Engineering Control Technologies to Reduce Occupational Silica Exposures in Masonry Cutting and Tuckpointing

John D. Meeker, MS, ScD, CIH[a]
Michael R. Cooper, MPH[a]
Daniel Lefkowitz, PhD[b]
Pam Susi, MSPH[c]

SYNOPSIS

Objectives. A number of tasks in construction generate worker overexposures to respirable crystalline silica dust, which is a significant contributor to occupational mortality and morbidity. This study evaluated the performance of commercially available engineering controls used in dusty construction tasks commonly performed by bricklayers.

Methods. Local exhaust ventilation (LEV) controls for a portable abrasive cutter and for tuckpointing grinders were examined at a bricklayers' training center, as were two stationary wet saws. Personal breathing zone air samples were collected with and without the use of LEV or water suppression during simulated concrete block cutting, brick cutting, and tuckpointing.

Results. Compared with the use of no exposure control during block and brick cutting, the portable LEV unit significantly reduced mean respirable quartz exposures by 96% for block cutting and 91% for brick cutting ($p<0.01$). The use of stationary wet saws was also associated with 91% reductions in exposure ($p<0.01$). For tuckpointing, the reductions in mean respirable quartz concentrations were between 91% and 93% with the LEV controls ($p<0.05$).

Conclusions. Reductions of up to 96% in mean respirable quartz concentration were observed between control and no-control scenarios. These reductions with commercially available off-the-shelf tools demonstrate the effectiveness of engineering control interventions to reduce crystalline silica exposures in construction. Strategies to further improve control performance and approaches for increasing control interventions in construction are needed.

[a]Department of Environmental Health Sciences, University of Michigan School of Public Health, Ann Arbor, MI

[b]New Jersey Department of Health and Senior Services, Trenton, NJ

[c]CPWR—The Center for Construction Research and Training, Silver Spring, MD

Address correspondence to: John D. Meeker, MS, ScD, CIH, Department of Environmental Health Sciences, University of Michigan School of Public Health, 6635 SPH Tower, 109 S. Observatory St., Ann Arbor, MI 48109; tel. 734-764-7184; fax 734-936-7283; e-mail <meekerj@umich.edu>.

The reduction of occupational exposure to crystalline silica is a regulatory priority at the federal and state levels.[1–4] Silicosis, a fibrotic disease of the lungs, is an occupational respiratory disease caused by the inhalation and deposition of respirable crystalline silica dust.[5] 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. Exposure to respirable crystalline silica dust occurs in many occupations, including construction. The three major forms of crystalline silica are quartz, cristobalite, and tridymite; quartz is the most common form.[6] The term *respirable* refers to that portion of airborne crystalline silica that is capable of entering the gas-exchange regions of the lungs if inhaled; this includes particles with aerodynamic diameters less than approximately 10 microns (μm).[7]

Silicosis was listed as the underlying cause of death in 6,322 fatalities in the United States from 1968 through 1990, according to a study reviewing multiple-cause-of-death data from the National Center for Health Statistics.[8] The total number of U.S. deaths with mention of silicosis for that period was 13,744. However, more detailed studies have shown that silicosis cases are significantly underreported,[9] so these figures likely underestimate the true prevalence of the disease. The National Institute for Occupational Safety and Health (NIOSH) estimated that 215,754 workers in construction (Standard Industrial Classification [SIC] codes 174, 176, and 179; North American Industry Classification System [NAICS] codes 236, 237, and 238) were potentially exposed to respirable crystalline silica in 1986.[7] Linch et al.[10] estimated that 13,800 masonry and plastering workers and 6,300 heavy construction workers were exposed to concentrations of respirable crystalline silica that were at least 10 times the NIOSH Recommended Exposure Limit (REL). More than a third of people who died with silicosis from 1990 through 1999 worked in the construction and mining industries.[11] A recent case report highlighted the dangers associated with these tasks, where a 30-year-old mason presented with silicoproteinosis following six months of work involving cutting and grinding brick with a demolition saw and tuckpointing grinder.[12]

