

**An Evaluation of Silica Exposure Controls for
Tuckpointing: DustControl 2900c Vacuum with the ICS
Dust Director Shroud and Metabo Grinder
Conducted August 13-15, 2012**

**CPWR – The Center for
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Executive Summary

This report describes the results of an evaluation of a tuckpointing dust control system consisting of a **Metabo model WE14-125 PLUS grinder; a Dust Director shroud and a DustControl 2900c vacuum** in a controlled setting. Removing mortar with a Metabo grinder without the dust control system resulted in a mean task time-weighted average (TWA) respirable silica exposure 127 times the recommended exposure limit. Use of the same grinder with the described dust control system reduced exposures by approximately 96 percent. However, exposures measured during the monitored period still exceeded occupational exposure limits.

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 and Background

In 2010 CPWR – The Center for Construction Research and Training began a four-year project which seeks 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 and union representatives, government, equipment manufacturers and health and safety researchers, selected tuckpointing local exhaust ventilation (LEV) systems to be considered for evaluation. A system consisted of a tuckpointing grinder, shroud, and vacuum. At least three systems will be tested before 2014, with and without LEV, in a controlled setting to determine effectiveness in silica exposure reduction. This report is the first in a series of reports that describes testing of the LEV systems selected by the PACT as most promising. The report describes the methods used to test the **DustControl 2900c vacuum with the ICS Dust Director shroud and Metabo 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 silica is generally defined as particles less than 10 micrometers (μm) in aerodynamic diameter (ACGIH, 2012). 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. While not necessarily specific to silica, construction workers exposed to dust 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. Work conducted by NIOSH and CPWR in a controlled setting between 2004 and 2006 demonstrated that grinding mortar without controls can result in elevated respirable silica exposures. Meeker et al., (2009) reported exposures between 5 and 25.8 milligrams per cubic meter (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. 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 **Metabo model WE14-125 PLUS grinder** (Metabo Corporation, West Chester, PA) (**Figures 1 and 2**) was fitted with a 1/4-inch wide, 4½-inch diameter segmented diamond abrasive blade made by DeWalt (model Model #DW4740). The grinder weighs five and a half pounds, draws 12 amps and has variable speed between 7,000 and 10,500 revolutions per minute (RPMs). The **DustControl 2900c vacuum** (DustControl, Inc., Wilmington, NC) (**Figure 3**) was tested in combination with the **Dust Director shroud** (Industrial Contractors' Supplies, Inc., Huntingdon, PA) (**Figures 1 and 3**) attached to the Metabo grinder.

The vacuum is specified to weigh **31 pounds** when empty and to provide a flow rate of 114 cubic feet of air per minute and a “static lift” or “vacuum suction pressure” of 84 inches of water. The vacuum is sold with a cyclonic pre-separator, to remove larger particles, a fine filter (rated 99.9 percent efficient) and a HEPA filter (rated to capture 99.97 percent of the particles with an aerodynamic diameter of 0.3 micrometers).

The HEPA filter was removed based on the manufacturer’s personal recommendation due to the heavy dust loading associated with tuckpointing. CPWR sponsored research and contractor experience have also found use of HEPA filters for tuckpointing to have an adverse effect on dust

Figure 1. Metabo grinder with Dust Director shroud



capture. While the cyclone and the fine filter would remove most of the dust, especially the large particles, before they reach the HEPA filter, the HEPA filter would still be subject to heavy loading, causing a pressure drop and subsequent decrease in air flow rate. 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 rate and ability to capture particles decreases.

Figure 2. Metabo grinder without tuckpointing LEV system



Dust collects in relatively inexpensive, heavy-gauge plastic bags below and outside of the cyclone. The bags can be removed and replaced without opening the vacuum. Some vacuums are equipped with a light to indicate that the filters need to be cleaned or changed.

