In-Depth Survey Report

Partnering to Control Dust from Fiber-Cement Siding

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Villas of the Valley
Lincoln Heights, Ohio

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DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Site Surveyed:

Villas of the Valley
Cross-section of Wayne Ave. and Lindy Ave.
Lincoln Heights, OH 45215

NAICS Code:

23611 Residential Building Construction

Survey Dates:

July 18th, 19th, 23rd and 24th, 2012

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Abstract

Background

Workplace exposure to respirable crystalline silica can cause silicosis, a progressive lung disease marked by scarring and thickening of the lung tissue. Quartz is the most common form of crystalline silica. Crystalline silica is found in several construction materials, such as brick, block, mortar and concrete. Construction tasks that cut, break, grind, abrade, or drill those materials have been associated with overexposure to dust containing respirable crystalline silica. Fiber-cement products can contain as much as 50 percent crystalline silica. Cutting this material has been shown to cause excessive exposures to respirable crystalline silica. NIOSH scientists are conducting a study to develop engineering control recommendations for respirable crystalline silica from cutting fiber-cement siding. This site visit was part of that study.

Assessment

NIOSH staff visited the Villas of the Valley construction site in Lincoln Heights, Ohio on July 18, 19, 23 and 24, 2012. During those visits, they performed industrial hygiene sampling which measured the exposures to respirable dust and respirable crystalline silica of one worker who cut fiber-cement siding for the construction of two single family houses. The NIOSH scientists also monitored the wind speed and direction at the site, and collected data about the work process in order to understand the conditions that led to the measured exposures.

Results

Air sampling for respirable dust and crystalline silica showed that on three of the four days, the worker was exposed to respirable quartz (the most common form of crystalline silica) at concentrations that exceeded the NIOSH Recommended Exposure Limit (REL) of 0.05 mg/m^3. The one day in which the worker's exposure to respirable quartz was lower than the NIOSH REL was probably due to shortened work time due to rain. The air sampling also showed that on one day, the worker was exposed to respirable dust in excess of the OSHA Permissible Exposure Limit for respirable dust that contains greater than 1% quartz.

Conclusions and Recommendations

The concentrations of respirable dust and respirable crystalline silica measured while the worker cut fiber-cement siding indicated that the potential for overexposure exists when no dust controls are used. The measured exposures indicate that dust controls should be used for the power saws cutting fiber-cement siding. In the absence of dust controls, respirators should be used to reduce exposures.

NIOSH recommends (and it is mandated by OSHA where the use of respirators is required) that respirators in the workplace be used as part of a comprehensive respiratory protection program following the OSHA standard.

Introduction

Background for Control Technology Studies

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Since 1976, EPHB has conducted a number of assessments of health hazard control technologies on the basis of industry, common industrial process, or specific control techniques. Examples of these completed studies include the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involve a number of steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concept techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

Background for this Study

Crystalline silica refers to a group of minerals composed of silicon and oxygen; a crystalline structure is one in which the atoms are arranged in a repeating three-dimensional pattern [Bureau of Mines 1992]. The three major forms of crystalline silica are quartz, cristobalite, and tridymite; quartz is the most common form [Bureau of Mines 1992]. Respirable crystalline silica refers to that portion of airborne crystalline silica dust that is capable of entering the gas-exchange regions of the lungs if inhaled; this includes particles with aerodynamic diameters less than approximately 10 micrometers (μm) [NIOSH 2002]. Silicosis, a fibrotic disease of the lungs, is an occupational respiratory disease caused by the inhalation and deposition of respirable crystalline silica dust [NIOSH 1986]. Silicosis is irreversible, often progressive (even after exposure has ceased), and potentially fatal. Because no effective treatment exists for silicosis, prevention through exposure control is essential.

Crystalline silica is a constituent of several materials commonly used in construction, including brick, block, and concrete. Many construction tasks have been associated with overexposure to dust containing crystalline silica [Chisholm 1999, Flanagan et al. 2003, Rappaport et al. 2003, Woskie et al. 2002]. Among these tasks are tuckpointing, concrete cutting, concrete grinding, abrasive blasting, and road milling [Nash and Williams 2000, Thorpe et al. 1999, Akbar-Kanzadeh and Brillhart 2002, Glindmeyer and Hammad 1988, Linch 2002, Rappaport et al. 2003]. Fiber-cement products can contain as much as 50 percent crystalline silica. Cutting this material has been shown to cause excessive exposures to respirable crystalline silica [Lofgren et al. 2004].