When proper work practices are not followed and controls are not used or maintained, respirable crystalline silica exposures can exceed the NIOSH REL, the American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Value (TLV®), or the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) (Table 1).[7,13,14] NIOSH recommends an exposure limit of 0.050 milligrams per cubic meter (mg/m^3) to reduce the risk of developing silicosis, lung cancer, and other adverse health effects such as certain autoimmune disorders and silicoproteinosis. The ACGIH TLV for respirable quartz and cristobalite is 0.025 mg/m^3.[13] The current TLV was established to minimize the risk of pulmonary fibrosis and inflammation, which have been associated with lung cancer. However, given the uncertainty associated with the epidemiology studies on which the TLV is based, the ACGIH recommends that "air concentrations be maintained as far below the proposed TLV as prudent practices will permit."[13] The current OSHA PEL is a function of the quartz, cristobalite, or tridymite content of the sample (Table 1).

Many construction tasks have been associated with overexposure to crystalline silica.[15–19] Among these tasks are tuckpointing, concrete cutting, concrete grinding, and abrasive blasting,[17,20–26] where time-weighted-average worker exposures can routinely exceed concentrations that are 20 to 100 times higher than recommended limits.[17,24] Despite these high exposure levels and the availability of engineering controls to reduce exposures associated with many of these tasks, the use of such controls in construction remains limited. Barriers to their widespread use include the absence of regulatory pressure, the perceived costs and logistical drawbacks, and limited awareness within the industry of the dangers of overexposure and the availability of engineering controls. Compounding the problem is a lack of data on the effectiveness of available controls to reduce silica exposure.

Nash et al.[20] and Yasui et al.[27] have previously described tuckpointing engineering controls. The engineering control evaluated by Nash et al., which consisted of a shroud on a grinder with a hose attachment leading to a collection bag, was capable of a nearly 93% reduction in respirable silica exposure, from 4.080 mg/m^3 to 0.306 mg/m^3.[20] The control evaluated by Yasui et al. reduced respirable dust exposures by more than 97% when either an angle grinder with a vacuum shroud or a mortar rake was used for tuckpointing.[27] Also in that study, use of an engineering control reduced respirable quartz exposures by about 98% when an angle grinder with a shroud and vacuum was used. The mortar rake tests by Yasui et al. were conducted in a lime mortar, which contains little to no cement and quartz, while the angle grinder tests were performed in a conventional mortar.[27] Thorpe et al.[21] described silica exposure reductions of at least 90% for cutting concrete slabs with cut-off saws using water to suppress dust and cutting concrete slabs with a grinder using local exhaust ventilation (LEV). Croteau et al.[28] examined the use of LEV for reducing

Table 1. Occupational exposure limits for crystalline silica

Organization or agency	*Form of crystalline silica*	*Limit (mg/m³)*
NIOSH[a]	Quartz	REL = 0.05 10-hour TWA during a 40-hour work week
	Cristobalite	REL = 0.05 10-hour TWA during a 40-hour work week
	Tridymite	REL = 0.05 10-hour TWA during a 40-hour work week
OSHA[b]	Quartz	PEL = 10 ÷ percent of quartz + 2 (8-hour TWA)
	Cristobalite	PEL = ½ (10 ÷ percent of cristobalite + 2) (8-hour TWA)
	Tridymite	PEL = ½ (10 ÷ percent of tridymite + 2) (8-hour TWA)
ACGIH	Crystalline silica	TLV = 0.025
	Quartz	2006—Combined into one TLV, crystalline silica
	Cristobalite	2006—Combined into one TLV, crystalline silica
	Tridymite	2005—Withdrawn due to insufficient data

[a]NIOSH Publication No. 2005-151

[b]The PEL for silica in OSHA's Safety and Health Regulations for Construction, 29 C.F.R. 1926.55(a), is expressed in terms of millions of particles per cubic foot (mppcf) instead of mg/m^3. The impinger method that was used to determine silica exposure in mppcf is obsolete and no longer used. Current methods account for particle size, are more cost-effective, and use gravimetric analysis to indicate concentration in terms of mg/m^3. The OSHA Special Emphasis Program for Silicosis states that the PELs for construction, expressed in mppcf, are equivalent to the PELs for general industry, expressed in mg/m^3, and that gravimetric methods should be used to determine compliance.