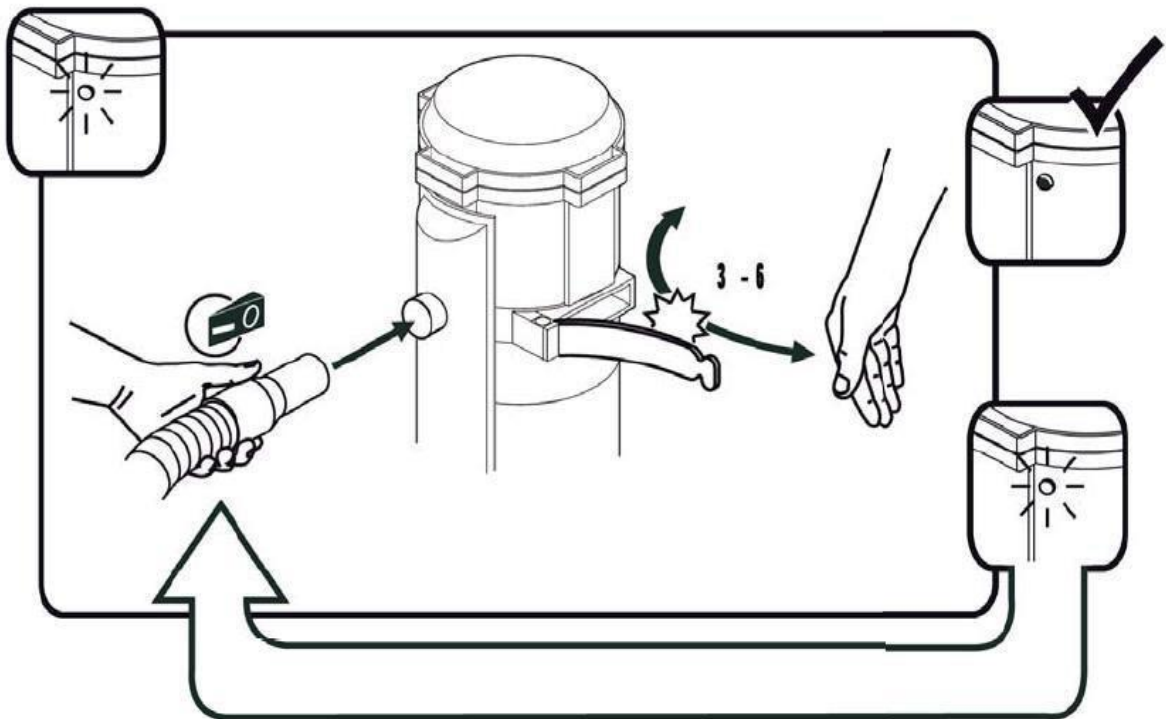
Figure 3. Metabo grinder with Dust Director shroud and DustControl 2900c vacuum



The DC2900c features a “reverse air pulse cleaning system,” which removes accumulated dust from the filters without having to remove them from the vacuum. The system, as illustrated in **Figure 4**, requires the operator to disconnect the hose from the shroud, place it over an air stop so that air through the hose is cut off and pressure in the vacuum is maximized. The flap covering the port on the side of the vacuum is repeatedly flipped open to release built up pressure in strong pulses that dislodge dust from the filter.

The manufacturer indicates “the filter is generally cleaned once or twice daily during normal continuous operation.” The Dust Director shroud has a 2-inch diameter take-off that was connected to the antistatic, corrugated 1.5-inch diameter, 15-foot long vacuum hose supplied with the DustControl vacuum.

Figure 4: Procedure for "cleaning" of or dust removal from filters (source: <http://dustcontrolusa.com/manuals/2800c.pdf>)



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 August 13-15, 2012. A single journeyman bricklayer, experienced in tuckpointing, used the grinder and LEV system being tested to remove mortar from joints wide enough to require two passes. 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). 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 high-efficiency particulate air (HEPA) filter (Interactive Safety Products, Inc., Huntersville, NC).

