistently below the OSHA PEL during stone countertop grinding and polishing. In the absence of sufficient dust controls, respirators should continue to be used to reduce exposures, and the employer should ensure that the company 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 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.

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 project

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 and Johnson, 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 (50 µg/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 published a new PEL of 0.05 mg/m^3 (50 µg/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 study

Previous studies suggest that among stone countertop fabrication and installation tasks, grinding and polishing stone countertops led to the highest exposure to RCS. This is true even when applying water as a dust-control measure [NIOSH 2016a; NIOSH 2016b; NIOSH 2016c]. In the previous studies, the grinders applied water through a water spray nozzle during operation. However, most of these grinding tools have a center-feed feature, which was not used. It was unknown whether the center-feed or other wetting methods would provide better wetting of the grinding spot and better dust suppression, thus resulting in lower RCS exposure to the workers. In this study, NIOSH researchers conducted three site visits to evaluate RCS exposures while the worker conducted the grinding task with three different wetting methods including water spray, center-feed, and sheet-wetting in combination with water spray. Personal breathing zone (PBZ) air samples were collected to assess the worker's short-term TWA respirable dust and RCS exposures while grinding with each wetting method. Area air samples were taken during the first site visit to assess the background RCS concentration in the final grinding and polishing area.

Evaluation Site and Process Description

Introduction

The evaluation site 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 was on the ground floor, while the office area was 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 were signs beside these doors reminding personnel to wear their respirators and hearing protection before entering the fabrication area. Large stone countertop slabs were transported into the shop at one end of the building and the completed products were transported out of the shop at the other end.

Process Description

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. 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 stone strips with a miter saw supplied with water, 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 were also conducted at this step using a handheld pneumatic wet grinder (GPW-216, Gison Machinery Co., Ltd., Taiwan, running ~7,000 RPM at 90 PSI) with diamond grinding cup wheels (coarse and medium ratings). The grinder abraded the surface and allowed the glue to adhere to the stone. After the glue cured, the stone assembly went to CNC machines 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 stones. One worker used a pneumatic wet grinder (GPW-216, Gison Machinery Co., Ltd., Taiwan) with diamond grinding cup wheels (coarse, medium and fine ratings) for final grinding of the stone edges. About half dozen workers used pneumatic wet polishers of a variety of models (~4,500 RPM at 90 PSI) with resin bonded polishing discs for final polishing. 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.

Control Technology

During the first site visit, the worker who participated in this study used two handheld pneumatic wet grinders, both of which used water to suppress dust as a control measure. The two grinders are identical except for having different wetting methods. Figure 1(a) shows a grinder that supplies water to the diamond grinding cup wheel through a water spray nozzle pointing at the edge of the cup wheel; while Figure 1(b) shows a grinder with a center-feed feature, which continuously supplies water through a stainless steel tube on the top of the grinder and releases water from three small holes on the shaft where the diamond grinding cup wheel is mounted. Both grinders have a water hose connected at the end of the handle and a water valve to adjust the amount of water used. During this evaluation, the water valves were kept fully open while the grinders were in operation, and NIOSH researchers measured the water flowrate daily.

During the other two site visits, the participating worker only used the handheld pneumatic wet grinder with wetting method of water spray. In addition, a sheet-water was provided by supplying water through a water hose and allowing water to flow gently on the surface of the stone toward the active grinding area. Thus, the water formed a continuous sheet covering the active grinding area during operation. During the evaluation of this wetting method, the NIOSH researcher carried the sheet-wetting device and operated it on the same workbench where the worker conducted grinding. Figure 2 illustrates both the water spray and sheet-water as a combined wetting method to suppress dust as a control measure. The addition of the sheet-wetting is intended to 1) keep the active grinding area wet all the time, thus suppressing the dust formation during operation; 2) keep flushing away the sludge generated from the wet operation, thus preventing it from being dried and becoming airborne dust at locations near the worker's breathing zone; and 3) reduce the splash created from a strong water spray colliding with the fast-spinning grinding cup wheel. The splash may result in sending some silica-containing-mists into the worker's breathing zone, increasing the RCS exposure. During this evaluation, the water valves for the water spray on the grinder and the sheet-water were kept fully open while the grinders were in operation, and the NIOSH researcher measured the water flowrate daily.