mg/m^3 = milligrams per cubic meter

NIOSH = National Institute for Occupational Safety and Health

REL = Recommended Exposure Limit

TWA = time-weighted average

OSHA = Occupational Safety and Health Administration

PEL = Permissible Exposure Limit

ACGIH = American Conference of Governmental Industrial Hygienists

TLV = Threshold Limit Value

exposures from several construction tasks, including tuckpointing and block cutting, with exposure reductions ranging from 80% to 95% at the higher of two ventilation rates tested.

The study presented in this article evaluated the use of water and/or LEV to control respirable silica exposures associated with cutting block and brick, and with use of tuckpointing grinders. This study documented the effectiveness of commercially available engineering controls for tools used in construction for masonry cutting and tuckpointing. We believe that this is the first study to evaluate controls designed and offered directly by tool manufacturers for use with grinding and cutting tools. In previous studies of similar tools and tasks, the manufacturer modified the equipment upon request[20] or the investigators used aftermarket controls and vacuums.[27–29] The manufacturers of the equipment used in our study designed the controls to be purchased as off-the-shelf, commercially available products that include the tool with the shroud and vacuum (LEV) or water suppression system (wet methods) as part of the package.

Testing the effectiveness of these readily available controls to reduce worker exposures is an important next step toward intervention strategies aimed at broadening acceptance by workers, contractors, and other stakeholders. Increased market demand for engineering controls such as the ones we tested will also lead to improved design, utility, availability, and affordability. Finally, providing solid, objective data on control effectiveness will allow employers to comply with OSHA standards and permit OSHA to enforce standards for which feasible controls are available.

METHODS

As part of a cooperative agreement with NIOSH, CPWR—the Center for Construction Research and Training (formerly the Center to Protect Workers' Rights) partnered with the International Union of Bricklayers and Allied Crafts (IUBAC) and the International Masonry Institute (IMI) to evaluate commercially available cutting and grinding tools equipped with dust controls.

Experimental design

Using a randomized block design, we conducted five trials for each no-control and exposure-control scenario. The order of the trials within each round was randomly selected to minimize bias that might be introduced due to variation associated with environmental factors, equipment operators, and factors unrelated to the controls being evaluated. Each trial for which a control was used lasted approximately 25 minutes. The no-control trials lasted approximately five minutes. These sampling durations were selected to obtain a quantifiable silica sample during the control trials, and to avoid filter overload during a no-control trial.

Each cutting trial consisted of using a handheld electric abrasive cutter or stationary wet saw to make cuts through bricks (8 x 2¼ x 3¾ inches) and concrete blocks (16 x 8 x 8 inches) outdoors at the IMI training facility located in Bordentown, New Jersey. Each tuckpointing trial consisted of using an electric angle grinder to remove mortar from a brick test wall (25 feet wide x 8 feet high) at the training center site. Both head (vertical) joints and bed (horizontal) joints were removed during the trials. Two experienced journeymen bricklayers performed the tasks. Workers were recruited and notified that their participation was voluntary in accordance with CPWR's Institutional Review Board policy.

Exposure assessment

The effectiveness of the engineering controls examined in this study was evaluated by measuring the reduction in the respirable silica exposures in the breathing zone of the construction worker when working with and without dust control systems. Personal breathing zone samples were collected at a flow rate of 4.2 liters/minute using a GK 2.69 Respirable/Thoracic Cyclone (BGI Inc., Waltham, Massachusetts) and a preweighed, 37-mm-diameter, 5-μm pore-size polyvinyl chloride (PVC) filter. The flow rates of the sampling pumps were calibrated before and after each day of sampling. Samples were analyzed using NIOSH method 7500 to determine quartz, cristobalite, and tridymite concentrations in the respirable mass.[30] Quartz was the only form of crystalline silica detected in all samples collected in the study. The limit of detection (LOD) for quartz on filters was 0.005 mg.