The study was designed to include five rounds of sampling during mortar removal. Each round included a trial using the Metabo grinder with a Dust Director shroud and Dust Collector 2900c vacuum and a trial using the Metabo grinder with the factory-supplied guard and without a vacuum. The order of the two trials within each round was randomly selected to minimize bias that might be introduced due to variation associated with environmental factors, equipment operator, and factors other than controls being evaluated. Tools were operated for approximately 26 minutes per trial with controls and for approximately 13 minutes when controls were not used. These times were selected based on estimates of the minimum sample time needed to achieve the analytical sensitivity necessary to accurately measure down to 0.05 mg/m³ – the National Institute for Occupational Safety and Health (NIOSH), Recommended Exposure Limit (REL) for respirable silica – with use of the LEV system. The bricklayer was required to take a 5 to 10 minute break in the middle of the 26-minute trials to reduce differences in fatigue, compared to the 13-minute trials.

Personal air samples were collected in the breathing zone of the operator 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.

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 at the end 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 and 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 respirable silica exposure concentrations or a reduction to less than the NIOSH REL of 0.05 mg/m³ as our criteria for determining whether or not a control was considered efficacious. This is consistent with criteria used by NIOSH in conducting a similar study in 2004

described by Echt et al. (2007) and by CPWR in 2006 and described by Meeker et al. (2009). Occupational exposure limits for respirable silica are listed in **Table 3**.

The flow of air in ventilation systems is governed by fundamental principles that describe the behavior of gases (in this case air). Pressure measurements taken within a ventilation system along with knowledge of hood (or shroud) entry losses can be used to calculate flow rates. 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)” which is the ratio of *actual* air flow through a hood and what the air flow would *theoretically* be if there were no hood entry losses whatsoever. Given this relationship and the coefficient of entry, static pressure measurements can be used to calculate air flow through a given hood. The coefficient of entry for the Dust Director shroud was previously determined by CPWR and used for calculating air flow based on static pressure measurements (Meeker et al., 2009). Static pressure, with the vacuum operating, was measured periodically throughout the evaluation to monitor air flow rate with use and after filter cleaning. The static pressure was measured at a port positioned more than 3 duct diameters downstream from the tool’s air intake using a U Ei EM200 Electronic Manometer (Universal Enterprises, Inc., Beaverton, OR).

The dust in the vacuum bag was monitored and, per the manufacturer’s instructions, the bag was changed before the dust level was within 5 centimeters of the valve at the bottom of the vacuum. Each time a vacuum bag was removed it was weighed to the nearest pound. 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 (head) and horizontal (bed) joints 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 level and configured to measure respirable particulate concentration.

V. **Results**

Personal air monitoring. Five pairs of respirable dust samples were collected while grinding with and without the LEV system. Samples were analyzed by RJ Lee, Inc. (Monroeville, PA) for respirable silica and respirable dust. Personal air monitoring results for respirable silica and a comparison of average exposures relative to the NIOSH REL for silica (0.05 mg/m³) appears in **Table 1**. Personal air monitoring results for respirable dust appears in **Table 2**. Graphical depictions of average respirable silica and dust exposures, with and without the dust control system, appear as **Figures 5 and 6**, respectively.

Figure 5. Average respirable silica exposures with and without the Dustcontrol 2900c vacuum and Dust Director shroud (milligrams per cubic meter of air - mg/m³)