The use of fiber-cement siding in construction and renovation is undergoing rapid growth. From 1999 to 2008, the market share of fiber-cement siding has climbed from 1 percent to 12 percent of the annual market of 7.3 to 8.5 billion square feet of siding used in exterior construction [Gupta 2006, Markovitz 2009, James Hardie Industries 2009, US Census Bureau 2009]. In contrast, the market share of wood siding in residential construction has decreased from 33 percent to 9 percent [US Census Bureau 2009]. The durability and appearance of fiber-cement siding, which simulates wood without the maintenance problems associated with wood siding, is appealing and provides a competitive advantage over other building materials [Bousquin 2009]. The use of fiber-cement siding is expected to continue to increase. The number of workers exposed to dust containing crystalline silica as a result can also be expected to increase as the use of fiber-cement siding displaces other siding products.

Cellulose fiber, sand or fly ash, cement, and water are the principal ingredients used in the manufacture of fiber-cement products. James Hardie Industries, CertainTeed, Maxitile and Nichiha are the major manufactures of fiber-cement products. James Hardie Industries [2009] has acknowledged that exposure to respirable crystalline silica during installation of fiber-cement products is a significant liability issue for their industry.

Fiber-cement board is cut using three methods: scoring and snapping the board, cutting the board using shears, and cutting the board using a power saw. When scoring and snapping the board, a knife is used to score the board by scribing a deep line into the board. The board is bent, and it breaks along the scored line. This method should be relatively dust-free. The score and snap method can be used when installing fiber-cement board used for tile underlayment, but is not applicable to siding. Commercially available tools used to shear fiber-cement siding include a foot-powered shear and hand-held powered shears. These shears are reportedly a relatively dust-free method of cutting fiber-cement siding. However, slow production rates and low precision limit the use of shears by siding contractors [Bousquin 2009].

Power saws, such as circular saws and compound miter saws, are widely used to cut fiber-cement siding. These saws are used with polycrystalline diamond-tipped blades with 4-8 teeth specifically designed to cut fiber-cement siding and minimize dust generation. Several commercially available saws are manufactured with hoods and exhaust take-offs that can be connected to vacuum cleaners or to dust-collection bags. These hoods partially enclose the saw blade. Available blade diameters are 5, 7.25, 10, and 12 inches.

The study by Lofgren et al. [2004] reported that cutters' exposures to respirable crystalline silica ranged from 0.02 milligrams per cubic meter (mg/m^3) to 0.27 mg/m^3 during sampling, and 8-hour (hr) time weighted average (TWA) exposure ranged from 0.01 mg/m^3 to 0.17 mg/m^3 depending on the length of exposure on the day sampled. The highest result was 3.4 times the NIOSH Recommended Exposure Limit (REL) for crystalline silica of 50 micrograms per cubic meter ($\mu g/m^3$).

The long-term objective of this study is to provide practical recommendations for effective dust controls that will prevent overexposures to respirable crystalline silica while cutting fiber-cement siding. The specific aims of the project are: 1) Develop dilution ventilation rate recommendations in the lab; 2) Experimentally develop local exhaust ventilation recommendations for circular saws and compound miter saws used to cut fiber-cement siding; 3) Validate, at actual construction sites, the recommendations developed from the laboratory studies; and 4) Disseminate information in the forms of technical reports, journal articles, NIOSH Workplace Solutions document, trade journals articles, home remodeling publications, and other media directed at the construction and remodeling industries, including the do-it-yourself market, to promote the use of the recommendations.

Background for this Survey

In order to assess the effectiveness of the dust controls, it was necessary to gather baseline data by evaluating exposures at a site where no dust controls were used for cutting fiber-cement siding (as is typically the case). This survey was performed on July 18, 19, 23 and 24, 2012 in the Villas of the Valley of Lincoln Heights, a suburb of Cincinnati, Ohio. Air sampling was conducted to assess the extent of respirable dust and crystalline silica exposure from cutting fiber-cement siding.