A Haz-Dust III, Model HD-1003, Real-Time Aerosol Monitor (Environmental Devices Corporation, Plaistow, New Hampshire) was used to verify that ambient dust levels returned to background levels between trials and

Photo 1. Block cutting using Bosch® abrasive cutter with Bosch Airsweep™ vacuum

during selected trials as an approximate and immediate assessment of effectiveness.

Statistical methods

Statistical tests were conducted to evaluate differences in exposure distributions between control and no-control scenarios. This was an experimental setting with distinct tasks and sample times, and exposure concentrations approximated a normal distribution within each test scenario. Control/no-control scenarios were compared using a Student's one-tailed t-test, assuming unequal variances. Average reductions were calculated using the mean of the results for the control treatments and no-control treatments. One block-cutting sample and three brick-cutting samples were below the LOD for quartz during trials where the exposure-control technology was being used. Values below the LOD were conservatively assigned a value equal to the LOD.[31] All calculations and tests were conducted using SAS® version 9.1.[32] or Microsoft® Excel 2003.

Description of tools and controls

Block and brick cutting. The block- and brick-cutting tools and controls tested were a handheld electric abrasive cutter equipped with an LEV shroud, and two stationary wet saws. The handheld cutting tool (Photo 1) was a Bosch® model 1364 12-inch abrasive cutter (and Bosch 12-inch all-purpose diamond blade) equipped with a Bosch model 1605510215 dust extraction guard. This guard was connected via 3 meters (9.84 feet) of 35-mm-diameter (1.38 inches) hose to a Bosch model 3931 Airsweep™ 13-gallon wet/dry local exhaust cleaner with "pulse clean" and high-efficiency particulate air (HEPA) filters (Robert Bosch Tool Corp., Mt. Prospect, Illinois). The vacuum was specified to provide a flow rate of 130 cubic feet of air per minute (ft^3/min) (free airflow, which does not account for pressure loss due to fittings, hose, filters, or debris on filters) and a "static water lift" or "vacuum suction pressure" of 100 inches of water. With the HEPA filters in place, the vacuum was specified to retain 99.97% of the particles with a diameter equal to 0.3 μm. Exposure measurements were also made during the use of the same saw without use of the LEV control. For these trials, the vacuum cleaner hose was removed from the Bosch dust extraction guard and the ventilation takeoff was sealed with duct tape.

Block cutting was also performed using a Felker® Mason Mate II electric masonry saw (Felker Products, Inc., Olathe, Kansas). The saw was equipped with a ⅛-inch-wide, 14-inch-diameter diamond blade and powered by a 5-horsepower electric motor (Photo 2). It uses a submersible pump to spray water on the descending side of the rotating blade.

For brick cutting, a Target® Portasaw model PS1411S electric masonry saw (Target [now Husqvarna], Olathe, Kansas) was used. This saw uses the same size blade and a similar water spray mechanism as the Felker saw, but has a 1.5-horsepower motor (Photo 3).

Because contractors are more commonly using portable masonry saws as a substitute for stationary wet saws and the former generates a great deal more dust than the latter, we elected to use the stationary wet saw as a viable control alternative with which to compare the portable masonry saw. Stationary wet saws use water to cool the blade and would not be operated dry.

Tuckpointing. The first of two LEV-equipped grinders evaluated was a Bosch model 1775E 5-inch tuckpointer, equipped with Bosch tuckpointing guard TG500 and Bosch vacuum adaptor VAC002, and paired with the same Bosch model 3931 Airsweep 13-gallon wet/dry vacuum cleaner and hose described previously (Photo 4). For the no-control Bosch grinder exposure trials, the hose was disconnected from the shroud and the local exhaust port was blocked with duct tape. The grinder was equipped with a ⅜-inch-wide, 5-inch-diameter segmented diamond abrasive blade.