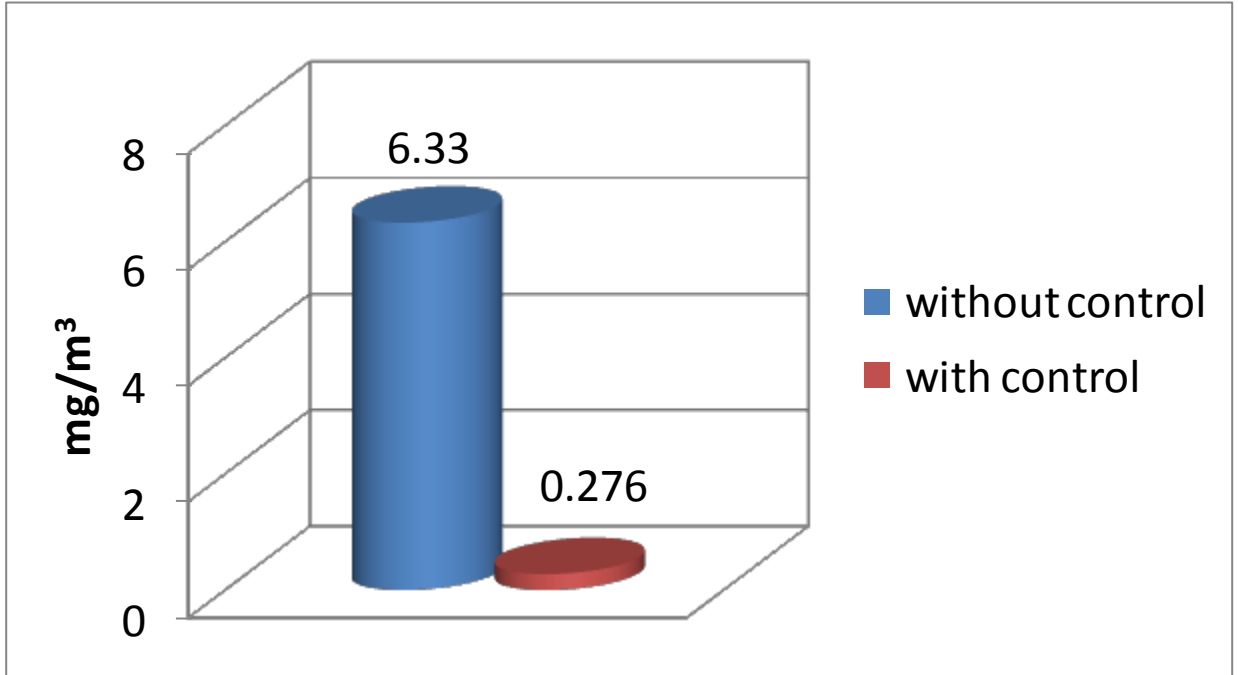


Table 1. Respirable Silica Exposures While Grinding Mortar^A

	Mean, mg/m ³ (range)	Std. Dev.	Percent Reduction	Hazard Ratio ^B
Metabo with Dust Director Shroud and DustControl 2900c Vacuum	0.276 (0.210 - 0.539)	0.160	95.6	5.52
Metabo with no Control	6.33 (5.06 - 7.26)	0.988	NA	127

^A n = 5 samples for each tool/control combination

^B Hazard Ratio = measured exposure / NIOSH REL of 0.05 mg/m³

Figure 6. Respirable dust exposures with and without Dustcontrol 2900c Vacuum and Dust Director Shroud (milligrams per cubic meter of air – mg/m³)