Construction Site and Process Description

Introduction

The Model Group is an integrated property development, construction, and management company in Cincinnati, Ohio. In 2011, the Model Group started a complete multi-phased redevelopment project named Villas of the Valley in Lincoln Heights, Ohio. The first phase of Villas of the Valley included the new construction of 42 senior cottages and the demolition and rebuilding of a 2,400 square foot community center. Phase II completed the demolition of the remaining vacant and decaying buildings on the site and in their place created a $6.7 million development of 35 rental townhomes. The final Villas phase is a homeownership project with the construction of five single family homes. This survey was taken in the final phase of the project on the construction of two single family houses. The task of installing fiber-cement siding was subcontracted by the Model Group to a group of contractors, who participated in the survey.

Process Description

Fiber-cement siding was installed on the outside of two single family houses by three construction laborers on all four days of air sampling. One laborer (cutter) operated either a circular saw or a compound miter saw to cut fiber-cement siding boards. Two other laborers (installers) who worked as a team, took the measurements, verbally communicated the size requirement to the cutter, and installed the siding boards. Personal air samples were taken only from the cutter, who had a beard and did not wear a respirator.

Figure 1 – The Construction Site.

The circular saw used was a Makita brand (Model 5007N), and the miter saw was a Kobalt brand (Model 0358937). Both saws used 4-teeth polycrystalline diamond blades (IRWIN, Model 4935473) with a blade diameter of 7.25-inch and a maximum RPM of 7,300. The Makita circular saw has an operating specification of 5,800 RPM, and the Kobalt miter saw has a specification of 5,000 RPM. Actual operating RPM of both saws were measured using a Pocket Tachometer (Model TAC2K, Dwyer Instruments Inc., Michigan City, IN). The Makita circular saw measured at 5765 RPM and the Kobalt miter saw measured at 5920 RPM. During the entire survey, the cutter cut only one board at a time and it was done mainly using the Makita circular saw (68% of the total number of cuts and 86% of the total siding length of cut).

The fiber cement siding boards installed during the survey were manufactured by CertainTeed. The manufacturing dates ranged from 08/04/2011 to 04/03/2012.

Figure 2 – Laborer (cutter) operating a circular saw and cutting the fiber-cement siding.

Occupational Exposure Limits and Health Effects

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH investigators use mandatory and recommended Occupational Exposure Limits (OELs) when evaluating chemical, physical, and biological agents in the workplace. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Combined effects are often not considered in the OEL. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus can increase the overall exposure. Finally, OELs may change over the years as new information on the toxic effects of an agent become available.

Most OELs are expressed as a TWA exposure. A TWA exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have a recommended Short Term Exposure Limit (STEL) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

In the U.S., OELs have been established by Federal agencies, professional organizations, state and local governments, and other entities. The U.S. Department of Labor OSHA Permissible Exposure Limits (PELs) [29 CFR 1910.1000 2003a] are occupational exposure limits that are legally enforceable in covered workplaces under the Occupational Safety and Health Act. NIOSH recommendations are based on a critical review of the scientific and technical information available on the prevalence of health effects, the existence of safety and health risks, and the adequacy of methods to identify and control hazards [NIOSH 1992]. They have been developed using a weight of evidence approach and formal peer review process. Other OELs that are commonly used and cited in the U.S. include the Threshold Limit Values (TLVs®) recommended by American Conference of Governmental Industrial Hygienists (ACGIH®), a professional organization [ACGIH® 2010a]. ACGIH® TLVs® are considered voluntary guidelines for use by industrial hygienists and others trained in this discipline “to assist in the control of health hazards.” Workplace Environmental Exposure Levels™ (WEELs) are recommended OELs developed by the American Industrial Hygiene Association® (AIHA), another professional organization. WEELs have been established for some chemicals “when no other legal or authoritative limits exist” [AIHA 2007].

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91–596, sec. 5(a)(1)]. Thus, employers are required to comply with OSHA PELs. Some hazardous agents do not have PELs, however, and for others, the PELs do not reflect the most current health-based information. Thus, NIOSH investigators encourage employers to consider the other OELs in making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminating or minimizing identified workplace hazards. This includes, in preferential order, the use of: (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation) (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection).

