Applied Occupational and Environmental Hygiene
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uaoh20

Assessment of Silica Exposure and Engineering Controls During Tuckpointing

Shojiro Yasui [a], Pam Susi [b], Mike McClean [a] & Mike Flynn [c]

[a] Harvard School of Public Health, Landmark Center, P.O. Box 15677, 401 Park Drive, Boston, MA 02215

[b] Center to Protect Workers' Rights, 8484 Georgia Avenue, Silver Spring, MD 20910

[c] University of North Carolina School of Public Health, Rosenau Hall, CB# 7400, Chapel Hill, NC 27599

Version of record first published: 18 Jun 2010

To cite this article: Shojiro Yasui, Pam Susi, Mike McClean & Mike Flynn (2003): Assessment of Silica Exposure and Engineering Controls During Tuckpointing, Applied Occupational and Environmental Hygiene, 18:12, 977-984

To link to this article: http://dx.doi.org/10.1080/714044186

Applied Occupational and Environmental Hygiene, 18: 977–984, 2003
ISSN: 1047-322X print / 1521-0898 online
DOI: 10.1080/10473220390244621

Graduate Student Case Study

Assessment of Silica Exposure and Engineering Controls During Tuckpointing

Dawn Tharr, Column Editor

Reported by Shojiro Yasui, Pam Susi, Mike McClean, and Mike Flynn
Advisor: Robert F. Herrick

Exposures to crystalline silica in the construction industry are widespread. This report documents exposures to crystalline silica and describes the effectiveness of a commercially available dust collection system designed for tuckpointing tools. Exposure to respirable crystalline silica (quartz) can result in silicosis, a serious and often fatal disease with symptoms including shortness of breath, weight loss, weakness, and the onset of autoimmune diseases. The American Conference of Governmental Industrial Hygienists (ACGIH®) regards silica as a suspected human carcinogen, and the National Toxicology Program (NTP) and the National Institute for Occupational Safety and Health (NIOSH) have designated crystalline silica as a potential occupational carcinogen. NIOSH estimates that more than one million workers are at risk for silicosis, with the majority of them in construction trades.[1]

The NIOSH Recommended Exposure Limit (REL) and ACGIH® Threshold Limit Value (TLV®) for respirable quartz are 0.05 mg/m^3. The Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) for respirable dust containing crystalline silica for the construction industry is measured in millions of particles per cubic foot (mppcf) and is calculated using the following formula: PEL = 250 mppcf/% silica + 5.[2] However, OSHA compliance officers use the general industry PEL for respirable silica to test for compliance on construction sites, calculating the allowable exposure based on the measured quartz percentage for each sample in accordance with the following equation: 10 mg/m^3/(% quartz + 2).[1] In this article, we used the NIOSH REL and the ACGIH TLV as the evaluation criteria, as these values reflect more current research on the health effects of silica exposure.

Construction workers are routinely exposed to silica-containing dust without any engineering controls. One study showed that tuckpointing workers were exposed to silica-containing dust at levels 17 to 116 times higher than the OSHA PEL and 212 to 4300 times higher than the NIOSH REL.[3] According to NIOSH, non-powered air purifying respirators are not recommended for workers who are exposed to greater than 10 times the NIOSH REL.[4] In cases such as this, engineering controls, not only respirators, are required to reduce the exposure to the workers. OSHA also requires that engineering controls be used to the extent feasible for reducing exposures to regulated agents.[5]

Exposures in construction are closely related to task.[6] For the grinding process during tuckpointing, personal silica exposures can vary substantially between the component tasks a worker conducts. Exposure assessment and the design of effective control technology require knowledge of each task component's relative contribution to the total exposure. Detailed work task–exposure analysis using a combination of direct reading monitor and videotaping is well suited to assess the exposure associated with each task component in the mortar grinding process.[7]

The goals of this study were as follows: 1) to evaluate the efficiency of engineering controls by calculating the respirable dust reduction as the ratio of exposure, both with and without the engineering control; 2) to determine the contribution of each component task to the total exposure in the grinding process based on the detailed task-exposure analysis; 3) to suggest improvements to the engineering control based on the data analysis and the comments of the journeyman bricklayers participating in the evaluation; and, 4) to evaluate the suitability of the disposable half-mask respirators typically used in this process.