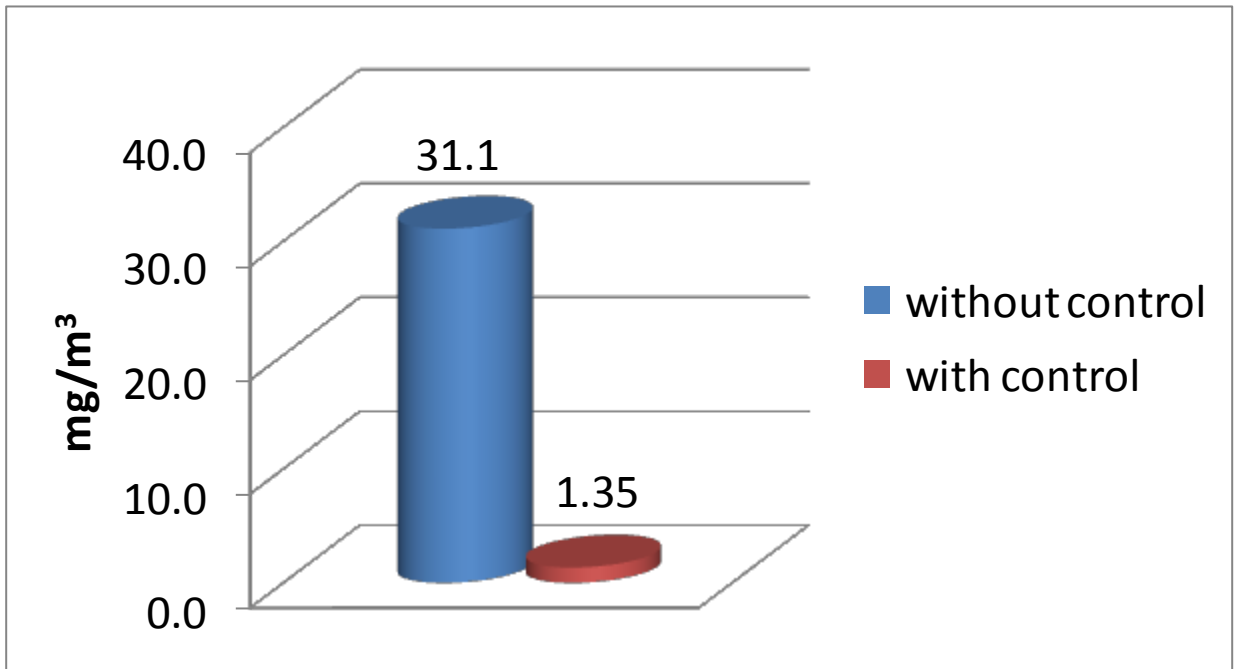


Table 2. Respirable Dust Exposures While Grinding Mortar^A

	Mean, mg/m ³ (range)	Std. Dev.	Percent Reduction
Metabo with Dust Director Shroud and DustControl 2900c Vacuum	1.35 (0.938 – 2.12)	0.497	95.6
Metabo with no Control	31.1 (20.7 – 51.1)	12.7	NA

^An = 5 samples for each tool/control combination

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 3** with 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 3. Occupational Exposure Limits for Respirable Crystalline Silica

Organization or Agency	Form of Crystalline Silica	Occupational Exposure Limits (mg/m³)
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

^ANIOSH Publication No. 2005-151 indicates 10-hour time-weighted average during a 40-hr workweek

^BThe 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 expressed in millions of particles per cubic foot (mppcf).

The impinger method that was once used to determine silica exposure in millions of particles per cubic foot (mppcf) is now obsolete. However, the construction PEL is still defined using those units. Dorr Oliver, Higgins Dewell, or other cyclone samplers which select for respirable particulate and gravimetric analysis are currently used with laboratory analysis to measure silica concentration in milligrams of silica per cubic meter of air (mg/m³). The formula used by OSHA to determine the PEL for silica is dependent on the percentage of silica in collected respirable dust and presented in Table 3. Milligrams per cubic meter can be derived by dividing mppcf by 10 (OSHA, 2009).

The respirable dust samples collected with use of the LEV system contained an average of 19 percent silica. The respirable dust samples collected during grinding without the LEV system contained an average of 22 percent silica. Using the formula in Table 3, the OSHA PELs for respirable dust containing 19 and 22 percent silica are calculated to be 1.042 and 0.926 mg/m³, respectively. The mean respirable dust exposures measured while grinding with and without the LEV system, reported in **Table 2**, exceeded these PELs.

The mean respirable silica concentration measured during use of the control was significantly less than the concentration measured while using the same tool without controls (p<0.01). Grinding mortar with the Metabo angle grinder without dust controls resulted in an average exposure to respirable silica that was **127 times the NIOSH REL**. Grinding with the Metabo angle grinder in combination with the Dust Director shroud and the DustControl 2900c vacuum reduced the average concentration of respirable silica by 95.6 percent. With use of these controls, the concentration of respirable silica was 5.52 times greater than the NIOSH REL of 0.05

mg/m³. However the NIOSH REL is based on a time-weighted average (TWA) over a 10-hour workday. Given these were *task* TWAs and samples were collected over continuous periods of grinding, they may overestimate exposures over an actual work day since some time would be spent performing tasks that would likely have lower, or no, silica exposures (setup, breaks, cleanup, etc.).

