CPWR THE CENTER FOR CONSTRUCTION RESEARCH AND TRAINING

An Evaluation of Silica Exposure Controls for Tuckpointing: Hilti VC40-U Vacuum with Hilti DC-EX Dust Guard and Hilti Grinder
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Executive Summary

This report describes the results of an evaluation of a tuckpointing dust control system consisting of a **Hilti VC40-U vacuum, a Hilti DC-EX shroud, and a Hilti DAG-500 grinder**. Randomized trials with and without use of the dust control system were conducted in a controlled setting. Removing mortar with the Hilti grinder without the dust control system resulted in a mean task time-weighted average (TWA) respirable silica exposure 220 times the National Institute of Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL) of 0.05mg/m^3. Use of the same grinder with the dust control system reduced exposures by approximately 97 percent. However, exposures measured during the use of the dust control system still exceeded the NIOSH REL. It should be noted that the NIOSH REL is based on exposures averaged over a ten-hour workday and our results represent exposures averaged over shorter periods of continuous grinding.

Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
CPWR	CPWR – The Center for Construction Research and Training
Ce	coefficient of entry
HEPA	high-efficiency particulate air
IUBAC	International Union of Bricklayers and Allied Craftworkers
LEV	local exhaust ventilation
PACT	Partnership for Advancing Control Technologies
NIOSH	National Institute for Occupational Safety and Health
OEL	occupational exposure limit
OSHA	Occupational Safety and Health Administration
PAPR	powered air-purifying respirator
PEL	Permissible Exposure Limit
PVC	polyvinyl chloride
REL	Recommended Exposure Limit
RPM	revolutions per minute
TWA	time-weighted average
SP	static pressure

I. Introduction

In 2010 CPWR – The Center for Construction Research and Training began a four-year project to identify and evaluate tuckpointing local exhaust ventilation (LEV) systems and disseminate information on their availability and effectiveness. A Partnership for Advancing Control Technologies (PACT), comprised of masonry contractors, representatives from unions, government, equipment manufacturers, and researchers, decided on important characteristics of control technologies. This information was used to identify LEV systems for tuckpointing to consider for evaluation. Each system consisted of a tuckpointing grinder, shroud (used to capture and direct dust into the vacuum duct), and vacuum. This report describes the fourth, and final, system evaluated between 2012 and 2014. These systems were among the most highly rated by contractor and labor members of the PACT. Each system was evaluated, with and without LEV, in a controlled setting to determine effectiveness in silica exposure reduction. The report describes the methods used to test the system consisting of the **Hilti VC40-U vacuum, a Hilti DC-EX Dust Guard, and Hilti DAG-500 grinder** and the results of the evaluation.

Excessive exposure to respirable silica can result in silicosis or other silica-related diseases including pulmonary tuberculosis, lung cancer, silicoproteinosis (Lyons et al, 2007) and autoimmune disorders such as rheumatoid arthritis, sarcoidosis and scleroderma (Miller et al, 2012). Respirable particulate is generally defined as particles less than 10 micrometers (μm) in aerodynamic diameter (ACGIH, 2013). Silicosis can lead to symptoms including shortness of breath, fatigue, chest pains, susceptibility to infection and possibly death. There is no cure for silicosis, however it is totally preventable. Construction workers exposed to dust, including silica, are known to have higher rates of chronic obstructive pulmonary disease (COPD).

There are many sources of silica in construction that result in exposures of varying intensity among workers. Masonry restoration workers are among the most highly silica-exposed trades in construction. The process of grinding out deteriorated mortar joints between masonry units and replacing or repointing with fresh mortar (often referred to as tuckpointing) is a fundamental part of masonry restoration work. The removal of mortar with powered angle grinders generates enormous levels of dust. Between 2004 and 2006, the National Institute for Occupational Safety and Health (NIOSH) and CPWR evaluated silica exposures while grinding mortar in a controlled setting, at a local training center, where tasks, sample times and task variables were defined by the study design. These studies demonstrated that grinding mortar without controls can result in elevated respirable silica exposures. Meeker et al., (2009) reported exposures between 4.99 and 25.8 milligrams per cubic meter (mg/m^3) in a controlled setting. The NIOSH Recommended Exposure Limit (REL) for respirable silica based on a 10-hour time weighted average (TWA) exposure is 0.05 mg/m^3. This study also showed that LEV systems for tuckpointing grinders can reduce exposures to respirable silica by greater than 90 percent.