The second LEV-equipped grinder was a Metabo®

Photo 2. Block cutting using Felker® stationary wet saw

Photo 3. Brick cutting using Target® stationary wet saw

model WE14-125 Plus grinder (Metabo Corporation, West Chester, Pennsylvania). The LEV unit used with the grinder (Photo 5) was a 13-gallon Dust Collector® professional wet/dry vacuum for fine silica dust, in combination with the Dust Director® shroud (Industrial Contractors Supplies, Inc., Huntingdon, Pennsylvania), connected to the grinder by a 1.5-inch-diameter hose that was 12 feet in length. The vacuum was specified to provide 120 ft^3/min (free airflow) and a static water lift of 110 inches of water. Although the shroud and vacuum were designed as aftermarket retrofits, they are offered by the vendor as a unit that includes the shroud and vacuum along with popular handheld grinders. In this evaluation, the Metabo grinder was equipped with the same blade as the Bosch grinder described previously.

Measurement of airflow and water flow rates. The coefficient of entry (C_e) for the intake of each LEV-equipped tool was calculated in the laboratory prior to the study. Hood static pressure was then measured periodically throughout the LEV trials using a static pressure tap located at least 3 duct diameters from the air intake, and airflow through the hood was calculated as follows:

$$Q = C_e(4{,}005)(A)(SP_h)$$

where

Q = flow rate (ft^3/min)
C_e = hood coefficient of entry
A = cross-sectional area of the duct at static pressure tap (ft^2)
SP_h = hood static pressure (inches of water)

Water flow rates for the wet saws were assessed periodically by measuring the volume of water dispensed during a one-minute period.

RESULTS

The results of the respirable quartz exposures measured during the evaluation of exposure controls for block and brick cutting are presented in Table 2. The Bosch LEV shroud and vacuum cleaner reduced quartz exposures by a mean of 96% during block cutting ($p<0.01$). The stationary wet saw was also associated

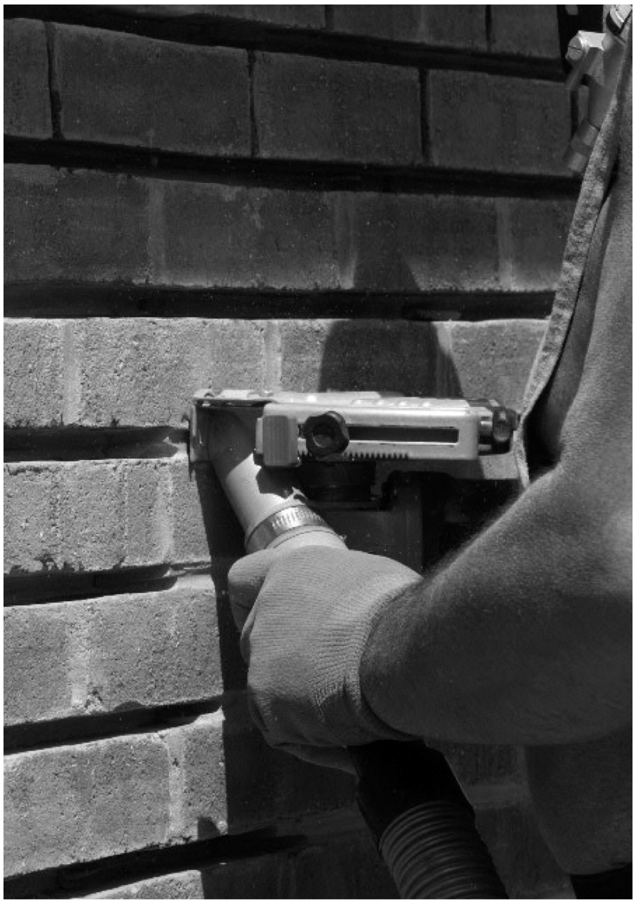

Photo 4. Tuckpointing using Bosch® grinder

with a statistically significant 91% reduction in quartz exposure ($p<0.01$). For brick cutting, the use of LEV or water suppression both significantly reduced respirable quartz concentrations by 91% ($p<0.01$). This dramatic reduction in exposure was found despite the lower amount of respirable quartz generated when cutting brick without exposure controls compared with cutting block. Table 2 also shows the large reductions in hazard ratios (calculated as the mean measured exposure divided by the NIOSH REL) associated with the use of control technologies vs. no control when cutting block or brick. For example, when cutting block using the Bosch cutter, the hazard ratio decreased from 56.6 with no control to 2.1 with the introduction of LEV.