Static pressure, dust mass collection and grinding rates. Static pressure was used as a surrogate for air flow as described earlier. Hood static pressure was measured periodically at a tap near the grinder more than 3 duct diameters from the air intake in the shroud. The static pressure, and thus air flow, was generally higher when the vacuum's filter had recently been cleaned. The mean, median, and range of calculated flow rates are presented in **Table A1 of the Appendix**.

Based on the data we collected, the air flow rate upstream from the Metabo grinder and Dust Director shroud ranged from 62 to 98 cubic feet per minute (cfm) with the DustControl vacuum. When the manufacturer's filter cleaning procedure was followed the vacuum performed relatively well and flow could be maintained at approximately 98 cfm with cleaning. However, based on a comparison of mean flow rates, flow drops substantially to 71 cfm after approximately 50 minutes of grinding without any filter cleaning. The flow rate returned to an average of 82 cfm when filters were cleaned correctly (without stopping air flow to the vacuum). Collingwood and Heitbrink (2007) found that the minimum exhaust flow rate for capture of silica and other particulate under ideal conditions is 21.25 cfm per inch of grinder blade diameter. This works out to about 96 cfm when using a 4.5 inch diameter grinding blade. We set 106 cfm as the minimum desired flow rate 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 DustControl vacuum provided the desired flow rate for a 4.5-inch blade but the flow rate fell below 96 cfm with repeated use.

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 after approximately 54 minutes of continuous grinding. A total of three bags were used to complete the five rounds of grinding. The DustControl vacuum captured 55 pounds of dust over 134 minutes of grinding for an average rate of dust collection of 0.397 pounds per minute. The rate of dust collection ranged from 0.333 to 0.481 pounds per minute. Based on these measurements, ***approximately 100 pounds of dust would likely be captured after just 4 hours of continuous grinding.***

The rate of grinding a combination of vertical and horizontal joints while using the LEV system ranged from 1.9 to 2.4 feet per minute. The rate of grinding vertical and horizontal joints without the use of the LEV system ranged from 2.1 to 4.9 feet per minute.

It's important to note that: 1) the operator had limited experience using dust control systems and cut rates appeared to improve over the 2-day period he used the tested

equipment; and 2) while the *lowest* measured cut rate with the dust control system was well below the *highest* cut rate without the system in place, the range of cut rates with and without the dust control system overlapped.

Given that grinding rates with and without use of this LEV system are only available for one operator and he had limited experience with the LEV system, we are unable to draw any general conclusions on the effect the LEV system has on the rate of grinding. However, since additional evaluations of other systems are planned using multiple operators, differences in grinding rates are important to document since the grinding rate is directly related to the dust generation rate. Comparing the percent reduction each system is capable of achieving without taking this into account would result in an unfair comparison between systems given operator variability.

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. The Dust Director shroud with the DustControl 2900c vacuum reduced respirable silica concentrations when grinding with the Metabo grinder by approximately 96 percent. Despite being considered effective by our test criteria (greater than 50% reduction), it still resulted in task TWA exposures that exceeded the NIOSH REL of 0.05 mg/m³ by 5.5 times. Depending on how much time is spent grinding over the course of a work day and exposures while performing other tasks, the 8-hour TWA exposures may or may not exceed the REL with this system. Based on our observation of visual dust emissions when the shroud and vacuum-equipped grinder was operated in the wrong direction, it appears that incorrect operator use and/or lack of training on correct use results in extremely high dust levels. Training and greater proficiency in use of this equipment will likely improve dust capture performance.

VII. **Conclusions**

With **96 percent reduction in respirable silica**, the **Dust Director shroud and DustControl 2900c vacuum with a Metabo** grinder was effective in reducing silica exposures based on 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 including reducing cutting times and training on correct use of the tested system. Employers must conduct personal air monitoring to verify control effectiveness for the materials and work conditions on their jobsites. Further evaluation of this system on actual job sites is needed to determine effectiveness under “real-world” conditions. These results demonstrate the availability of viable engineering controls for tuckpointing operations associated with elevated silica exposure.