II. Objectives

The objective of this evaluation was to assess the effectiveness of an LEV system for controlling exposure to silica during the grinding of mortar. The control technology was tested under controlled conditions, similar to those experienced by tuckpointers on actual job sites, using journeymen bricklayers experienced in tuckpointing and repeat, randomized trials with and without LEV. The test conditions were designed so that the only variable was whether the control was or was not used.

III. Description of Equipment Tested

A **Hilti DAG 500-D grinder** (Hilti, Inc., Tulsa, OK) (**Figures 1, 2 and 4**) was fitted with new 1/4-inch wide, 4½-inch diameter segmented diamond abrasive blade made by DeWalt (model #DW4740). The grinder weighs approximately 5 pounds, draws 8.5 amps, and has variable speed up to 11,000 revolutions per minute (RPMs).

Figure 1. Hilti grinder without tuckpointing LEV system

The **Hilti VC40-U vacuum** (Hilti, Inc., Tulsa, OK) (**Figures 2 and 3**) was tested in combination with the **Hilti DC-EX 125/5 Dust Guard** (Hilti, Inc, Tulsa, OK) (**Figures 2 and 4**) attached to Hilti grinder.

The vacuum is specified to weigh **32 pounds** when empty and to provide 129 cubic feet of air flow per minute (cfm). The vacuum has a filter and a device that automatically cleans the filter with a blast of air every 15 seconds. Based on the manufacturer's recommendation, the vacuum was operated with a 99.9 percent efficient filter, instead of a more efficient high-efficiency particulate air (HEPA) filter (which by definition is designed to capture 99.97 percent of the particles with an aerodynamic diameter of 0.3 micrometers).

CPWR-sponsored research and contractor experience have found the use of HEPA filters for tuckpointing may have an adverse effect on dust capture. Because the HEPA filter will remove more dust than the 99.9 percent efficient filter, it is subject to heavier loading, causing a greater pressure drop and subsequent decrease in air flow. The relatively small increase in the efficiency of the filtration system while using the HEPA filter is expected to be quickly offset by a more significant decrease in capture efficiency as the air flow and ability to capture particles decreases. The Hilti system's automatic cleaning system further reduces the impact of filter dust loading.

Figure 2. Hilti Grinder with Shroud

IV. Study Methods

This evaluation was conducted at the International Union of Bricklayers and Allied Craftworkers (IUBAC) Local 1 Philadelphia/Delaware Training Center in Philadelphia, PA on May 12 and 13, 2014. A journeyman bricklayer, experienced in tuckpointing, used the Hilti system to remove mortar from joints generally wide enough to require two passes (5/16 to 1/2 inches). Both vertical (head) and horizontal (bed) joints were cut out over the course of testing. The type S mortar had been allowed to cure for at least four weeks. The bricklayer either possessed or was provided with personal protective equipment including sturdy work boots, gloves, hearing protection and a powered air-purifying respirator (PAPR) for use when not using the vacuum system. The PAPR was a Pureflo PF60 ESM with type 1, class G head protection (meeting ANSI Z89.1-2003), a loose-fitting face piece with a face shield (meeting ANSI Z87.1+), and a HEPA filter (Interactive Safety Products, Inc., Huntersville, NC). The worker operating the equipment wore his own negative air-purifying respirator when using the vacuum.

Figure 3. Hilti grinder with Dust Guard and VC40-U vacuum

The study was designed to include five paired rounds of sampling during mortar removal. Each round included a trial using the Hilti grinder with the Hilti DC-EX Dust Guard connected to the Hilti VC40-U vacuum and a trial with the same worker using the Hilti grinder with the factory-supplied guard and without a vacuum. The order of the trials (with and without LEV) within each round was randomly selected to minimize bias that might be introduced due to variation associated with environmental factors, equipment operator, blade wear, and any other factors unrelated to LEV use. Tools were operated for approximately 24 minutes per trial with controls and for approximately 10 minutes when controls were not used.