Process Description

Tuckpointing is the process of restoring mortar to masonry wall joints that deteriorate over time. The procedure is performed by bricklayers and masonry restoration workers, and it involves grinding mortar from the joint between the masonry units (such as blocks or bricks) and replacing it with fresh mortar. The depth of the cut is typically three quarters of an inch. During this process, workers are exposed to high levels of dust, including respirable crystalline silica (see Figure 1). Because the grinding portion of tuckpointing generates the majority of respirable dust, this report focuses on that step in the tuckpointing job.

Handheld angle grinders equipped with 4.5-inch diamond blades are the most commonly used tools for tuckpointing in the United States. For the controlled evaluation described here, two systems were evaluated: 1) a Metabo angle grinder equipped with a 5-inch-diameter diamond blade (see Figure 2) and an exhaust shroud connected to a High Efficiency Particulate Air (HEPA) vacuum system (see Figure 3)

FIGURE 1
Typical uncontrolled tuckpointing grinding.

designed to capture dust at the point of generation (Dust Director High Power Vacuum System, Industrial Contractors' Supplies, North Huntingdon, PA); and 2) a Dewalt angle grinder (see Figure 4) equipped with a tungsten carbide–tipped mortar rake (Joran Bor, Randers, Denmark). A Rigid wet-dry 8-gallon shopvac attached to the shroud on the Dewalt grinder was used to capture dust generated by the mortar rake system. The air flow rate in the exhaust hose of the Dust Director High Power Vacuum on the diamond blade was approximately 2500 feet per minute (fpm), and the capture velocity was approximately 1500 fpm two feet outside the inlet to the shroud.

To evaluate the exposure, we created four scenarios. The first two scenarios involved grinding mortar from a brick wall using the Metabo grinder equipped with the diamond blade, with and without the Dust Director collection equipment. The latter two scenarios involved the use of the Dewalt grinder equipped with the tungsten carbide mortar rake, with and without the Rigid shopvac dust collection equipment. The grinders with the vacuum dust collection are described as "controlled," and those without the dust collection as "uncontrolled." Table I shows the details of each of the control technology scenarios.

FIGURE 2
Diamond blade grinder with exhaust shroud.

Materials and Methods

An experienced journeyman pointer/caulker/cleaner (PCC) was recruited to operate each of the tool configurations. Personal air sampling was conducted using integrated and real-time methods to produce matched results for each scenario. Integrated sampling was conducted to measure the time-weighted average (TWA) exposure over the sampling period. Personal air samples were collected using sampling trains that consisted of a 10-mm Dorr Oliver nylon cyclone, a 37-mm cassette containing a 5-μm pore size polyvinyl chloride (PVC) filter, and a 36-inch length of PVC tubing. Each sampling train was attached to a Gilian High Volume air sampling pump, which was pre- and post-calibrated to 1.7 L/min using a Gilabrator primary flowmeter. The pumps were attached at the worker's waist, and the cyclone samplers were fastened to the lapel, as close to the worker's breathing zone as possible. The same worker was measured in all scenarios. He was provided a 3M belt-mounted GVP-series powered air-purifying respirator with a loose-fitting helmet, with an assigned protection factor (APF) of 25 for use throughout this study.

In addition to the integrated dust sampling method, real-time monitoring was conducted using the detailed work analysis method. This method consists of combining direct-reading real-time exposure monitoring and videotaping. The worker's dust exposure was monitored using a DustTrak Model 8520 real-time aerosol monitor manufactured by TSI with the 10-μm preclassification impactor to measure PM_{10} exposure. Videotaping was simultaneously conducted to record the worker's activities. An analysis of the videotape from

TABLE I
Control technology scenarios

Scenario number	Tool type	Attachment	Control	Material
1	Angle grinder (Metabo)	Diamond blade	Uncontrolled	Mortar
2	Angle grinder (Metabo)	Diamond blade and shroud	Controlled	Mortar
3	Angle grinder (DeWalt)	Mortar rake	Uncontrolled	Lime mortar
4	Angle grinder (DeWalt)	Mortar rake and shroud	Controlled	Lime mortar

FIGURE 3
Dust director HEPA vacuum.