Table 3 lists the results of the quartz sampling and analyses during the tuckpointing tests. Reductions in respirable quartz concentrations were 91% for the Bosch grinder and 93% for the Metabo grinder when the LEV was used. The difference in mean quartz concentrations was statistically significant between no control and use of LEV ($p<0.01$ and $p=0.025$). Hazard ratios decreased for both grinders, most significantly with the Metabo grinder, where the hazard ratio decreased from 218.0 with no control to 6.5 with the use of the Dust Director engineering control.

Airflow and water flow rates

Prior to dust collection, the Bosch saw with vacuum had a mean airflow of 77 ft^3/min, while the Bosch grinder with vacuum was associated with an airflow rate of 65 ft^3/min (this difference was due to a smaller air inlet and, thus, lower C_e for the grinder). The Dust Collector/Director combination used with the Metabo grinder had a mean airflow of 97 ft^3/min prior to dust collection. Declines in airflow were observed during the LEV trials, but they were not linear with time as dust was collected. This may be due to various factors that can periodically dislodge dust and debris that accumulate on the filters (e.g., movement of the vacuum during the task, mechanical vibration, or the Bosch vacuum's pulse cleaning feature).

The Felker stationary wet saw was operating with the flow-control valve completely open, which supplied

Photo 5. Tuckpointing using Metabo® grinder with Dust Director® shroud

Table 2. Personal breathing zone results for respirable quartz while cutting block or brick[a]

	Mean mg/m³ (range)	*Standard deviation*	*Percent reduction*	*Hazard ratio[b]*	*P-value*
Block cutting					
Bosch abrasive cutter, no control	2.83 (1.00–4.04)	1.14	NA	56.6	NA
Bosch abrasive cutter with LEV	0.11 (<0.05–0.17)	0.04	96.2	2.1	0.003
Felker stationary wet saw	0.26 (0.09–0.61)	0.21	90.7	5.3	0.003
Brick cutting					
Bosch abrasive cutter, no control	0.94 (0.45–1.58)	0.49	NA	18.8	NA
Bosch abrasive cutter with LEV	0.08 (<0.05–0.15)	0.04	91.1	1.7	0.009
Target stationary wet saw	0.09 (<0.05–0.14)	0.04	90.6	1.8	0.009

[a]n=5 samples for each tool/control combination

[b]Hazard ratio = measured exposure divided by National Institute for Occupational Safety and Health Recommended Exposure Limit

mg/m³ = milligrams per cubic meter

NA = not applicable

LEV = local exhaust ventilation

2.30 liters of water per minute to the cutting surface. The Target stationary wet saw was operating with the flow-control valve only partially open for all of the trials except one where it was completely open. The mean flow rate was 0.73 liters of water per minute when the valve was partially open, and 2.40 liters per minute when the valve was completely open. The exposure sample collected with the valve completely open had the lowest measured quartz concentration (<0.05 mg/m³).

DISCUSSION

The results of these tests showed that exposures to respirable dust and quartz can be significantly reduced through the use of commercially available engineering controls during block or brick cutting and tuckpointing. However, even with the reductions seen in this study, exposures would exceed applicable exposure limits in some cases if this work were carried out for a full shift. This means that appropriate respiratory protection must be used in the context of a comprehensive respiratory protection program. Alternatively, the amount of time these tasks can be performed could be restricted. For example, use of LEV while cutting block resulted in brief silica exposures of up to 3.4 times the REL. Under these conditions, a worker could cut block for up to 141 minutes in an eight-hour day with no additional quartz exposures without exceeding the REL. The allowable time for this task would thus

Table 3. Personal breathing zone results for respirable quartz while tuckpointing brick[a]