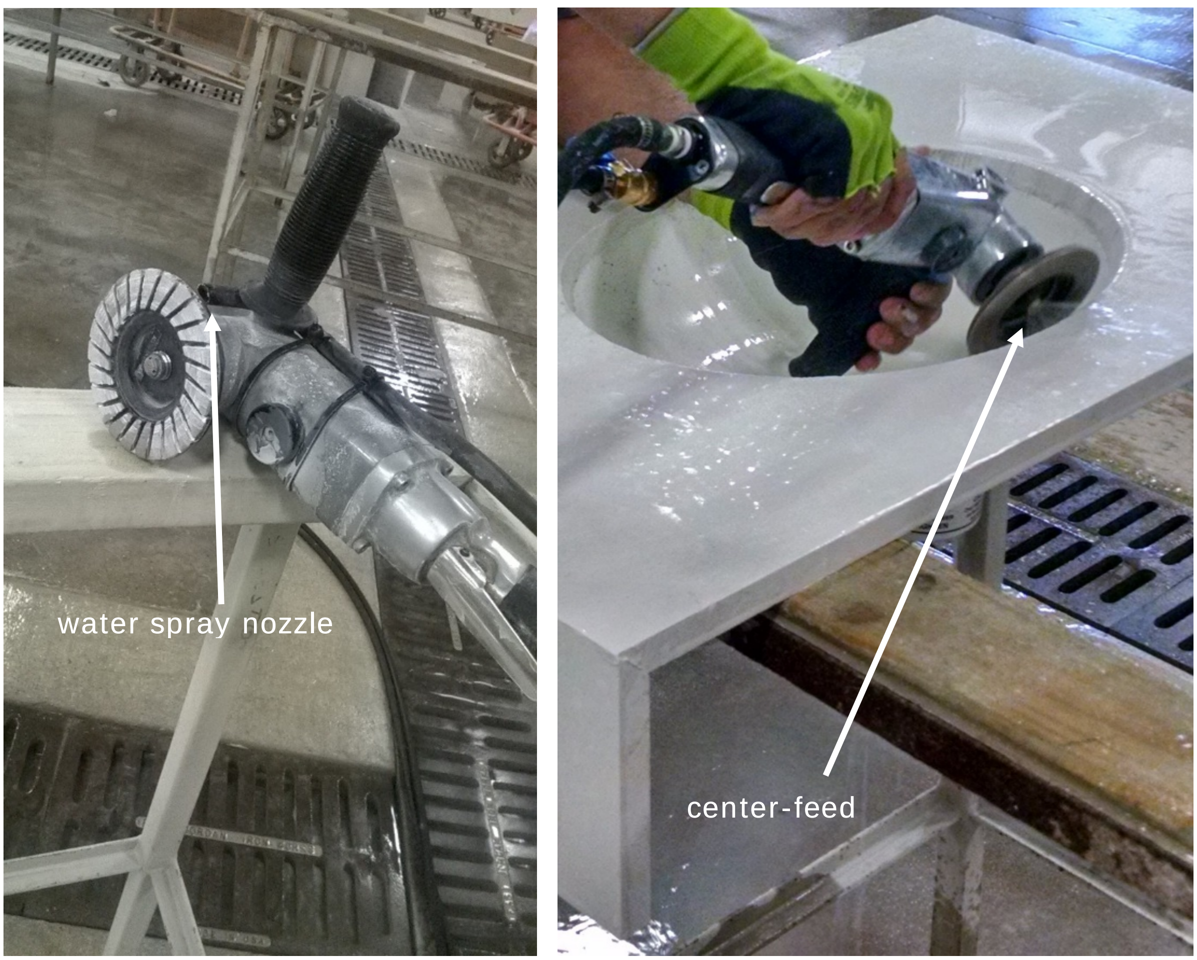

Figure 1 – (a) the handheld pneumatic wet grinder with a water spray nozzle (b) the handheld pneumatic wet grinder with a center-feed feature. Photos by NIOSH.

