In-Depth Survey Report

Partnering to Control Dust from Fiber-Cement Siding

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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:

430 St. Clair Avenue
Huntsville, AL 35801

NAICS Code:

238170 Siding Contractors

Survey Dates:

September 24-26, 2013

Surveys Conducted By:

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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% crystalline silica and 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 Twickenham Square construction site in Huntsville, AL on September 24-26, 2013. During the site visit, they performed industrial hygiene sampling which measured the exposures to respirable dust and respirable crystalline silica of two workers who cut fiber-cement panel siding. An engineering control measure was implemented by connecting a dust-collecting circular saw to a regular shop vacuum. The shop vacuum provided local exhaust ventilation to remove the dust generated from cutting fiber-cement siding using the dust-collecting circular saw. 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 crystalline silica showed that on all three days, both workers' 10-hour time weighted average (TWA) exposures to respirable quartz (the most common form of crystalline silica) were in the range of 0.007 to 0.012 mg/m^3. These results were considerably lower than the NIOSH Recommended Exposure Limit (REL) of 0.05 mg/m^3, applicable up to a 10-hour workday in a 40-hour workweek, and the Threshold Limit Value (TLV®) of 0.025 mg/m^3 TWA applicable for an 8-hour workday and a 40-hour workweek. The TLV® is a product of the American Conference of Governmental Industrial Hygienists (ACGIH®). The observed exposures were also considerably lower than the OSHA Permissible Exposure Limit (PEL) for respirable dust that contains greater than 1% quartz, with the 8-hour TWA exposures during the sampling periods in the range of 0.07 to 0.15 mg/m^3, and the corresponding PEL in the range of 0.97 to 1.76 mg/m^3.

Conclusions and Recommendations

The exposure levels indicated that the evaluated engineering control measure was effective in reducing the workers' exposures to concentrations below the NIOSH REL for respirable quartz, and the OSHA PEL for respirable dust containing silica. This engineering control measure has the potential to provide an effective, simple and low cost solution for workers cutting fiber-cement siding.

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-Khanzadeh and Brillhart 2002, Glindmeyer and Hammad 1988, Linch 2002, Rappaport et al. 2003]. Fiber-cement products can contain as much as 50% crystalline silica. Cutting this material has been shown to cause excessive exposures to respirable crystalline silica [Lofgren et al. 2004, Qi et al. 2013].

The use of fiber-cement siding in construction and renovation is undergoing rapid growth. From 1991 to 2010, the market share of fiber-cement siding has climbed from 1% to 13% [US Census Bureau 2013]. In contrast, the market share of wood siding in residential construction has decreased from 38% to 8% [US Census Bureau 2013]. The durability and appearance of fiber-cement siding, which simulates wood without the maintenance issues 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, GAF, and Nichiha are the major manufactures of fiber-cement products.

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 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 (in).

The study by Lofgren et al. [2004] reported that cutters' uncontrolled 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 respirable crystalline silica of 0.05 mg/m^3.

In an earlier in-depth field survey, Qi et al. [2013] reported that a cutter's uncontrolled exposures to respirable crystalline silica ranged from 0.059 to 0.127 mg/m^3 during sampling, and 8-hr TWA exposure ranged from 0.021 mg/m^3 to 0.127 mg/m^3 depending on the time of exposure on the day sampled. The highest result was 2.54 times the NIOSH REL for respirable crystalline silica of 0.05 mg/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) determine the dust generation rate from cutting fiber-cement siding in the lab; 2) experimentally develop local exhaust ventilation recommendations for circular saws used to cut fiber-cement siding; 3) validate, at actual construction sites, the recommendations developed from the laboratory studies; and 4) disseminate the information in the form of technical reports, journal articles, a NIOSH Workplace Solutions document, trade journal 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