Crystalline Silica Exposure Limits

When dust controls are not used or maintained or proper practices are not followed, respirable crystalline silica exposures can exceed the NIOSH REL, the OSHA PEL, or the ACGIH® TLV®. NIOSH recommends an exposure limit for respirable crystalline silica of 0.05 mg/m^3 as a TWA determined during a full-shift sample for up to a 10-hr workday during a 40-hr workweek to reduce the risk of developing silicosis, lung cancer, and other adverse health effects [NIOSH 2002]. When source controls cannot keep exposures below the NIOSH REL, NIOSH also recommends minimizing the risk of illness that remains for workers exposed at the REL by substituting less hazardous materials for crystalline silica when feasible, by using appropriate respiratory protection, and by making medical examinations available to exposed workers [NIOSH 2002]. In cases of simultaneous exposure to more than one form of crystalline silica, the concentration of free silica in air can be expressed as micrograms of free silica per cubic meter of air sampled (µg/m^3) [NIOSH 1975].

$$\mu g\, SiO_2/m^3 = \frac{\mu g\, Q + \mu g\, C + \mu g\, T + \mu g\, P}{V} \qquad (1)$$

Where Q is quartz, C is cristobalite, and T is tridymite, P is “other polymorphs”, and V is sampled air volume.

The current OSHA PEL for respirable dust containing crystalline silica for the construction industry is measured by impinger sampling. In the construction industry, the PELs for cristobalite and quartz are the same. The PELs are expressed in millions of particles per cubic foot (mppcf) and calculated using the following formula [29 CFR 1926.55 2003b]:

$$\text{Respirable PEL} = \frac{250\ \text{mppcf}}{\%\ \text{Silica} + 5} \qquad (2)$$

Since the PELs were adopted, the impinger sampling method has been rendered obsolete by gravimetric sampling [OSHA 1996]. OSHA currently instructs its compliance officers to apply a conversion factor of 0.1 mg/m^3 per mppcf when converting between gravimetric sampling and the particle count standard when characterizing construction operation exposures [OSHA 2008].

The ACGIH® TLV® for α-quartz (the most abundant toxic form of silica, stable below 573°C) and cristobalite (respirable fraction) is 0.025 mg/m^3 [ACGIH® 2010a].

For the purposes of this survey, when the workday exceeded eight hours, the model developed by Brief and Scala [1975] was used to adjust the PEL and TLV®. The conservative Brief and Scala model results in the calculation of a reduction factor, expressed as:

$$RF = \frac{8}{h} \times \frac{24 - h}{16} \qquad (3)$$

Where RF is the reduction factor and h is the actual work shift time in hours. The occupational exposure limit (e.g., the PEL or TLV®; the numbers 10 and 14 are substituted for 8 and 16, respectively, for the REL when the work shift exceeds 10 hours) is multiplied by the reduction factor to arrive at an adjusted occupational exposure limit.

Methodology

Sampling Strategy

In three of the four survey days, one sample was taken before lunch break and one after lunch break. On July 19th, only one sample was taken in the morning because work was canceled in the late morning and afternoon due to rain. The total sampling times reflect the period sampled while the cutter was working on the survey construction site.

Sampling Procedures

Air Sampling

Personal breathing zone air samples for respirable particulate were collected at a flow rate of 4.2 liters/minute (L/min) using a battery-operated sampling pump (model 224-PCXR8, SKC, Inc., Eighty Four, PA) calibrated before and after each day's use. A sampling pump was clipped to the sampled cutter's belt worn at his waist. The pump was connected via Tygon® tubing and a tapered Leur-type fitting to a pre-weighed, 37-mm diameter, 5-micron (µm) pore-size polyvinyl chloride filter supported by a backup pad in a three-piece filter cassette sealed with a cellulose shrink band (in accordance with NIOSH Methods 0600 and 7500) [NIOSH 1998, NIOSH 2003]. The front portion of the cassette was removed and the cassette was attached to a respirable dust cyclone (model GK2.69, BGI Inc., Waltham, MA). At a flow rate of 4.2 L/min, the GK2.69 cyclone has a 50% cut point of (D_{50}) of 4.0 µm [BGI 2011]. D_{50} is the aerodynamic diameter of the particle at which penetration into the cyclone declines to 50% [Vincent 2007]. The cyclone was clipped to the sampled cutter's shirt near his head and neck. Bulk samples of dust were also collected in accordance with NIOSH Method 7500 [NIOSH 2003].