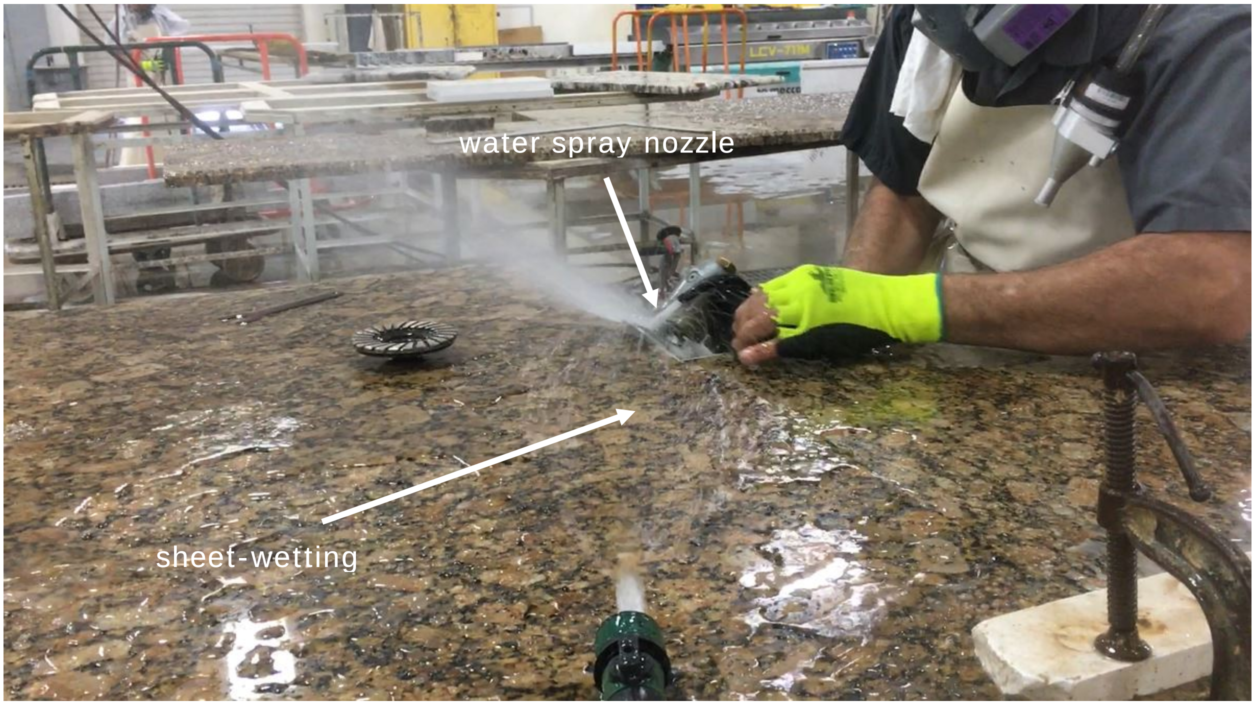

Figure 2 – The worker conducting the grinding task with a wetting method of combining water spray and sheet-wetting. Photo by NIOSH.

In addition, one of the workers on the site flushed the floor in the grinding and polishing area with water once or twice a day as a housekeeping measure. There are floor drains surrounding this area, which collect the water for onsite treatment and reuse. This housekeeping measure should help reduce the overall background RCS concentration. The grinding and polishing processes generated a large amount of sludge on the floor, which is a mixture of water and dust from the processes. Flushing cleaning the floor with water reduced the chance of the sludge drying and aerosolizing silica dust.

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 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 following 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 ($\mu g/m^3$) [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 (50 $\mu g/m^3$) as an 8-hr 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 (25 $\mu g/m^3$) [ACGIH 2013]. The TLV is intended to mitigate the risk of pulmonary fibrosis and lung cancer.

Methodology

Sampling Strategy

The aim of this study was to evaluate the effectiveness of the three wetting methods for reducing RCS exposures when grinding. Most of the time, the worker grinded continuously for only a few minutes and spent the remainder of his time moving stone slabs and taking measurements on stone dimensions. Therefore, multiple short-term (less than the full-shift of 8 hours) PBZ air samples were collected from the worker performing wet grinding when a specific wetting method was deployed. However, this sampling strategy also means that the short-term task-based sampling results should not be directly compared to OELs such as the OSHA PEL or the NIOSH REL, which are for full-shift (8 hour or 10 hour) exposures.