A laboratory study on the generation rate and engineering control of dust from cutting fiber-cement siding was conducted at the NIOSH Alice Hamilton Laboratory in Cincinnati, OH. Several circular saws with dust-reduction designs and miter saws were tested. The study found that connecting a dust-collecting circular saw (described in detail later in this report) to a dust collector can remove 80-90% of the dust from cutting fiber-cement siding, even at a low flow rate of about 0.014 cubic meter per second (m^3/s) (30 cubic feet per minute (CFM)). This result suggests that connecting a dust-collecting circular saw to a regular shop vacuum with built-in air filters, which normally runs at a higher flow rate than 0.014 m^3/s (30 CFM), is a simple and low-cost engineering control for the dust generated from cutting fiber-cement siding. In order to assess the effectiveness of this dust control measure, a field survey was conducted to evaluate exposures at a site where it was used for cutting fiber-cement siding. This survey was performed on September 24rd, 25th, and 26th, 2013 at the Twickenham Square construction site in Huntsville, AL. Air sampling was conducted to assess the respirable dust and crystalline silica exposures of workers cutting fiber-cement siding.

Construction Site and Process Description

Introduction

The Twickenham Square project was a new four-story apartment building under construction in Huntsville, AL. Brasfield & Gorrie, which is one of the nation's largest privately held construction firms, is the construction manager of the building. Fiber-cement siding was selected for use on part of the external wall of the building. The siding job was done by R&B Construction. Figure 1 shows a corner of the building where fiber-cement siding was installed. The fiber-cement siding cut and installed during this survey was HardiePanel® vertical siding manufactured by James Hardie Industries. Each siding panel was 1.22 meters (4 feet) by 2.44 meters (8 feet) and was cut to the desired size before the installation.

Figure 1 – A corner of the construction site. Photo courtesy of NIOSH.

Process Description

Fiber-cement siding was installed on the external walls of the building by six construction workers on all three days of the survey. The six workers were divided into two groups. Each group consisted of one cutter who operated a circular saw to cut fiber-cement siding on a work bench, and two installers, who took the measurements, verbally communicated the size requirement to the cutter, and installed the siding. Figure 2 shows a cutter cutting fiber-cement siding on his work bench using a dust-collecting circular saw connected to a shop vacuum. During the survey, the two work benches were located about 30-50 meters (98-164 feet) apart. The installers were normally on a boom lift. Personal breathing zone air samples were taken from the two cutters during this survey. None of the workers wore a respirator during the survey.

Figure 2 – A worker (cutter) cutting fiber-cement siding using a dust-collecting circular saw that was connected to a shop vacuum. Photo courtesy of NIOSH.

The dust-collecting circular saw (Model 5057KB, Makita U.S.A., Inc., La Mirada, CA) was equipped with a built-in dust collection container, which serves as a hood and covers about 69% of the saw blade's surface. When fiber-cement siding was cut, the flow induced by the spinning blade caused a large portion of the dust generated to be collected in the container and also directed the dust to an exhaust port at the end of the container, which could be connected to an external dust collector or shop vacuum.

The saws used a polycrystalline diamond blade (Model D0704DH, Freud America, Inc., High Point, NC) with four teeth and a diameter of 18.2 centimeters (7.25 in), a kerf width of 1.8 millimeters (mm) (0.071 in) and a maximum speed of 10,000 rotations per minute (RPM). The Makita circular saw has a no-load speed of 5,800 RPM, according to the manufacturer's technical specification. The actual no-load speed of this saw was measured in the lab using a Pocket Tachometer (Model TAC2K, Dwyer Instruments Inc., Michigan City, IN) and it was found to be 5,500 RPM.

Both the fiber-cement siding boards and the trim boards cut and installed during this survey were manufactured by James Hardie Industries. Table 1 lists the specifications of the boards used. Both types of boards contained crystalline silica (quartz) as reported by the manufacturer's Material Safety Data Sheet (MSDS). Since the MSDS provides only a range of the quartz content for each type of board, averaged quartz contents were taken from it and included in Table 1. The averaged quartz content was used later in the report to estimate the amount of quartz in the material removed by the cutters.