The filter samples were analyzed for respirable particulates according to NIOSH Method 0600 [NIOSH 1998]. The filters were allowed to equilibrate for a minimum of two hours before weighing. A static neutralizer was placed in front of the balance (model AT201, Mettler-Toledo, Columbus, OH) and each filter was passed over the neutralizer before weighing. The limit of detection (LOD) was 40 µg/sample. The limit of quantitation (LOQ) was 130 µg/sample. The results in this report were corrected for laboratory and field blanks.

Crystalline silica analysis of filter and bulk samples was performed using X-ray diffraction according to NIOSH Method 7500 [NIOSH 2003]. The LODs for quartz, cristobalite and tridymite were 5 µg/sample, 10 µg/sample, and 10 µg/sample, respectively. The LOQs for quartz, cristobalite and tridymite were 17 µg/sample, 33 µg/sample, and 33 µg/sample, respectively. The results in this report were corrected for laboratory and field blanks.

Weather Monitoring Methods

On each survey working day, the NIOSH researchers used a Kestrel model 4500 Weather Meter (Nielsen-Kellerman Co., Boothwyn, PA), which was placed atop a tripod at the backyard of the construction site. The weather meter was programmed to record data (including wind direction and speed, temperature, relative humidity and altitude) every 10 minutes.

Average wind direction was calculated using the equation [EPA 2000]

$$\bar{\theta}_{RV} = ArcTan\left(V_x/V_y\right) + FLOW \qquad (4)$$

$$FLOW \begin{matrix} = +180; for\ ArcTan\left(V_x/V_y\right) < 180 \\ = -180; for\ ArcTan\left(V_x/V_y\right) > 180 \end{matrix} \qquad (5)$$

Where

$$V_x = -\frac{1}{N}\sum \sin\theta_i \qquad (6)$$

And

$$V_y = -\frac{1}{N}\sum \cos\theta_i \qquad (7)$$

$\bar{\theta}_{RV}$ is the resultant mean wind direction

V_x is the magnitude of the east-west component of the unit vector mean wind

V_y is the magnitude of the north-south component of the unit vector mean wind

θ_i is the azimuth angle of the wind vector, measured clockwise from north (i.e., the wind direction)

In spreadsheet programs, use of the function ATAN2 avoids the extra checks needed to insure that V_x and V_y are nonzero, and are defined over a full 360 degree range [EPA 2000].

Measuring Productivity

Productivity was measured by counting the number of cut and the length of each cut using one of the two power saws during each sampling period. During the survey, the cutter cut only one board at a time and all the fiber-cement siding boards have the same thickness of 0.375 inch. The kerf width of the IRWIN blade is 0.071 inch. Thus, the volume of material removed during each sampling period can be calculated by multiplying the total length of cut, the board thickness and the kerf width of the blade. Both the length of cut and the volume of material removed were used as measures of productivity in this survey.

Control Technology

No engineering control technology to control dust from cutting fiber-cement siding was used during this site visit.

Results

The data in Table 1 were used to calculate percent quartz in the samples to compute the respirable dust PELs. The tables in the Appendix provide the sampling data used to calculate the results provided in Tables 1–3.

Silica Content in Air and Bulk Samples

Table 1 presents the respirable crystalline silica and respirable dust masses reported for every air sample collected during this survey. The sum of the respirable crystalline silica masses for each sample included in each day's TWA is divided by the sum of the respirable dust masses for those samples and multiplied by 100 to calculate the percent silica over the workday. That value is used to calculate the OSHA PEL [OSHA 2008].

$$\% \text{ Silica} = \frac{\text{Sample}_1 \text{ Silica Mass } (\mu g) + \cdots + \text{Sample}_n \text{ Silica Mass } (\mu g)}{\text{Sample}_1 \text{ Dust Mass } (\mu g) + \cdots + \text{Sample}_n \text{ Dust Mass } (\mu g)} \text{ x } 100 \qquad (8)$$

Table 1 – Respirable Silica Masses, Respirable Dust Masses, and Percent Silica.