The first site visit was to compare the wetting methods of water spray and center-feed. Multiple short-term PBZ air samples were collected from a worker performing wet grinding using the two wetting methods. Sampling was paused when the worker was not actually grinding. This sampling strategy allows direct comparison of the two wetting methods upon worker exposure.

The following two site visits focused on the evaluation of the wetting method of combining water spray and sheet-wetting, with the PBZ samples taken continuously while working in the final grinding and polishing area, which is a rectangular (62' by 40') area with stones on multiple workbenches. The water hose providing sheet-water, however, can only cover a limited range of this area. To obtain results with consistent operation of the wetting method under evaluation, sampling was stopped when the worker moved out of the range of the sheet-wetting application.

In addition to the PBZ air samples, we collected two area samples each day during the first site visit to assess the background RCS concentration within the final grinding and polishing area. Figure 3 illustrates the layout of this area and the two area sampling locations.

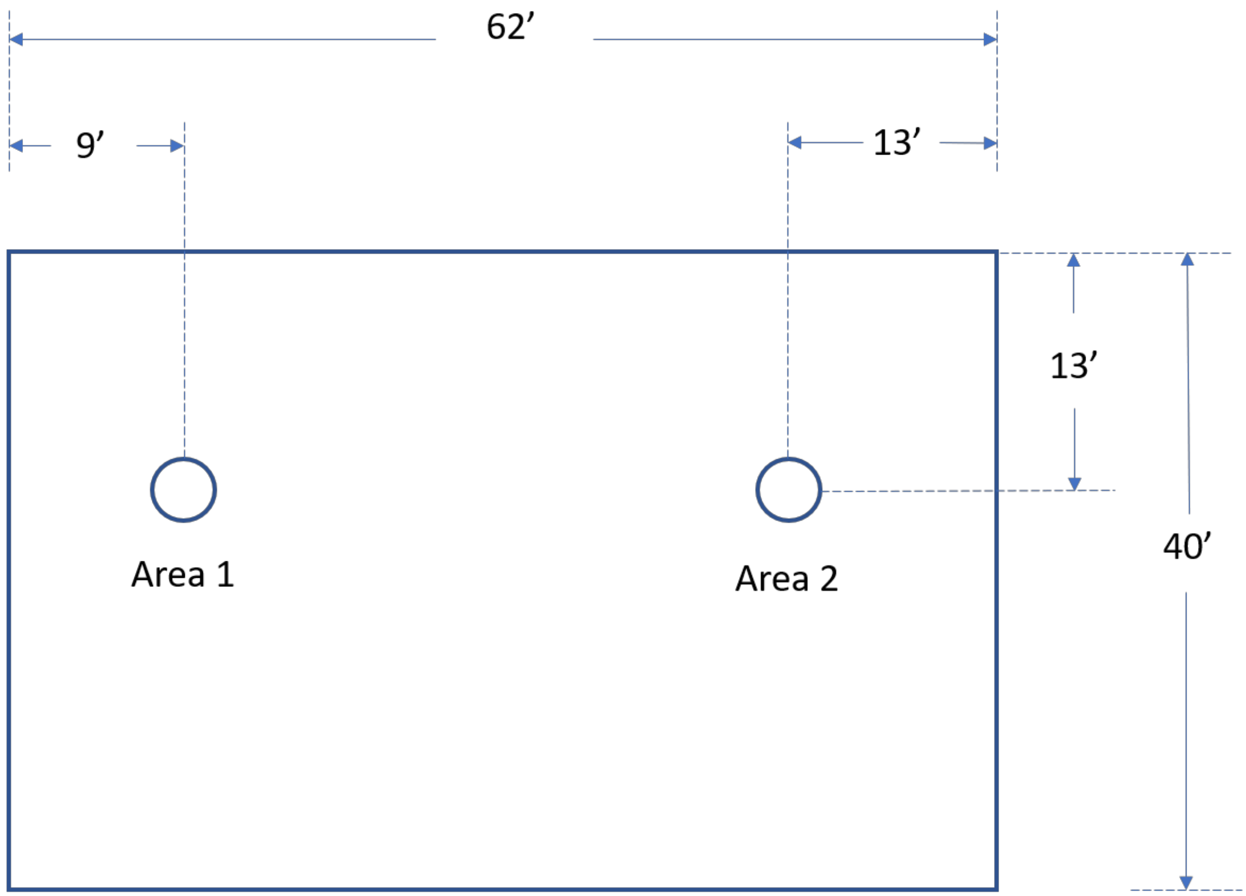

Figure 3 – Final grinding and polishing area and the sample locations for area sampling.