VIII. References

American Conference of Governmental Industrial Hygienists. Threshold limit values for chemical substances (TLV®-CS). [2012]. ACGIH, Cincinnati.

Bergdahl I.A., Toren K., Eriksson K., et al. [2004]. Increased mortality in COPD among construction workers exposed to inorganic dust. *European Respiratory Journal*, 23: 402–06.

Blanc P.D. & Torén K. [2007]. Occupation in chronic obstructive pulmonary disease and chronic bronchitis: an update [State of the Art Series. Occupational lung disease in high-and low-income countries, Edited by M. Chan-Yeung. Number 2 in the series]. *The International Journal of Tuberculosis and Lung Disease*, 11(3), 251-257.

Collingwood S. & Heitbrink W.A. [2007] 'Field Evaluation of an Engineering Control for Respirable Crystalline Silica Exposures During Mortar Removal'. *Journal of Occupational and Environmental Hygiene*, 4:11, 875 – 887.

DHHS (NIOSH) Publication No. 2002-129
April 2002 <http://www.cdc.gov/niosh/pdfs/02-129.pdf>

Echt A., Sieber W.K., Lefkowitz D., Meeker J., Susi P., Cardwell B., Heitbrink, W.A. In-depth survey of dust control technology for cutting concrete block and tuckpointing brick at The International Masonry Institute Bordentown Training Center, Bordentown, NJ. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Report.

Heitbrink W., Bennett J. [2006]. A numerical and experimental investigation of crystalline silica exposure control during tuck pointing. *Journal of Occupational and Environmental Hygiene*, Vol. 3, pp 366-378.

Lyons et al, [2007]. A breathless builder. *Breathe*, Vol. 3, no. 4, pp 386-390.

Mastrangelo G., Tartari M., Fedeli U., Fadda E., Saia B. [2003]. Ascertaining the risk of chronic obstructive pulmonary disease in relation to occupation using a case-control design. *Occupational Medicine*, 53: 165–172.

Meeker J., Cooper M., Lefrowitz D., Susi P. [2009]. Engineering control technologies to reduce occupational silica exposures in masonry cutting and tuckpointing. *Public Health Reports*, Supplement 1, Vol. 124, June.

Meeker J, Flynn M, Susi P, Cardwell, B [2004]. Performance evaluation of a masonry concrete vacuum. Unpublished Report.

Miller F. W., Alfredsson L., Costenbader K. H., Kamen D. L., Nelson L. M., Norris J. M., & De Roos A. J. [2012]. Epidemiology of environmental exposures and human autoimmune diseases: findings from a National Institute of Environmental Health Sciences Expert Panel workshop. *Journal of autoimmunity*. No. EPHB 282-13; 2007. <http://www.cdc.gov/niosh/surveyreports/pdfs/ECTB-282-13.pdf>.

Occupational Safety and Health Administration U.S Department of Labor. Controlling Silica Exposures in Construction. [2009]. OSHA 3362-05.

Rappaport SM, Goldberg M, Susi P, Herrick RF [2003]. Excessive exposure to silica in the U.S. construction industry. *Annals of Occupational Hygiene*, Vol. 47, pp. 111-122.

IX. Appendices

Table A1. Flow Rates Calculated From Static Pressure Measurements

Measurement Conditions	n	Flow Rate (cfm)*		
		Mean	Median	Range
After grinding, before filter cleaning	3	72	74	62-78
After filter cleaning following manufacturer directions	2	98	98	98
After improper filter cleaning	5	82	80	78-92

* Static pressure was measured in millibars and converted to inches of water gauge. Flow rates were calculated using the formula $Q = C_e (A) 4005 \sqrt{SP}$ where: Q = flow rate in cubic feet per minute (cfm), C_e = 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	Collection Period (min.)	Dust Collection Rate (lb/min.)
Metabo grinder/DustDirector shroud & DustControl 2900c vacuum	54	0.481
	53	0.377
	27	0.333
	Average	0.397