Figure 4. Hilti vacuum

These times were selected based on the results of previous sampling efforts and estimates of the minimum sample time necessary to accurately measure down to 0.05 mg/m^3 – the NIOSH REL for respirable silica – during use of the LEV system. The bricklayer was required to take a 5-minute break in the middle of the 24-minute trials to reduce variability in fatigue, compared to the 10-minute trials.

Personal air samples were collected in the operator's breathing zone during each trial to measure respirable silica concentrations during grinding with and without LEV. The samples were collected using a GilAir-5 pump (Sensidyne, Inc., Clearwater, FL) to draw 4.2 liters of air per minute through a GK2.69 Respirable Cyclone (BGI Inc., Waltham, MA) with a pre-weighed, 37 mm diameter, 5-micron pore size polyvinyl chloride (PVC) filter positioned on the operator's lapel.

Figure 5. Hilti grinder and Dust Guard

The flow rates of the sampling pumps were calibrated at the beginning of each day using a DryCal DC-Lite Primary Flow Meter (Bios International Corporation, Butler, NJ). Flow rates were measured again near the middle of the day to ensure that post-sampling flow rates were within 5% of pre-sampling flow rates. Average flow rates were used to calculate sample air volumes. Samples were analyzed by R.J. Lee Group, Inc., (Pittsburgh, PA) using NIOSH Method 0600, to determine exposure to total mass of respirable dust. The same samples were also analyzed using X-Ray diffraction following NIOSH method 7500 to determine quartz, cristobalite and tridymite concentration in the respirable mass. Reported masses for these analytes were used with the sample air volumes to calculate airborne concentrations of total respirable dust, quartz, cristobalite and tridymite.

We used a reduction of greater than 50 percent in airborne respirable silica exposure concentrations or a reduction to less than the NIOSH REL of 0.05 mg/m^3 as our criteria for determining whether or not a control was considered effective. This is consistent with criteria used in previous studies conducted by NIOSH (Echt et al., 2007) and CPWR (Meeker et al., 2009). The Occupational Safety and Health Administration (OSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH) publish additional occupational exposure limits (OELs) for silica, which are listed in **Table 1** with the NIOSH RELs. OELs for silica are based on the respirable fraction of the aerosol, which consists of particles less than 10 μm in aerodynamic diameter.

Table 1. Occupational Exposure Limits for Respirable Crystalline Silica

Organization or Agency	Form of Crystalline Silica	Occupational Exposure Limits (mg/m^3)
NIOSH[A]	Quartz	REL = 0.05 mg/m^3
	Cristobalite	REL = 0.05 mg/m^3
	Tridymite	REL = 0.05 mg/m^3
OSHA - Construction[B]	Quartz	PEL = 250 / (5 + % quartz)
	Cristobalite	PEL = 250 / (5 + % cristobalite)
	Tridymite	PEL = 250/ (5 + % tridymite)
ACGIH	Crystalline Silica	TLV = 0.025 mg/m^3

[A] NIOSH Publication No. 2005-151 indicates 10-hour time-weighted average during a 40-hr workweek

[B] The PEL for silica in OSHA's Safety and Health Regulations for Construction, 29 C.F.R. 1926.55(a), is an 8-hour time-weighted average (TWA) expressed in millions of particles per cubic foot (mppcf). However, the units mppcf can be converted to milligrams per cubic meter by dividing mppcf by 10 (OSHA, 2009). The formula used by OSHA to determine the PEL for silica is dependent on the percentage of silica in each collected sample. The concentration of respirable dust measured is compared to the sample specific PEL to determine if the PEL has been exceeded. In September 2013, OSHA proposed lowering the PEL to 0.05 mg/m^3 of respirable silica as an 8-hour TWA (OSHA, 2013).