Sampling Procedures

Both PBZ and area samples for respirable dust were collected at a flowrate 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 using a DryCal Primary Flow Calibrator (Bios Defender 510, Mesa Laboratories, Inc., Lakewood, CO). For PBZ samples, 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 flowrates 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. The sample sets for the two area samples were installed on two tripods with customized mounts for holding the sampling pumps and cyclones. In addition to the air samples, two field blank samples were taken on each sampling day. Two bulk dust samples were also collected during the first site visit in accordance with NIOSH Method 7500 [NIOSH 2003] to check the potential interference of the sampled material on silica analysis.

The filter samples were analyzed for respirable dust 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	40 and 20	4	4	10	0.2	0.2	0.5
LOQ	130 and 52	13	13	33	0.67	0.67	1.7

Notes on *: the first value is for the samples collected in the first site visit; and the second value is for the samples collected in the other two site visits. The different LOD and LOQ for respirable dust from the two batches of samples are normal occurrences that resulted from different media blanks analyzed at different times after the site visits.

Crystalline silica analysis of filter and bulk dust 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 filter samples and bulk samples are also listed in Table 1.

Based on the sampling flowrate 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 PBZ air sample in this survey was collected with a cumulative sampling time greater than 9 minutes from multiple instances of grinding. For the first site visit, each instance of grinding normally lasted only a few minutes and the sampling pump was paused when one instance was completed. During this site visit, we took PBZ air samples only when the worker grinded engineered quartz stones to allow consistent comparison of the two wetting methods under evaluation, i.e., water spray and center-feed. During the other two site visits, each PBZ air sample was collected with a sampling time much greater than 9 minutes while the worker grinded both natural and engineered stones with the wetting method of combining water spray and sheet-wetting.

Water Flow Measurement

For each wetting method, we measured the water flowrate by filling water from the tool into a container of known volume while documenting the fill time with a stopwatch. Three measurements were taken for each wetting method during the study.

Results

The two bulk samples collected during the first site visit from surfaces near the workbenches of the sampled worker contained 36% and 40% quartz, respectively. No cristobalite or tridymite was detected in the bulk or filter samples. Thus, only the quartz results were used in the calculation of the crystalline silica content of the filter samples. All of the air samples also have respirable dust masses below the 2 mg upper limit specified by the NIOSH Methods 0600 [NIOSH 1998]. No respirable dust or crystalline silica were detected on any of the field blank samples.

Table 2 presents the respirable dust and RCS masses reported for every PBZ air sample collected during this study. There were nine, seven and ten samples collected from working with the three wetting methods under evaluation, respectively, i.e., water spray, center-feed, and the combination of water spray and sheet-wetting. The respirable dust and RCS masses in Table 2 were used to calculate the short-term task-based TWA exposures to respirable dust and RCS corresponding to these samples.

Sampling time for the PBZ air samples ranges from 15.0 to 167.7 minutes, which exceeded the required sampling time of 9 minutes as explained above. All the PBZ air samples collected RCS over the quartz LOD of 4.0 μg/sample.

Table 2 – Respirable dust masses, RCS masses, and short-term TWA exposure to respirable dust and RCS for PBZ air samples.