FIGURE 4
Mortar rake.

the grinding portion of tuckpointing was conducted to identify the components of the major tasks. TWA exposure was determined for each task component, and the proportion of the total exposure contributed by each task component was computed.[7]

The air samples and field blanks were sent to the RJ Lee Group, Inc. in Monroeville, Pennsylvania, to be analyzed. Respirable dust samples were analyzed in accordance with NIOSH Method 0600 for Particulates not Otherwise Regulated, Respirable. The samples were then analyzed for crystalline-free silica dust using X-ray diffraction in accordance with NIOSH Method 7500. The analytical limit of detection (LOD) for the samples was 0.005 mg quartz, resulting in an LOD for the field samples ranging from 0.059 to 0.59 mg/m^3.

Results

Personal Exposures to Respirable Silica

TWA personal exposures to respirable dust and quartz are presented in Table II. All respirable quartz exposures were below the detection limits except in Scenario 1. Because of limited sampling time, detection limits are slightly higher than 0.05 mg/m^3, the NIOSH REL and ACGIH TLV. The use of the uncontrolled diamond blade grinder (Scenario 1) created 2.84 mg/m^3 respirable quartz exposure averaged over the sampling period. When the diamond blade grinder was controlled with the Dust Director exhaust ventilation system, respirable quartz exposure was reduced to <0.059 mg/m^3, a reduction of approximately 98 percent. A reduction in respirable quartz exposures (approximately 80%) was observed with the use of the ventilated mortar rake; however, the tool malfunctioned after about five minutes of sampling in the uncontrolled configuration. This limited our ability to evaluate the control's effectiveness (Scenarios 3 and 4).

Real-Time Monitoring for Respirable Dust

Using the data measured with the DusTrak, we estimated the respirable

TABLE II
Respirable dust and quartz from personal samples (NIOSH Method 7500)

Scenario number	Tool type	Attachment	Control	Sample time (min)	Respirable dust (mg/m^3)	Respirable quartz (mg/m^3)	Exposure exceeds REL (multiple of REL)
1	Angle grinder (Metabo)	Diamond blade	Uncontrolled	15	13.3	2.84	57
2	Angle grinder (Metabo)	Diamond blade and shroud	Controlled	50	<1.17	<0.059	<1.2
3	Angle grinder (DeWalt)	Mortar rake	Uncontrolled	5	12.8	<0.59	<11.8
4	Angle grinder (DeWalt)	Mortar rake and shroud	Controlled	27	<2.17	<0.11	<2.2

quartz dust concentration using the matched personal sample for Scenario 1. We calculated the ratio of respirable quartz concentration measured by PVC filter samples to the respirable dust concentration measured by DusTrak for the same sampling period. The respirable quartz concentration by NIOSH Method 7500 for Scenario 1 is 2.84 mg/m^3, and the respirable dust concentration by DusTrak is 36.42 mg/m^3; therefore, the respirable quartz concentration is approximately 7 percent of the respirable dust concentration measured by DusTrak. This ratio of respirable dust measured by the DusTrak to respirable quartz (12.8 to 1) could not be applied to estimate the respirable quartz exposures for Scenarios 3 and 4, however, because the mortar used in these scenarios had a different silica content than that used in Scenarios 1 and 2. The mortar used in these scenarios was known as "lime mortar" and did not contain cement, while the conventional mortar used in Scenarios 1 and 2 did contain cement. The data from the DusTrak monitor (see Table III) revealed that the reduction in respirable dust exposure from use of the control ventilation in grinding with the diamond blade grinder was 97.9 percent, and for the mortar rake it was 97.4 percent.

Detailed Work Analysis of the Grinding Task with the Diamond Blade Grinder

Examination of the pattern of respirable dust exposure in both the controlled and uncontrolled scenarios (see Figures 5 and 6) reveals that the exposure is extremely variable, with short, intense peaks of exposure. The grinding process can be divided into two major task components. The first one is grinding the mortar in horizontal masonry joints, and the second is grinding of mortar in the vertical masonry joints. Horizontal joints are longer and are ground in a continuous motion after the blade is inserted into the masonry joint. Horizontal grinding has three directional patterns: 1) from right to left (HL); 2) left to right (HR); and 3) repeated motion in both directions (HP).