	Mean mg/m³ (range)	*Standard deviation*	*Percent reduction*	*Hazard ratio[b]*	*P-value*
Tuckpointing					
Bosch grinder, no control	4.99 (3.06–7.24)	1.56	NA	99.8	NA
Bosch grinder with Bosch LEV	0.47 (0.28–0.85)	0.28	90.6	9.3	0.001
Metabo grinder, no control	10.90 (5.25–25.80)	8.56	NA	218.0	NA
Metabo grinder with Dust Director LEV	0.33 (0.19–0.50)	0.13	93.4	6.5	0.025

[a]n=5 samples for each tool/control combination

[b]Hazard ratio = measured exposure divided by National Institute for Occupational Safety and Health Recommended Exposure Limit

mg/m³ = milligrams per cubic meter

NA = not applicable

LEV = local exhaust ventilation

be significantly greater with the use of LEV compared with using no control.

Historically, stationary wet saws served as the primary tool bricklayers used to cut masonry units such as brick. However, contractors have increasingly used portable masonry abrasive cutters, often referred to as "chop saws," in lieu of the stationary wet saw. Stationary wet saws require the user to be on the ground to make cuts. Some contractors, therefore, view the use of portable masonry saws as a productivity gain because they can be used without getting down from scaffolding. However, gasoline-powered equipment is prohibited on suspended scaffolding.[33] In addition, portable abrasive cutters are heavy, generate high dust levels, and pose an increased safety risk for accidental cuts and amputations if not used correctly. The stationary wet saw also offers many ergonomic advantages compared with the portable saw. As shown in Photo 2, the operator was able to work in an upright position and did not have to bear any of the saw's weight. With the portable masonry saw, on the other hand, the operator often used a bent posture and had to pick up the full weight of the saw.

Our study results showed that the portable abrasive cutter with LEV was effective in controlling respirable quartz. However, due to safety concerns associated with the use of portable abrasive cutters, we recommend the use of stationary wet saws, which were also effective at reducing respirable quartz exposures. Potential safety concerns associated with the use of wet saws should also be considered, including the presence of water near an electrical source and the formation of slippery surfaces due to ice formation in colder temperatures.

Laboratory studies have shown a direct correlation between increased water flows and reduced dust concentrations generated during cutting masonry with portable masonry saws for flow rates up to 0.50 liters per minute.[21] However, we are not aware of any studies or specifications for optimum water flow rates for stationary saws. The stationary wet saws we evaluated were operated at flow rates in excess of 0.50 liters per minute (2.30 liters per minute for the Felker and 0.73 to 2.40 liters per minute for the Target saw). Given that the highest flow rate used with the Target saw (2.40 liters per minute) during brick cutting resulted in the lowest silica exposure among five trials, it is likely that flow rates higher than those recommended for portable masonry saws are needed for stationary wet saws.

Tuckpointing generates a large amount of dust in a short amount of time. Although engineering controls for tuckpointing such as those tested in this study are effective at capturing dust, the large amount of dust collected by vacuum cleaner filters and bags increases pressure losses and decreases collection flow rates and efficiencies.[29] Thus, during heavy tuckpointing work, flow rate should be monitored, and frequent maintenance may be required to dislodge buildup on filters and to change vacuum bags. In the future, vacuums designed for this application should include a pressure gauge and should alert the user when airflow becomes less than adequate. Laboratory studies have suggested that maintaining an airflow rate higher than 80 to 85 ft^3/min is required to adequately control respirable silica exposures during tuckpointing.[29] In this study, we demonstrated a high level of control with airflow rates below these recommended values, but mean exposures exceeded the NIOSH REL. These results, in addition to the potential for maintenance activities (e.g., discarding a full vacuum bag) to create uncontrolled dust generation and intermittent peak silica exposures, highlight the need for improvements in the control design so that they are more durable and maintain adequate airflow for longer durations.