Table 1 – Specifications of the fiber-cement siding and trim boards

Board type	Board thickness (mm; in)	Board density (kg/m^2; lbs/ft^2, MSDS)	Quartz % (MSDS)	Quartz % (used in this report)
HardiePanel® vertical siding	7.94; 5/16	11.2; 2.3	30-45	37.5
trim board	25.4; 1.0	27.6; 5.65	15-30	22.5

Notes: kg/m^2 means kilograms per square meter, and lbs/ft^2 means pounds per square feet.

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 2013]. 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 ($\mu g/m^3$) [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]. In August 2013, OSHA proposed a new PEL of 0.05 mg/m^3 for 8-hr TWA exposures [OSHA 2013].

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 2013]. The TLV is intended to mitigate the risk of pulmonary fibrosis and lung cancer.

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 8 and 16 are substituted for 10 and 14, 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

On all three sampling days, one sample was taken before lunch and one after lunch for each sampled worker. The total sampling times reflect the period sampled while the workers were working on the construction site.

Sampling Procedures

Air Sampling

Personal breathing zone air samples for respirable particulate were collected at a flow rate of 4.2 liters per minute (L/min) using a battery-operated sampling pump (Gilian GilAir Plus, Sensidyne LP, Clearwater, FL) calibrated before and after each day's use using a DryCal Primary Flow Calibrator (Bios Defender 510, Mesa Laboratories, Inc., Lakewood, CO). A sampling pump was clipped to the sampled worker'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- µm pore-size polyvinyl chloride (PVC) 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 workers' shirts near their breathing zone. In addition to the personal breathing zone air samples, at least two field blank samples were taken on each sampling day. Bulk dust samples 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 20 µg/sample. The limit of quantitation (LOQ) was 53 µg/sample.

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, 5 µg/sample, and 10 µg/sample, respectively. The LOQs for quartz, cristobalite, and tridymite were 17 µg/sample, 17 µg/sample, and 33 µg/sample, respectively.

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 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 of the cutters was measured by counting the number of cuts, their length, the number of boards stacked and cut, and the thickness of each board cut during each sampling period. The kerf width of the diamond blade is 1.8 mm (0.071 inch). Thus, the volume of material removed for each cut could be estimated by multiplying the length of the cut, the number of boards in the stack, the board thickness and the kerf width of the blade. The mass of material removed was calculated by multiplying the volume of material removed and the board density according to the manufacturer's MSDS, as listed in Table 1. The amount of quartz in the removed material of each cut was then calculated by multiplying the mass of the material removed and the average quartz percentage of the board, which is also listed in Table 1. The daily productivity of the cutters and the productivity corresponding to each individual air sample can thus be estimated by summing up the above-mentioned metrics from all the corresponding cuts.

Control Technology

A laboratory study on the generation rate and engineering control of dust from cutting fiber-cement siding was conducted at the NIOSH Alice Hamilton Laboratory in Cincinnati, OH. That study found that connecting a dust-collecting circular saw to a dust collector removed about 80-90% of the dust produced when fiber-cement siding was cut, even at a low dust collector flow rate of about 0.014 m^3/s (30 CFM). It was also found that further increasing the flow rate of the dust collector did not lead to a higher dust collection rate. These results suggest that connecting a dust-collecting circular saw to a regular shop vacuum, typically having a higher flow rate than 0.014 m^3/s (30 CFM) can be a simple and low-cost engineering solution to control the dust generated from cutting fiber-cement siding.

In this survey, a 12-gallon shop vacuum (model 586-62-11, Shop-Vac® Corporation, Williamsport, PA) was used to provide local exhaust ventilation for the Makita dust-collecting circular saw used by each cutter. As described earlier, this dust-collecting circular saw has a built-in container which serves as a hood and covers most of the saw blade. When fiber-cement siding is cut, the flow induced by the spinning blade causes a large portion of the dust generated to be collected in the container and also directs this dust to an exhaust port at the end of the container. A vacuum hose was used to connect the saw's exhaust port to the shop vacuum. Figure 3 shows the dust-collecting circular saw and its connection to the shop vacuum. A high efficiency disposable filter bag (fine filtration bag, part number 90672, Shop-Vac® Corporation, Williamsport, PA) was used in the shop vacuum to trap most of the dust and a Prolong cartridge filter (part number 90304, Shop-Vac® Corporation, Williamsport, PA) was used to capture the dust passing through the filter bag. Since most of the dust was captured in the filter bag rather than the cartridge filter, the life of the cartridge filter was greatly extended.