Vertical masonry joints between bricks are approximately 2 inches in length. They are ground in a series of short plunge cuts in which the diamond blade is inserted and then almost immediately removed from each vertical joint. Vertical grinding is conducted with the tool in two positions: grinding using the grinder in an upright position (VU);

TABLE III
Respirable dust and control efficiencies using DusTrak data

Scenario number	Tool type	Attachment	Control	Exposure time (sec)	Respirable dust (mg/m^3)	Reduction (%)
1	Angle grinder (Metabo)	Diamond blade	Uncontrolled	858	36.42	—
2	Angle grinder (Metabo)	Diamond blade and shroud	Controlled	2,901	0.78	97.9
3	Angle grinder (DeWalt)	Mortar rake	Uncontrolled	209	24.07	—
4	Angle grinder (DeWalt)	Mortar rake and shroud	Controlled	1,474	0.62	97.4

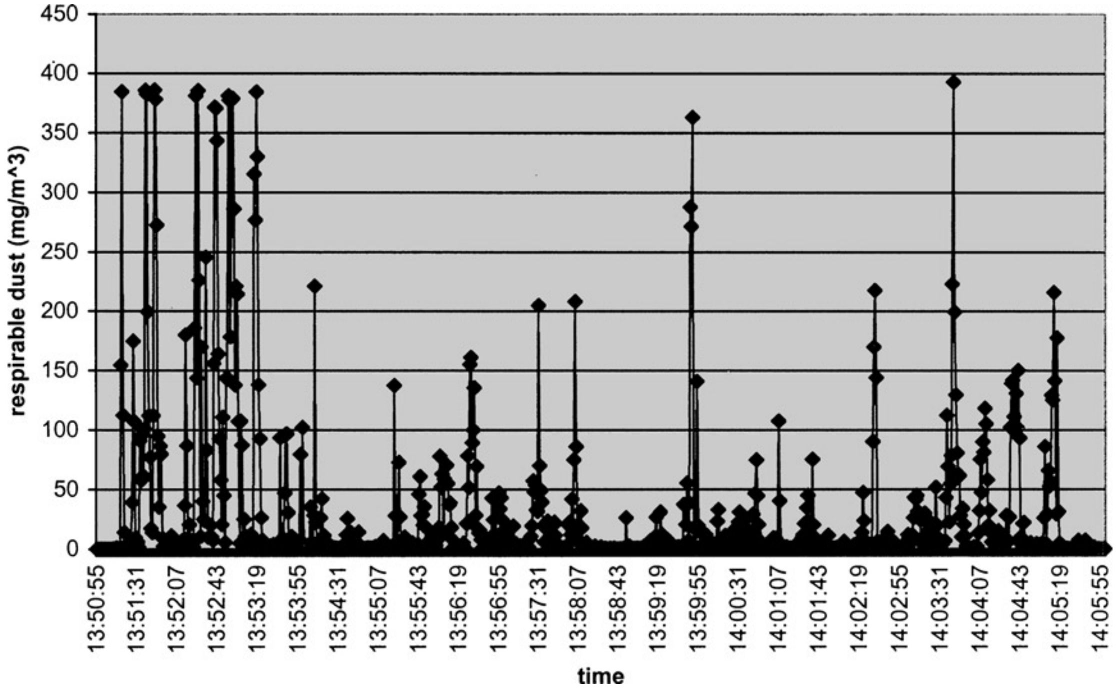

FIGURE 5
Uncontrolled grinding scenario 1.