Future LEV systems used for tuckpointing tasks should include automated mechanisms to periodically clean buildup from filters and should also be equipped with effective prefilters. For example, one promising solution is the use of inertial separators (e.g., cyclones) to collect the larger dust particles before they reach the filters and bag. Such designs may allow the vacuum to maintain flow rate and decrease the need for filter and bag maintenance and replacement.[29] In the present study, the vacuum bags were only changed as needed and were used for up to 105 minutes of grinding. However, most bags were used for a shorter duration because they were damaged or full.

The use of a larger diameter vacuum hose and takeoff from both shrouds may also improve performance, and design of the shroud should be optimized. We conducted laboratory tests to calculate the C_e for both the Bosch and Dust Director shrouds. C_e is the ratio of actual airflow to ideal flow, where values near 1 represent efficient transfer of energy for airflow into the system, while values approaching 0 represent high energy losses upon shroud entry. The Dust Director had a C_e of 0.8, while the C_e for the Bosch shroud was just 0.5, signifying another potential opportunity for improvement in control design and effectiveness. Finally, input from the end users of the equipment should also be considered in the design to maximize usability and efficiency.

Despite being on OSHA's regulatory agenda since 1994, there is still no comprehensive federal silica standard in place. In the absence of such a rule, OSHA issued a Special Emphasis Program (SEP) for Silica in 1997 and has expanded on the SEP with a National

Emphasis Program (NEP) for Silica that went into effect on January 24, 2008. Both programs utilize existing regulations to cite employers who fail to reduce employee exposures to silica to below the OSHA PEL. The NEP requires that at least 2% of inspections conducted by regional and area OSHA offices be silica-related.[1] The NEP targets industries in which potential overexposures to silica are documented, including SIC code 1741/ NAICS code 238140 Masonry, Stone Setting, and other Stone work. The NEP directs OSHA inspectors to cite employers who fail to implement feasible controls for reducing respirable crystalline silica exposures to levels below the OSHA PEL. The NEP lists various engineering controls including wet methods for cutting, drilling, sawing, and grinding, and the use of tools with dust-collecting systems.

In addition to federal OSHA initiatives, state and local governments have also started regulating silica through regulations or specification requirements. In addition, labor organizations have initiated collective bargaining agreement negotiations requiring the use of engineering controls to reduce silica exposure. California, which is a "state-plan" state and therefore enforces its own regulations through its Division of Occupational Safety and Health (known as Cal/ OSHA), has proposed amending its codes to include requirements for the use of water or LEV and training when workers cut, grind, core, and drill concrete and masonry materials.[4] In 2006, New Jersey passed a state law that restricts dry-cutting of masonry unless the employer can demonstrate that the use of water is not feasible.[34] In the event that an employer is permitted to dry-cut, the following rules apply: (*1*) engineering controls such as vacuums with HEPA filters must be used to reduce dust, (*2*) work must be in a designated area to limit additional worker exposure, and (*3*) the employer must provide workers with a full-face respirator as part of a comprehensive respiratory protection program.[35]

Prior to the proposal and/or passage of these various state standards, the IUBAC developed model collective bargaining language to prohibit the dry-cutting of masonry and to encourage the use of engineering controls to reduce silica exposure. Such language is included in the collective bargaining agreements between IUBAC locals and their signatory contractors in several jurisdictions including Eastern Massachusetts, New Jersey, Michigan, and California.

Finally, municipal agencies may have specifications or work requirements that require the use of engineering controls to reduce silica exposure. The City of Boston Environment Department provides contractors with guidelines for construction that encourage the use of wet saws for brick and masonry cutting and the use of hand tools, wet methods, or vacuum systems for re-pointing work.[36] The City of Boston Environment Department has the authority to stop work where visible dust is present. Therefore, the guidelines, though voluntary, are generally followed to prevent work stoppages.

CONCLUSIONS

The next step in evaluating these commercially available tools is to confirm their performance through exposure monitoring during their use on actual construction jobs. While this study demonstrated that the use of these controls resulted in substantial and significant reductions in personal exposures to respirable silica, additional work must be conducted to achieve compliance with occupational exposure limits through the use of engineering control interventions, without resorting to the supplemental use of respiratory protection or administrative controls.

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