The shop vacuum was rated to provide a 0.094 m^3/s (200 CFM) flow rate by the manufacturer, which is sufficient to provide good local exhaust ventilation for the cutting task, based on the NIOSH laboratory study. However, the actual flow rate can be affected when the shop vacuum is connected to the filters and vacuum hose. More importantly, the flow rate might change from dust loading on the filter bag and cartridge filter. Thus, a data logging pressure transducer (Smart Reader SRP-004-30G-128K 0-30 PSI-G, ACR Systems, Surrey, BC, Canada) was placed in the tank of the shop vacuum, between the filter bag and the cartridge filter in the flow path, to log the local absolute air pressure. A laboratory study at NIOSH found that the difference between the absolute air pressure in the shop vacuum tank when the shop vacuum is on and off is linearly correlated with the actual air flow rate, as measured using a Delta tube (model # 307BZ-11-AO, Mid-West Instrument, Sterling Heights, MI). In the laboratory study, a gate valve was used to adjust the air flow rate so that the correlation between the actual flow rate read from the Delta tube and the absolute air pressure difference from the data logging pressure transducer in the shop vacuum tank could be obtained. This correlation was used with the pressure data collected from the shop vacuums at the job site to estimate their actual flow rates during the survey. A battery pack (model # BP-101, ACR

Systems, Surrey, BC, Canada) was used together with the data logging pressure transducer in each shop vacuum in order to obtain the vacuum tank pressure readings every 2 seconds.

Figure 3 –The dust-collecting circular saw and its connection to the shop vacuum used in this survey. Photo courtesy of NIOSH.

Both the circular saw and the shop vacuum were plugged into an iVAC switch (iVAC Switch Box 10031-0100, BCTINT Ltd, Kanata, ON, Canada), which automatically turns on/off the shop vacuum whenever the circular saw is turned on/off. The iVAC switch also featured a 6-second delay in turning off the shop vacuum when the saw is turned off, thus removing the remaining dust in the vacuum hose following the cutting of a board.

Results

The respirable dust and respirable quartz data in Table 2 were used to calculate percent quartz in the samples, and then used to compute the respirable dust PELs. The tables in the Appendix provide the sampling data used to calculate the results provided in Tables 2–4.

Silica Content in Air and Bulk Samples

Table 2 presents the respirable crystalline silica and respirable dust masses reported for every air sample collected during this survey. For each worker, the sum of the respirable crystalline silica masses for each of their samples included in their daily 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 for each worker, for each day [OSHA 2008].

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

Table 2 – Respirable Silica Masses, Respirable Dust Masses, and Percent Silica.

Date	Worker	Sample period	Respirable dust (µg/sample)	Respirable quartz (µg/sample)	Quartz %	Daily Quartz %
9/24/2013	Cutter 1	1	67	8.9	13.3	13.8
9/24/2013	Cutter 1	2	77	11.0	14.3	
9/24/2013	Cutter 2	1	120	9.7	8.1	9.2
9/24/2013	Cutter 2	2	180	18.0	10.0	
9/25/2013	Cutter 1	1	57	11.0	19.3	11.1
9/25/2013	Cutter 1	2	150	12.0	8.0	
9/25/2013	Cutter 2	1	170	18.0	10.6	11.4
9/25/2013	Cutter 2	2	110	14.0	12.7	
9/26/2013	Cutter 1	1	87	10.0	11.5	10.9
9/26/2013	Cutter 1	2	67	6.8	10.1	
9/26/2013	Cutter 2	1	97	34.0	35.1	20.9
9/26/2013	Cutter 2	2	190	26.0	13.7	

Based on the data presented in Table 2, the Daily Quartz % (percent silica over the workday) for each worker was calculated using Equation (8) and listed in the last column. Overall, the air samples contained from 8.1 to 35.1% quartz. The mean of the quartz percentage for all of the samples was 13.1%. Two blank samples were collected each day and no crystalline silica was detected on any of the blank samples. Three bulk samples were collected from the dust captured in the bag filter of the shop vacuums and they contained 31%, 27%, and 21% quartz, respectively. No cristobalite or tridymite were detected in the bulk samples.