The flow of air in ventilation systems is governed by fundamental principles that describe the behavior of gases. Pressure measurements taken within a ventilation system along with knowledge of hood (or shroud) entry losses can be used to calculate air flow. Hood entry losses are dependent on the shape and configuration of a particular hood or shroud and described by the term "coefficient of entry (Ce)". The Ce is the ratio of *actual* air flow through a hood and *theoretical air flow* absent hood entry losses. Given hood Ce, static pressure (SP) measurements, and the area of the duct where SP measurements were taken, air flow can be calculated. CPWR determined the Ce for the Hilti DC-EX Dust Guard to be 0.53. Static pressure, with the vacuum on and the grinder off, was measured before and after each trial utilizing the vacuum to monitor changes in air flow over time. The static pressure was measured at a port in a PVC pipe with an inner diameter of approximately 1.4 inches and positioned more than 3 duct diameters downstream from the shroud's air intake using a UEi EM200 Electronic Manometer (Universal Enterprises, Inc., Beaverton, OR).

The vacuum bag was changed after each trial and its weight to the nearest pound was recorded. The bag weights and corresponding grinding durations were used to calculate the average weight of dust collected per unit time. After each trial, cut lengths were measured on the wall to determine total linear feet of vertical and horizontal joints cut per unit time.

A Haz-Dust III, Model HD-1003, Real-Time Aerosol Monitor (Environmental Devices Corporation, Plaistow, NH) was used to confirm clearance of dust between trials. The Haz-Dust monitor was positioned on the test wall near the operator at approximately breathing zone height and configured to measure respirable particulate concentration.

V. Results

Personal air monitoring

Respirable Silica. Five respirable dust samples were collected during grinding with the vacuum system and five samples were collected without use of the vacuum system. Personal air monitoring results for respirable silica and a comparison of average exposures relative to the NIOSH REL for silica (0.05 mg/m^3) appears in **Table 2.** A graphical depiction of average respirable silica exposures, with and without the dust control system, appears as **Figure 6.**

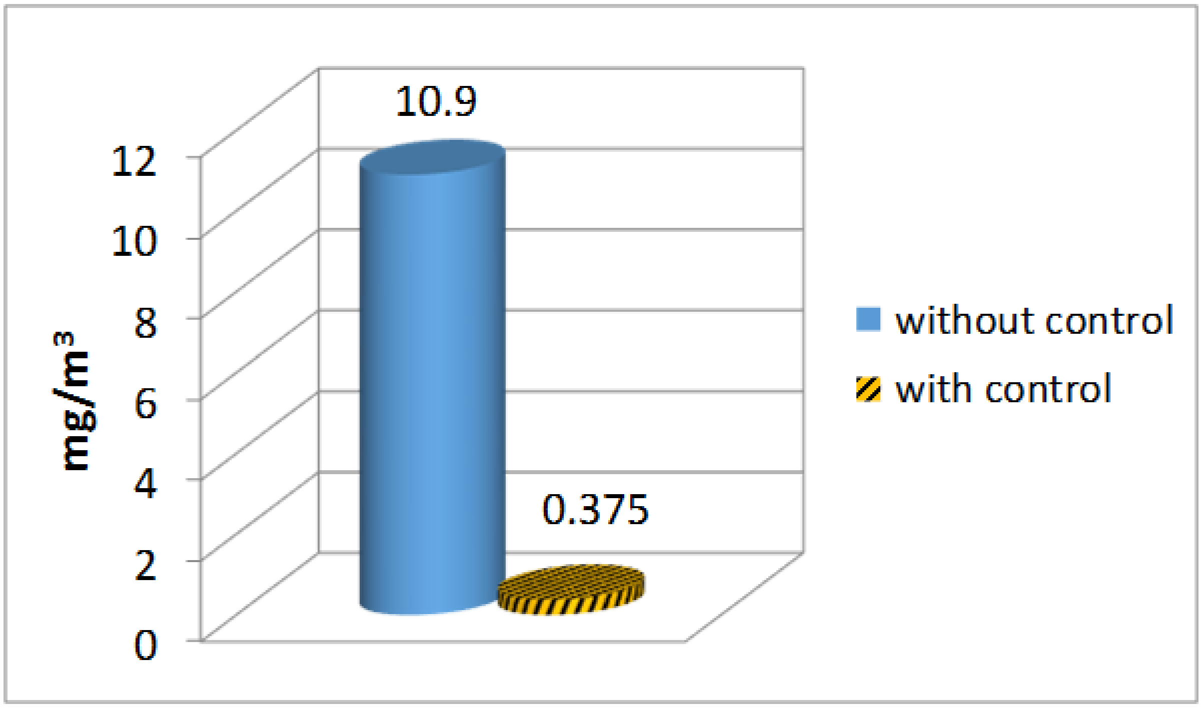
Table 2. Respirable Silica Exposures While Grinding Mortar[A]