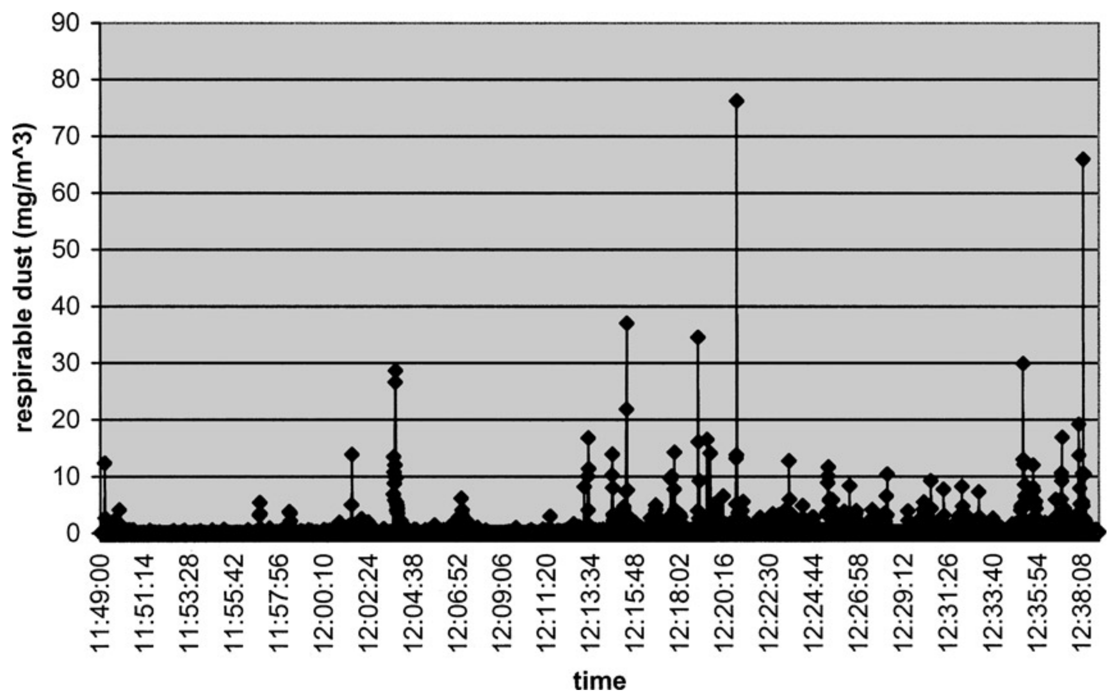

FIGURE 6
Controlled grinding scenario 2.

TABLE IV
Results of uncontrolled grinding work on masonry walls (Scenario 1)

Task ID	Task description	Exposure time (sec)	TWA exposure (mg/m^3)	Proportion of total time (%)	Proportion of total exposure (%)
	Background	19	0.12		
HL	Horizontal grinding to left	491	44.42	57.2	69.8
HR	Horizontal grinding to right	142	47.25	16.6	21.5
HP	Horizontal grinding to right and left repeatedly	41	16.83	4.8	2.2
VD	Vertical grinding with grinder inverted	118	13.92	13.8	5.3
VU	Vertical grinding with grinder upright	66	6.01	7.7	1.3
	Total	858	36.42	100	100

or upside down in the inverted position (VD). When the grinder is in the upright position, the recorded video image shows that rotation of the blade causes the grinding swarf of air from the wheel to blow upward, so the exhausted dust and air is directed over the worker's head and away from his breathing zone. When he carefully examined the video with the monitoring results displayed on the screen, the journeyman PCC worker noticed that the stream of dust directed upward over his head was particularly apparent when the grinder was held at chest-level and higher. The opposite occurred when the tool was inverted, as the air flow (and entrained dust) from the grinding wheel was directed downward and toward the worker's body as he held the grinder against the wall. When the ventilation control was in use, the worker held the tool in the inverted position only, to keep the exhaust hose extending downward from the tool. He also spent a portion of his time moving into position to grind a new section of wall, and in preparation and adjustment of the tool. This included tightening the connection between the exhaust hose and the ventilation shroud by pushing and twisting the pieces together.

The task-exposure analysis of uncontrolled grinding task (see Table IV) revealed that horizontal grinding (78.6% of total exposure time) contributed 93.4 percent of total exposure; the vertical grinding step (21.5% of total exposure time) contributed just 6.5 percent. For uncontrolled grinding, horizontal grinding produced approximately three times higher levels of exposure than vertical grinding. Vertical grinding with the tool inverted (VD) produced exposures approximately two times greater than when the tool was in the upright position (VU).