Date	Cutter	Sample period	Respirable quartz (µg/sample)	Respirable dust (µg/sample)	Quartz %
7/18/2012	1	1	75	950	7.9
7/18/2010	1	2	38	350	10.9
7/19/2012	1	1	42	480	8.8
7/23/2012	1	1	73	1100	6.6
7/23/2012	1	2	86	1300	6.6
7/24/2012	1	1	200	3100	6.5
7/24/2012	1	2	110	1700	6.5

Based on the data presented in Table 1 and using Equation (8), on July 18, the cutter's air samples contained 8.7% quartz. On July 19, the cutter's air sample contained 8.8% quartz. The cutter's air samples contained 6.6% quartz on July 23 and 6.5% quartz on July 24.

Overall, the air samples contained from 6.5 to 10.9% quartz, with a mean of 6.9% quartz for all the samples (calculated using Equation (8) for all the samples). Two blank samples were collected each day and no crystalline silica was detected on any of the blank samples. One bulk sample of dust was collected near the worker. It contained 1.0% quartz. No cristobalite or tridymite were detected in the bulk sample.

Respirable Dust Results

As noted above, the quartz content in the cutter's daily respirable dust samples ranged from 6.5% to 8.8%, resulting in unadjusted PELs from 2.2 mg/m^3 to 1.8 mg/m^3 according to the calculation using Equation (2) and the corresponding conversion factor. Table 2 reports the TWA respirable dust results, eight-hour TWA respirable dust results, respirable dust PELs and adjusted respirable dust PELs, using Equation (3), where the cutters' sampling times exceeded eight hours. Eight-hour TWAs were calculated assuming that no further exposure occurred during the unsampled portion of the workday [OSHA 2008]. This was the case for the Cutter on all four days.

Overall, TWA respirable dust exposures ranged from 0.67 mg/m^3 to 1.97 mg/m^3. The exposure only exceeded the OSHA PEL on July 24.

Table 2 – Respirable Dust Results.

Date	Cutter	Sampling time (minutes)	Respirable dust TWA concentration (mg/m^3)	Respirable dust 8-Hour TWA concentration (mg/m^3)	OSHA PEL (mg/m^3)	Adjusted PEL
7/18/2012	1	434	0.71	0.64	1.8	no
7/19/2012	1	172	0.67	0.24	1.8	no
7/23/2012	1	510	1.14	1.14*	2.0	yes
7/24/2012	1	575	1.97	1.97*	1.6	yes

Notes: data with a * means that the sampling time exceeded eight hours and calculating an eight-hour TWA was not applicable so the actual TWA value was used.

Respirable Crystalline Silica Results

Table 3 presents the respirable crystalline silica sampling results. The REL was not adjusted because no daily sampling time exceeded 10 hours in this survey. The TLV® was adjusted when the sampling period exceeded 8 hours. The highest recorded results were on July 24. The cutter's 10-hour TWA was 2.4 times the REL and his TWA for the 9 hour 35 minute sample was 6.7 times the adjusted TLV®. The lowest values found were on July 19. His 10-hour TWA was less than the REL and his 8-hour TWA did not exceed the TLV®. As mentioned before, this was probably because the work was canceled in the afternoon of July 19 due to rain. Eight and ten hour TWAs were calculated assuming no further exposure during the unsampled portion of the work day. Overall, the TWA exposures for the sampling days were higher than the NIOSH REL for three of the four survey days.

The TWA respirable crystalline silica results ranged from 0.062mg/m^3 to 0.127 mg/m^3.

Table 3 – Respirable Crystalline Silica Results.