	Mean, mg/m^3 (range)	Std. Dev.	Percent Reduction	Hazard Ratio[B]
Hilti Grinder with DC-EX Dust Guard and Hilti VC40-U Vacuum	0.375 (0.224 – 0.738)	0.217	96.6	7.50
Hilti Grinder with no Control	10.9 (3.46 – 31.4)	11.5	NA	218

[A] n = 5 samples for each tool/control combination
[B] Hazard Ratio = measured exposure / NIOSH REL of 0.05 mg/m^3

Grinding mortar with the Hilti angle grinder without dust controls resulted in an average exposure to respirable silica that was ***218 times the NIOSH REL***. Grinding with the Hilti angle grinder in combination with the Hilti DC-EX Dust Guard and Hilti VC40-U vacuum reduced the average concentration of respirable silica by 96.6 percent ($p=0.055$). With use of these controls, the concentration of respirable silica was 7.5 times greater than the NIOSH REL of 0.05 mg/m^3. However, the NIOSH REL is based on exposure concentrations averaged over a 10-hour workday. Given these were *task* TWAs and samples were collected over continuous periods of grinding, they may overestimate exposures likely to occur during an actual workday since some time will be spent on tasks generating minimal, if any, silica (e.g. setup, breaks, cleanup, etc.).

Figure 6. Average respirable silica exposures with and without the Hilti VC40-U vacuum and DC-EX Dust Guard in milligrams per cubic meter of air (mg/m^3)