Grinding with the ventilation control in place (see Table V) produced exposures that were approximately 98 percent less than the uncontrolled exposures. With the control in place, exposures during vertical grinding exceeded exposure in horizontal grinding by factors of 2 to 3. This indicates that the vacuum collection equipment worked less efficiently during the vertical grinding than in horizontal grinding. Although vertical grinding occupied 16.4 percent of the total time, it contributed 31.9 percent of the overall exposure. On the other hand, the horizontal grinding (75.5% of total time) contributed only 50.2 percent. In addition, the adjustment/preparation task generated the highest level of exposure; while it comprised only 8.1 percent of the total time, it contributed 17.9 percent of total exposure.

TABLE V
Results of controlled grinding work on masonry walls (Scenario 2)

Task ID	Task description	Exposure time (sec)	TWA exposure (mg/m^3)	Proportion of total time (%)	Proportion of total exposure (%)
BG	Background (before start of grinding)	71	0.54		
HL	Horizontal grinding to left	2,076	0.50	71.6	46.3
HR	Horizontal grinding to right	114	0.77	3.9	3.9
VD	Vertical grinding with grinder inverted	475	1.52	16.4	31.9
P	Preparation/ adjustment of grinder	236	1.71	8.1	17.9
	Total	2,901	0.78	100	100

TABLE VI
Exposure during use of the mortar rake (Scenarios 3 and 4)

Control	Task description	Exposure time (sec)	TWA exposure (mg/m^3)	Proportion of total time (%)	Proportion of total exposure (%)
Uncontrolled	Background	41	0.29		
	Grinding	209	24.07		
Controlled	Background	20	0.25		
	Grinding	1,197	0.53	80.1	68.8
	Preparation	277	1.02	18.5	30.7
	Total	1,474	0.62	98.6	99.5

Detailed Work Analysis of Grinding Using the Mortar Rake

In the case of the grinding task using the mortar rake grinders, we were unable to distinguish separate tasks within the overall grinding process. Table VI presents the results of the uncontrolled mortar grinding with the mortar rake. The uncontrolled exposure during this task is 24.07 mg/m^3. The use of the exhaust ventilation system reduced exposure by approximately 98 percent. Table VI also reveals that the adjustment/preparation step produced the highest concentration when the ventilation control was in use (18.5% of total time, contributing 30.7% of total exposure).

Discussion

The results of the personal integrated samples indicate that uncontrolled exposure to respirable quartz can be up to 57 times greater than the NIOSH REL. These exposure levels should be of great concern, particularly because they exceed the REL by more than 10 times, surpassing the protection factor assigned to half-face negative-pressure respirators typically used by the workers conducting tuckpointing processes. The dust collection equipment system we evaluated can reduce the exposure by 98 percent. However, the respirable quartz exposures may still exceed the REL if workers are exposed at the levels we measured for a full 8-hour day. Workers may still have to rely on respiratory protection, with all the requirements of the OSHA Respiratory Protection Standard (29 CFR 1910.134). Further improvements in the effectiveness of the engineering controls to reduce exposures to levels below the REL are needed to make the use of respirators unnecessary.

Detailed work analysis of diamond blade grinding revealed that the vacuum collection system reduced overall exposure by over 98 percent (Scenario 2). However, it performed much more effectively during horizontal grinding than in vertical grinding. In the controlled case, horizontal grinding resulted in approximately half the dust exposure of vertical grinding (Scenario 2). When the ventilation system was in use, the worker always held the tool in the inverted position during vertical grinding to keep the exhaust hose pointed downward. In the case of vertical grinding without the ventilation control, grinding with the tool inverted (VD, Table IV) produced exposures two times greater than with the tool upright (VU). The flow of air produced by the rotation of the diamond blade in the grinding tool is suspected to be the cause of elevated exposure when the grinder is held in the inverted position during vertical grinding. Grinding with the tool in the inverted vertical position is suspected to contribute to exposures higher than those measured when the tool is in the horizontal position, as the portion of the exhaust air stream escaping from the tool is more likely to reach the worker's breathing zone.