Date	Cutter	Sampling time (minutes)	Respirable crystalline silica TWA concentration (mg/m^3)	Respirable crystalline silica 10 Hour/8-Hour TWA concentration (mg/m^3)	NIOSH REL/ACGIH® TLV® (mg/m^3)	Adjusted
7/18/2012	1	434	0.062	0.045/0.056	0.05/0.025	no
7/19/2012	1	172	0.059	0.017/0.021	0.05/0.025	no
7/23/2012	1	510	0.075	0.064/0.075*	0.05/0.023	yes(TLV®)
7/24/2012	1	575	0.127	0.122/0.127*	0.05/0.019	yes(TLV®)

Notes: data with a * means that the sampling time exceeded eight hours and calculating an eight-hour TWA was not applicable so the actual TWA value was used. The TLV® was adjusted according to Equation (3) if the sampling time exceeded eight hours.

Weather Monitoring Results

During the four day survey, the air temperature at the survey site was from approximately 71°F to 102°F; and the relative humidity was from 39.2% to 91.8%. Matching the wind speed and direction to the Cutter's sampling periods resulted in the data shown in Table 4. Table 5 presents the wind speed and direction for the Cutter's sampling days (i.e., averaged over his total sampling periods). The standard deviation of the wind speed was about 59%, 50%, 100% and 75% of the average wind speed for the four days. The variation of the wind direction on each day was small, with the wind direction frequently within 90° of the average wind direction at about 86%, 100%, 71%, and 54% of the four days.

Table 4 Wind speed and direction by worker and sample period.

Date	Cutter	Sample period	Average wind speed (kph)	Average wind speed (mph)	Average wind direction (degrees)
7/18/2012	1	1	5.6	3.5	157
7/18/2010	1	2	7.5	4.7	155
7/19/2012	1	1	6.2	3.8	155
7/23/2012	1	1	5.7	3.6	168
7/23/2012	1	2	0	0	223
7/24/2012	1	1	2.6	1.6	106
7/24/2012	1	2	4.4	2.8	159

Table 5 – Wind speed and direction by sampling day.

Date	Cutter	Average wind speed (kph)	Average wind speed (mph)	Average wind direction (degrees)
7/18/2012	1	6.2	3.9	156
7/19/2012	1	6.2	3.8	155
7/23/2012	1	3.2	2.0	180
7/24/2012	1	3.3	2.1	130

Productivity Results

The number and length of cut were recorded during each sampling period. As mentioned above, both the length of cut and the volume of material removed were used as measures of productivity in this survey. The results were listed in Table 6. The cutter had substantially higher productivity numbers on July 24.

Table 6 – Number of cut, total length and volume of material removed by date and sample period.

Date	Cutter	Sample period	Number of cut	Total length of cut (m)	Volume of material removed (cm^3)
7/18/2012	1	1	102	52.4	900
7/18/2010	1	2	40	18.8	323
7/19/2012	1	1	98	41.4	711
7/23/2012	1	1	178	55.4	951
7/23/2012	1	2	129	49.5	850
7/24/2012	1	1	272	81.4	1398
7/24/2012	1	2	154	77.0	1322

Data analyses

The summary statistics of the sampled exposure data (seven samples in this survey) indicates that the cutter's TWA exposure to respirable crystalline silica had an arithmetic mean of 0.084 mg/m^3 with a standard deviation of 0.035 mg/m^3 and the 95% confidence limits of the arithmetic mean of 0.052 mg/m^3 and 0.117 mg/m^3. Since environmental measurements are usually log-normally distributed, the exposure data were also log-transformed for analyses. The geometric mean of the TWA exposure to respirable crystalline silica was 0.079 mg/m^3; the geometric standard deviation was 1.466; and the 95% confidence limits of the geometric mean were 0.055 mg/m^3 and 0.113 mg/m^3. It should be noted that the 95% confidence lower limit of both the arithmetic mean (0.052 mg/m^3) and geometric mean (0.055 mg/m^3) in this survey were still higher than the NIOSH REL of 0.05 mg/m^3. It was also noted that there was a borderline significant correlation between the volume of material removed of fiber-cement siding cut and the TWA exposure to respirable crystalline silica corresponding to each sample, with a

Pearson correlation coefficient of 0.753 and a p-value of 0.0506. There were only seven samples collected during this survey, and all the samples were taken from the same cutter. An exposure model could not be constructed based on the small number of samples.