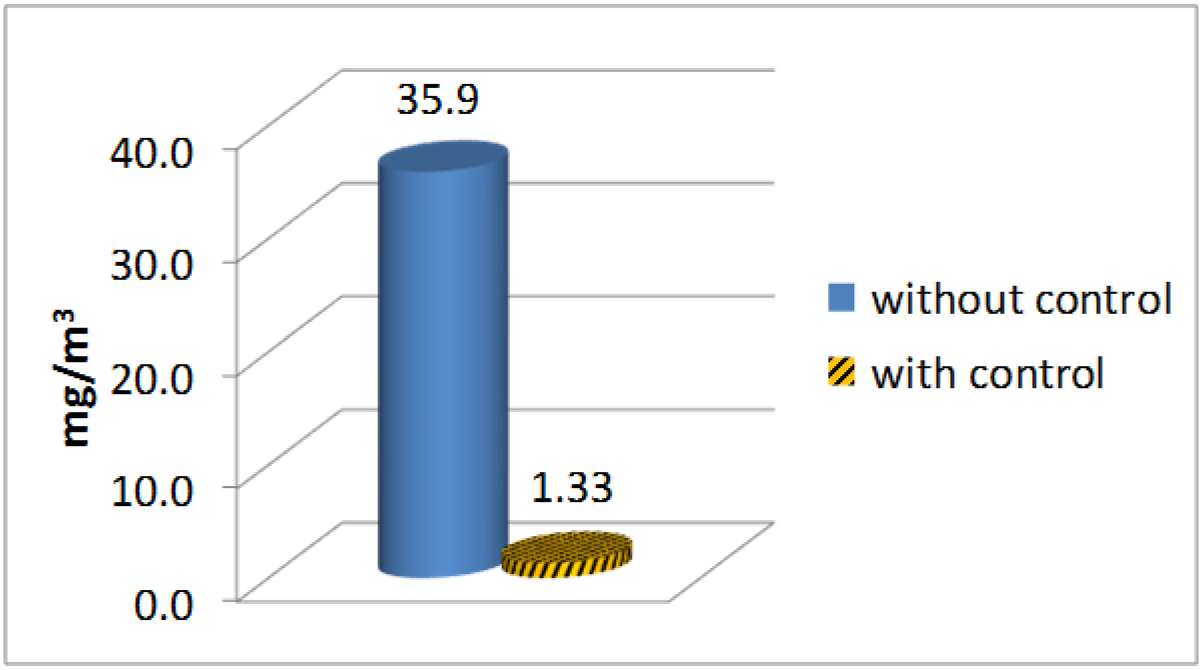


Respirable Dust. The mean respirable dust level measured without LEV was 35.9 mg/m^3. The mean respirable dust levels measured with use of LEV was 1.33 mg/m^3. Use of LEV resulted in a 96.3% reduction in mean respirable dust levels. A graphical depiction of average respirable dust exposures, with and without the dust control system, appears as **Figure 7.**

The respirable dust samples collected with use of the LEV system contained an average of 33 percent silica. The respirable dust samples collected during grinding without the LEV system contained an average of 32 percent silica[1].

[1] Using the formula in **Table 1**, the OSHA PEL for respirable dust containing 33 and 32 percent silica are calculated to be 0.658 and 0.677 mg/m^3, respectively. All of the respirable dust exposures measured while grinding with and without the LEV system, reported in **Table 2**, exceeded these PELs.

Figure 7. Respirable dust exposures with and without Hilti VC40-U Vacuum and DC-EX Dust Guard in milligrams per cubic meter of air (mg/m³)



Static pressure, dust mass collection and grinding rates

Static pressure was used as a field measure from which to derive air flow as described earlier. Hood static pressure was measured before and after each trial at a tap in the hose between the grinder and vacuum and more than 3 duct diameters (approximately 4.25 inches) from the air intake at the shroud. The mean, median, and range of calculated air flow rates are presented in **Table A1 of the Appendix.**

Based on the data we collected during the trials, the air flow measured at the pressure tap downstream from the Hilti grinder and shroud ranged from 65 to 71 cfm with the Hilti VC40-U vacuum. Collingwood and Heitbrink (2007) found that the minimum exhaust flow for capturing silica and other particulate under ideal conditions is 21.25 cfm per inch of grinder blade diameter (96 cfm for a 4.5-inch diameter grinding blade). We set 106 cfm as the minimum desired air flow for this study to allow for potential decline in equipment performance and the possibility of inadequate maintenance, both of which may be likely after repeated use under actual work conditions. At its best, the Hilti VC40-U vacuum provided substantially less than the desired air flow rate for a 4.5-inch blade but air flow did not decrease with use[2].

[2] The average measured air flow was 53% of manufacturer's specifications and 71% of our target of 106 cfm

The duration of vacuum bag use and mass of dust collected were recorded and are presented in **Table A2 of the Appendix**. The vacuum bags were changed and weighed after each trial utilizing the LEV system for a total of five bags were used over 121 minutes. The Hilti VC40-U vacuum captured 38 pounds of dust during 121 minutes of grinding. The rate of dust collection ranged from 0.29 to 0.36 pounds per minute with an average 0.31 pounds per minute. Based on these measurements***, approximately 75 pounds of dust would be captured after one worker completes just 4 hours of continuous grinding***.

The rate of grinding a combination of vertical and horizontal joints while using the LEV system ranged from 2.0 to 2.8 feet per minute with an average of 2.4 feet per minute. The rate of grinding vertical and horizontal joints without the use of the LEV system and with the stock blade guard ranged from 2.5 to 4.0 feet per minute with an average of 3.2 feet per minute. The differences in mean rate of grinding with and without the LEV system was statistically significant ($p<0.02$). This represents a 26% reduction in average cut rates.