Site visit; Day	Wetting method	Sample period; time (min)	Respirable dust (μg/sample)	RCS (μg/sample)	Short-term TWA exposure to Respirable dust (μg/m^3)	Short-term TWA exposure to RCS (μg/m^3)
1; 1	Water spray	1; 15.3	< LOD	10.0	n/a	73.2
1; 1	Center-feed	1; 18.0	< LOD	22.0	n/a	136.8
1; 2	Water spray	1; 18.0	< LOD	8.4	n/a	51.5

Site visit; Day	Wetting method	Sample period; time (min)	Respirable dust (µg/sample)	RCS (µg/sample)	Short-term TWA exposure to Respirable dust (µg/m^3)	Short-term TWA exposure to RCS (µg/m^3)
1; 2	Water spray	2; 19.6	61	25.0	344.1	141.0
1; 2	Center-feed	1; 15.4	< LOD	13.0	n/a	93.5
1; 3	Water spray	1; 18.2	41	45.0*	248.7	272.9
1; 3	Water spray	2; 15.0	41	19.0	302.4	140.1
1; 3	Water spray	3; 19.4	71	41.0	405.9	234.4
1; 3	Center-feed	1; 18.6	< LOD	27.0	n/a	160.6
1; 3	Center-feed	2; 19.9	61	35.0	339.4	194.7
1; 3	Center-feed	3; 17.5	81	90.0*	511.7	568.5
1; 4	Water spray	1; 15.3	51	24.0	368.1	173.2
1; 4	Water spray	2; 22.2	81	48.0	401.5	237.9
1; 4	Water spray	3; 21.8	81	77.0	409.7	389.4
1; 4	Center-feed	1; 17.5	< LOD	18.0	n/a	113.7
1; 4	Center-feed	2; 21.2	41	19.0	213.7	99.0
2; 1	Water spray + sheet-wetting	1; 95.2	140.0	46.0	164.1	53.9
2; 1	Water spray + sheet-wetting	2; 167.7	210.0	67.0	139.8	44.6
2; 2	Water spray + sheet-wetting	1; 156.6	230.0	56.0	163.4	39.8
2; 3	Water spray + sheet-wetting	1; 161.1	190.0	55.0	131.2	38.0
2; 3	Water spray + sheet-wetting	2; 159.0	150.0	40.0	104.9	28.0
3; 1	Water spray + sheet-wetting	1; 132.8	160.0	34.0	133.9	28.5
3; 2	Water spray + sheet-wetting	1; 132.3	130.0	40.0	109.2	33.6
3; 2	Water spray + sheet-wetting	2; 141.3	110.0	27.0	86.5	21.2
3; 3	Water spray + sheet-wetting	1; 120.6	100.0	16.0	92.2	14.7
3; 3	Water spray + sheet-wetting	2; 122.6	120.0	33.0	108.8	29.9

Notes: n/a means not available because the mass of respirable dust for the samples was below the respirable dust LOD (40 µg/sample). Data with a * indicates samples with RCS masses greater than their respirable dust masses due to the greater sensitivity of the silica analysis and the amount of respirable dust being close to the dust LOD.

Overall, the short-term task-based RCS exposure was 190.4 ± 105.4 µg/m^3 (mean ± standard deviation) and 195.3 ± 168.4 µg/m^3 when using water spray and center-feed, respectively. However, there were six samples with respirable dust below the respirable dust LOD (40 µg/sample). Excluding those six samples, the seven samples for using water spray have the respirable dust exposure of 354.3 ± 60.7 µg/m^3; and the three samples for using center-feed have the respirable dust exposure of 354.9 ± 149.6 µg/m^3.

It should be noted that there were two air samples from the first site visit with RCS masses 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 4 µg/sample versus a dust LOD of 40 µg/sample).

When using the wetting method of combining water spray and sheet-wetting, the short-term task-based exposure was 33.2 ± 11.4 µg/m^3 and 123.4 ± 27.5 µg/m^3 for RCS and respirable dust, respectively.

Table 3 lists the respirable dust and RCS masses for every area sample collected. All the area samples have both the respirable dust and RCS masses over their respective LOD. The respirable dust and RCS masses in Table 3 were used to calculate the short-term task-based respirable dust and RCS concentrations corresponding to these samples. Overall, Area 1 has a respirable dust concentration of 161.2 ± 82.5 µg/m^3 and a RCS concentration of 50.1 ± 29.0 µg/m^3; and Area 2 has a respirable dust concentration of 182.3 ± 28.5 µg/m^3 and a RCS concentration of 44.5 ± 12.6 µg/m^3.

Table 3 – Respirable dust masses, RCS masses, percent silica, and short-term TWA concentration of respirable dust and RCS for area samples.