The adjustment and preparation of the grinder can cause substantial silica exposure. Tables V and VI show that the adjustment/preparation activities yield more dust exposure than the actual grinding under the controlled situation. This is apparently the result of redispersion of dust settled on the tool and the associated vacuum system, as well as on the worker's coveralls. It is very important to recognize the contribution of the exposure during the adjustment/preparation step to total dust exposure under the controlled situation.

Recommendations

Engineering controls are strongly recommended during tuckpointing for the prevention of silica-related diseases among tuckpointing workers. The engineering controls should reduce the exposures to a level at least below the NIOSH REL. Where this is not feasible, exposures should be reduced to at least a level not exceeding 10 times the REL, so that the commonly used disposable respirators (APF 10) will provide adequate protection.

To improve the vacuum dust collection during vertical grinding, a reconfiguration of the exhaust shroud is recommended. The detailed work analysis revealed that the flow of dust and air from the rotating blade is suspected to be the source of high exposure to silica-containing dust. Reconfiguration of the exhaust shroud may improve the collection efficiency of the control system.

Improved durability and easier handling of dust collection equipment is necessary to reduce the amount of adjustment/preparation needed and improve productivity. It is also important to recognize that the adjustment/preparation step made a substantial contribution to the total exposure when the ventilation control systems were in use. The worker who tested the tool in this study told us that the equipment is usable but needs improvements. For example, the hose of the vacuum cleaner, and the vacuum cleaner itself, sometimes disturbed his work. The shroud of the mortar rake grinder became disconnected and was unserviceable within five minutes of starting work, demonstrating that more durability is needed for actual use in the field.

ACKNOWLEDGMENTS

This work could not have been accomplished without the help of George Weymouth and the International Union of Bricklayers and Allied Craftworkers (IUBAC) Local Union 3. Barry Cardwell, the BAC 1 member who did the PCC work also deserves special thanks. The IUBAC and the International Masonry Institute provided the test facilities at which the study was conducted. This research was supported by grant U60/CCU317202 from the National Institute for Occupational Safety and Health.

REFERENCES

1. Dear, J.A.: Memorandum for Regional Administrators: Special Emphasis Program (SEP) for Silicosis. U.S. Department of Labor, Occupational Safety and Health Administration, Washington, DC (May 2, 1996).
2. Code of Federal Regulations: 29 CFR 1926.55: Gases, Vapors, Fumes, Dusts, and Mists. U.S. Department of Labor, Occupational Safety and Health Administration, Washington, DC.
3. Nash, T.N.; Williams, D.R.: Occupational Exposure to Crystalline Silica During Tuckpointing and the Use of Engineering Controls. Appl Occup Environ Hyg 15(1):8–10 (2000).
4. National Institute for Occupational Safety and Health: NIOSH Guide to the Selection and Use of Particulate Respirators Certified Under 42 CFR 84; DHHS (NIOSH) Publication No. 96-101. NIOSH, Washington, DC (January 1996).
5. Code of Federal Regulations: 29 CFR 1910.134: Respiratory Protection. U.S. Department of Labor, Occupational Safety and Health Administration, Washington, DC.
6. Susi, P.; Goldberg, M.; Barnes, P.; et al.: The Use of a Task-Based Exposure Assessment Model (T-BEAM) for Assessment of Metal Fume Exposures During Welding and Thermal Cutting. Appl Occup Environ Hyg 15(1):26–38 (2000).
7. Andersson, I.-A.; Rosén, G.: Detailed Work Analysis for Control of Exposure to Airborne Contaminants in the Workplace. Appl Occup Environ Hyg 10(6):537–544 (1995).

EDITORIAL NOTE: Shojiro Yasui, Mike McClean, and Robert Herrick are with the Harvard School of Public Health, Landmark Center, P.O. Box 15677, 401 Park Drive, Boston, MA 02215. Pam Susi is with the Center to Protect Workers' Rights, 8484 Georgia Avenue, Silver Spring, MD 20910. Mike Flynn is with the University of North Carolina School of Public Health, Rosenau Hall, CB# 7400, Chapel Hill, NC 27599.