VI. Discussion

The objective of these trials was to evaluate the effectiveness of a tuckpointing LEV system for controlling respirable silica while grinding out mortar joints. A Hilti DC-EX Dust Guard and Hilti VC40-U vacuum reduced respirable silica concentrations when grinding with the Hilti grinder by approximately 97 percent. Despite being considered effective by our test criteria (greater than 50% reduction), the results were not statistically significant. In addition, the task TWA exposure with use of the control system still exceeded the 10-hour TWA NIOSH REL of 0.05 mg/m^3 by 7.5 times. Since both sample size and variance influence statistical power calculations, the highly variable nature of tuckpointing silica exposures and the small number of samples (n=5) collected for each treatment (with or without LEV) made it more difficult to demonstrate statistical significance. Exposures measured without use of LEV are particularly variable. For example, among the five samples collected without the LEV system, the highest measured exposure was over nine times the lowest measured exposure. Depending on how much time is spent grinding over the course of a workday and the extent of exposure while performing other tasks, the full shift TWA exposures may or may not exceed the REL with this system.

It's important to note that: 1) the operator had limited experience using the dust control system; and 2) the range of cut rates with and without the dust control system overlapped; that is, the highest cut rate measured with LEV was greater than the lowest cut rate measured without LEV. Given that grinding rates with and without use of this LEV system are only available for a single operator who had limited experience with the LEV system, these reported cut rates are in no way intended to represent the impact use of this LEV system is likely to have on overall productivity rates on an actual job site.

The effectiveness of a tuckpointing LEV system is dependent on the operator's technique and work practices. System performance is likely to increase as workers become more proficient in LEV use. Such proficiency is likely to improve with training and experience. Exposure reduction is greatly influenced by correct use of this system which includes: 1) grinding from right to left[3]; 2) making sure the shroud is held flush against the wall; and 3) making sure that the tool travels at a pace that doesn't exceed the ability of the system to capture dust as it's generated. Deviation from any of these measures produces visible dust clouds, which were observed during trials.

VII. <u>Conclusions</u>

The LEV system we evaluated, which consisted of a Hilti grinder, a Hilti DC-EX Dust Guard, and a VC40-U vacuum reduced TWA respirable silica exposures by 97 percent. Therefore, it met our criteria of reducing exposure by 50%. Use of the tested dust control system may be effective in reducing silica exposure on the job to less than the NIOSH REL if used in combination with administrative controls such as work scheduling to reduce cutting times. Training on correct use of the tested system is also essential. However, employers must conduct personal air monitoring to verify control effectiveness for the materials and work conditions on their respective jobsites. Personal air monitoring is necessary to verify control effectiveness under "real-world" conditions and determine if supplemental controls (administrative or respiratory protection) are needed and are adequate. Nevertheless, these results clearly demonstrate the availability of viable engineering controls for tuckpointing – a task associated with extremely high silica exposures

[3] Grinding from right to left is required for this combination of shroud and grinder. Other shrouds and grinder combinations may allow working from left to right or both directions.

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VIII. Appendices

Table A1. Air Flow Rates Calculated From Static Pressure Measurements

		Air Flow (cfm)*		
Measurement Conditions	**n**	**Mean**	**Median**	**Range**
Grinder not running	11	68	68	65-71

* Static pressure was measured in inches of water gauge. Air flow was calculated using the formula $Q = Ce (A) 4005 (SP)^{1/2}$ where: Q = air flow in cubic feet per minute (cfm), Ce = coefficient of entry, A = area of the duct where static pressure measurements were taken in square feet, and SP = static pressure in inches of water gauge.

Table A2. Rate of Dust Collection

Tool/Control	**Mass Collected (lb)**	**Collection Period (min.)**	**Dust Collection Rate (lb/min.)**
	7	24	0.29
Hilti Grinder with DC-EX	7	24	0.29
Dust Guard and Hilti	8	24	0.33
VC40-U Vacuum	7	24	0.29
	9	25	0.26
		Average	0.31