Site visit; Day	Area	Sample time (min)	Respirable dust (µg/sample)	RCS (µg/sample)	Short-term TWA Respirable dust concentration (µg/m^3)	Short-term TWA RCS concentration (µg/m^3)
1, 1	Area 1	167	360	110.0	239.9	73.3
1, 1	Area 2	168	300	53.0	197.6	34.9
1, 2	Area 1	178	120	28.0	75.4	17.6
1, 2	Area 2	178	240	64.0	149.3	39.8
1, 3	Area 1	178	270	95.0	168.4	59.2
1, 3	Area 2	178	320	94.0	199.8	58.7

The measured water flowrate was 7.10 ± 0.40 L/min and 1.52 ± 0.05 L/min for the water spray and center-feed wetting methods, respectively, during the first site visit. During the other two site visits, the measured water flowrate was 15.82 ± 1.25 L/min and 6.58 ± 0.03 L/min for the sheet-wetting and water spray, respectively.

Data analyses and discussion

The analysis on the results of area samples suggests that the two area sample locations have no significant difference on either RCS concentration (P = 0.78) or respirable dust concentration (P = 0.70). The area sample results also indicate that the background RCS concentration in the final grinding and polishing area of the site was near the OSHA PEL and NIOSH REL of 50 µg/m^3. There were no grinding or polishing activities within a few feet of either area sampling location. Therefore, workers in this area are likely to experience overexposure to RCS when their PBZs are close to the dust generated from their tools (grinders and polishers) without additional dust control measures.

Table 4 lists a summary of the statistics of data analyses for the PBZ exposure data. Besides data from this study, four full-shift TWAs reported by NIOSH [2016a] when only water spray was used as a control measure for grinding is listed in Table 4 for comparison.

Table 4 – Summary Statistics of Data Analyses on PBZ Samples

Wetting Method	Number of samples	Water flowrate (L/min)	TWA Respirable dust exposure (µg/m^3)	TWA RCS exposure(µg/m^3)
water spray*	4	n/a	300.0 ± 88.3	120.8 ± 20.2
water spray	9	7.10 ± 0.40	354.3 ± 60.7**	190.4 ± 105.4
center-feed	7	1.52 ± 0.05	354.9 ± 149.6***	195.3 ± 168.4
water spray + sheet-wetting	10	6.58 ± 0.03 15.82 ± 1.25	123.4 ± 27.5	33.2 ± 11.4

Notes: the first row of data for “water spray*” were full-shift TWAs reported by NIOSH [2016a] when only water spray was used as the control measure for grinding; n/a means water flowrate was not available. Data with a ** is based on 7 samples excluding samples with respirable dust below the respirable dust LOD (40 µg/sample). Data with a *** is based on 3 samples excluding samples with respirable dust below the respirable dust LOD.

The results in Table 4 suggest that the wetting methods of water spray and center-feed evaluated in this study have no significant difference on reducing the exposure to RCS (P = 0.30) or respirable dust (P = 1.00). Although water spray provided a much higher water flowrate than the center-feed method, both wetting methods failed to satisfactorily reduce the RCS exposures, which show similarly high levels (> 190 µg/m^3). Considering that the worker experienced these high levels of RCS exposure only during active grinding and the exposure in other times during the shift may be close to the background RCS concentration in the area (50.1 ± 29.0 µg/m^3 in Area sample 1 and 44.5 ± 12.6 µg/m^3 in Area sample 2), the worker’s full-shift TWA RCS exposure is expected to be similarly close to the full-shift TWAs reported by NIOSH [2016a] (120.8 ± 20.2 µg/m^3).

The insignificant difference on the short-term respirable dust and RCS exposures between the wetting methods of water spray and center-feed indicates that both methods performed equally poor on suppressing the dust formation and release from grinding. The likely reason is neither method provides effective wetting of the active grinding spot on the stone countertop, thus resulting in partially dry grinding during the operation. As evidenced in Figure 4, the water coming out of the grinder when using both wetting methods missed the active grinding spot on the stone depending on the position of the grinder and its manipulation by the worker. This issue is more pronounced for the water spray method as the entire stream of water can miss the active grinding spot. However, the wetting effectiveness of the center-feed method may be more limited by its much lower water flowrate. The overall result of the comparison is that both of the two wetting methods performed equally poor in terms of wetting the active grinding spot, suppressing the dust release (as evidenced by the similar levels of respirable dust exposure), and reducing the worker's RCS exposure (as evidenced by the similar levels of RCS exposure).