Conclusions and Recommendations

Controlling exposures to occupational hazards is the fundamental method of protecting workers. Traditionally, a hierarchy of controls has been used as a means of determining how to implement feasible and effective controls. One representation of the hierarchy controls can be summarized as follows:

- Elimination
- Substitution
- Engineering Controls (e.g. ventilation)
- Administrative Controls (e.g. reduced work schedules)
- Personal Protective Equipment (e.g. respirators)

The idea behind this hierarchy is that the control methods at the top of the list are potentially more effective, protective, and economical (in the long run) than those at the bottom. Following the hierarchy normally leads to the implementation of inherently safer systems, ones where the risk of illness or injury has been substantially reduced.

From this survey, respirable crystalline silica exposures up to 2.4 times the NIOSH REL and up to 6.7 times the ACGIH TLV indicate that steps should be taken to reduce these exposures. The use of engineering control technology such as local exhaust ventilation for the power saws is the preferred solution and adhere to the hierarchy of controls.

NIOSH recommends (and it is mandated by OSHA where the use of respirators is required) that respirators in the workplace be used as part of a comprehensive respiratory protection program following the OSHA standard (29 CFR 1910.134 2003c). If N-95 filtering facepiece respirators are worn properly and used in accordance with good practices, they may be used to reduce respirable crystalline silica exposures to acceptable levels when exposures do not exceed 10 times the occupational exposure limit [NIOSH 2008]. The 8-hour TWA exposures measured during this survey did not exceed 10 times the OSHA PEL for respirable dust calculated based upon the quartz content of the samples. The measured 10-hour TWA exposures did not exceed 10 times the NIOSH REL for respirable crystalline silica, either. The comprehensive respiratory protection program should include written standard operating procedures; workplace monitoring; hazard-based selection; fit-testing and training of the user; procedures for cleaning, disinfection, maintenance, and storage of reusable respirators; respirator inspection and program evaluation; medical qualification of the user; and the use of NIOSH-certified respirators [NIOSH 1987].

For bearded workers who cannot achieve a satisfactory seal of the respirator facepiece, several loose-fitting type respirators are available, such as the hood or helmet-type powered air-purifying respirators (PAPRs), continuous flow supplied air respirators (SAR) and hood-type self-contained breathing apparatus. These respirators could accommodate bearded wearers because facial hair does not interfere with the facepiece seal of these units. However, each of these respirator types has its own limitations. Its acceptability of use must be determined on a case-by-case basis by the employer (Baier, 1985).

These respiratory protection provisions may be difficult to comply with in the construction industry. This suggests that engineering control technology would be the preferred method to reduce exposures associated with cutting-fiber cement siding. Air sampling should be conducted with the engineering controls in place to determine if respiratory protection is still needed to further reduce exposures to acceptable concentrations.

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Appendix

Table A1 - Respirable Dust Sampling Results

Date	Cutter	Sampling Period	Duration (min)	Volume (L)	Respirable Particulate (µg/sample)	Respirable Concentration (mg/m^3)
7/18/2012	1	1	275	1155	950	0.82
7/18/2010	1	2	159	668	350	0.52
7/19/2012	1	1	172	718	480	0.67
7/23/2012	1	1	310	1284	1100	0.86
7/23/2012	1	2	200	828	1300	1.57
7/24/2012	1	1	318	1346	3100	2.30
7/24/2012	1	2	257	1088	1700	1.56

Notes: min means minutes, L means liters, µg means micrograms, and mg/m^3 means milligrams/cubic meter.

Table A2 – Silica Sampling Results

Date	Cutter	Sampling Period	Duration (min)	Volume (L)	Quartz (µg/sample)	Quartz Concentration (mg/m^3)
7/18/2012	1	1	275	1155	75	0.065
7/18/2010	1	2	159	668	38	0.057
7/19/2012	1	1	172	718	42	0.058
7/23/2012	1	1	310	1284	73	0.057
7/23/2012	1	2	200	828	86	0.104
7/24/2012	1	1	318	1346	200	0.149
7/24/2012	1	2	257	1088	110	0.101

Notes: min means minutes, L means liters, µg means micrograms, and mg/m^3 means milligrams/cubic meter.

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