The results in Table 4 also suggest that the exposures to respirable dust (P = 0.026) and RCS (P = 0.002) are both significantly reduced with the addition of sheet-wetting compared to the exposure reported by NIOSH [2016a] when only water spray was used. The addition of sheet-wetting marks a significant improvement in engineering controls. The significantly reduced respirable dust exposure is evidence that the addition of sheet-wetting helped wet the active grinding area effectively, thus successfully suppressing the dust formation. It is worth noting that the average RCS exposure with the addition of sheet-wetting was only 27.5% of the level reported by NIOSH [2016a] when only water spray was used. The RCS exposure under this improved wetting method was lower than the OSHA PEL and NIOSH REL of 50 µg/m^3 on all but one sample.

Figure 4 – Ineffective wetting of the stone surface during grinding (a) water spray; (b) center-feed. Photos by NIOSH.

The water flowrate for water spray when used in combination with sheet-wetting was slightly lower than the water flowrate when water spray was used alone (6.58 ± 0.03 vs 7.10 ± 0.40 L/min). Therefore, the significantly reduced exposure under the improved wetting method is likely attributed to the addition of sheet-wetting.

One advantage of the sheet-wetting method is that it is independent from the grinding operation. Therefore, it has a good chance of keeping the active grinding area wet regardless of the position of the grinder and its manipulation by the worker, which was an issue for both water spray and center-feed when they were used alone.

It should be noted that the result from the wetting method of combining water spray and sheet-wetting is not compared with those of the other two wetting methods evaluated in this study because of different sampling strategies used for the two groups of samples (the samples for the other two wetting methods were taken only during active grinding).

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 background RCS concentration in the final grinding and polishing area of the facility was near the OSHA PEL and NIOSH REL of 50 $\mu g/m^3$. It suggests that the background RCS concentration can be high despite the use of wet grinding and polishing as well as the housekeeping measure of occasional floor-flushing. Workers in this area are likely to be overexposed to RCS when their PBZs are close to the dust source generated from the grinding and polishing tools without additional dust control measures.

The results from this study reveal that both water spray and center-feed wetting methods performed equally poor in terms of wetting the active grinding spot and reducing the worker’s respirable dust and RCS exposures, despite having very different water flowrates. Although the short-term task-based sampling results are not to be directly compared to OELs such as the OSHA PEL or the NIOSH REL, which are for full-shift (8 hour or 10 hour) exposures, the results in this study of these two wetting methods indicate that the worker's full-shift TWA RCS exposure when using these two wetting methods alone for grinding is expected to be similarly close to the full-shift TWAs (120.8 ± 20.2 $\mu g/m^3$) reported by NIOSH [2016a].

Adding sheet-wetting on top of the water spray wetting for grinding indeed significantly reduced respirable dust and RCS exposures. The short-term sampling results reported in this study are not be directly compared to the OSHA PEL or the NIOSH REL, but they suggest that the TWA RCS exposure for grinding can be reduced to levels below the OSHA PEL and NIOSH REL of 50 $\mu g/m^3$ with the addition of sheet-wetting. It can become a promising and practical engineering control solution for grinding after some improvements including: 1) making it easier to cover the entire final grinding and polishing area so that evaluation of its effectiveness during full-shift can be carried out; and 2) making it automatic so that the sheet-water can be applied effectively whenever grinding starts. Additional field surveys will then be needed to gather data to further validate that this engineering control solution can reduce the workers RCS exposure consistently below the OSHA PEL during stone countertop grinding and polishing.

A review of the respiratory protection program was beyond the scope of this study. 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 RCS exposures to acceptable levels when TWA RCS concentration in the air of PBZ do not exceed 10 times the NIOSH REL [NIOSH 2008]. The 10-hour TWA exposure observed in this survey do not exceed 10 times the NIOSH REL for RCS. 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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