Respirable Dust Results

As shown in Table 2, the quartz content in the workers' daily respirable dust samples ranged from 9.2% to 20.9%, resulting in respirable dust containing crystalline silica PELs from 0.97 mg/m^3 to 1.76 mg/m^3 according to the calculation using Equations (2) and the corresponding conversion factor. As shown in the last column of Table 2, the PEL was adjusted using Equation (3) when the work shift exceeded 8 hours. Table 3 reports the TWA respirable dust concentrations, 8-hour TWA respirable dust concentrations, and applicable respirable dust PELs. The 8-hour TWAs were calculated assuming that no further exposure occurred during the unsampled portion of the workday [OSHA 2008]. This was the case for both workers on all three days.

Table 3 – Respirable Dust Results.

Date	Worker	Daily sampling time (minutes)	Respirable dust TWA concentration (mg/m^3)	Respirable dust 8-hr TWA concentration (mg/m^3)	OSHA PEL (mg/m^3)	Adjusted PEL
9/24/2013	Cutter 1	486	0.07	0.07	1.30	yes
9/24/2013	Cutter 2	456	0.16	0.15	1.76	no
9/25/2013	Cutter 1	513	0.09	0.10	1.40	yes
9/25/2013	Cutter 2	499	0.13	0.14	1.44	yes
9/26/2013	Cutter 1	410	0.09	0.08	1.57	no
9/26/2013	Cutter 2	411	0.16	0.14	0.97	no

Overall, the 8-hour TWA respirable dust exposures ranged from 0.07 mg/m^3 to 0.15 mg/m^3 for the two cutters. They were all considerably lower than the corresponding OSHA PELs, with the highest percentage of 8-hour TWA exposure to the corresponding PEL being only 14.6%.

Respirable Crystalline Silica Results

Table 4 presents the respirable crystalline silica sampling results including the TWA respirable crystalline silica concentrations, 10-hour and 8-hour TWA respirable crystalline silica concentrations, the NIOSH REL and the ACGIH® TLV®. As shown in the last column of Table 4, the TLV® was adjusted using Equation (3) when the work shift exceeded 8 hours.

Table 4 – Respirable Crystalline Silica Results.

Date	Worker	Daily sampling time (minutes)	Respirable crystalline silica TWA concentration (mg/m^3)	Respirable crystalline silica 10 hr/8-hr TWA concentration (mg/m^3)	NIOSH REL/ACGIH® TLV® (mg/m^3)	Adjusted
9/24/2013	Cutter 1	486	0.010	0.008/0.010	0.05/0.0245	yes(TLV®)
9/24/2013	Cutter 2	456	0.014	0.011/0.014	0.05/0.025	no
9/25/2013	Cutter 1	513	0.010	0.009/0.011	0.05/0.0226	yes(TLV®)
9/25/2013	Cutter 2	499	0.015	0.012/0.016	0.05/0.0236	yes(TLV®)
9/26/2013	Cutter 1	410	0.010	0.007/0.008	0.05/0.025	no
9/26/2013	Cutter 2	411	0.034*	0.024*/0.029*	0.05/0.025	no

Notes: data with a * is questionable as one of the two samples for Cutter 2 on September 26th was determined to be an outlier based on the lognormal distribution of the data (detailed discussion is in the Data Analyses section of this report). Nevertheless, this result was below the NIOSH REL.

When reviewing the results of the respirable crystalline silica TWA concentrations, one of the two samples for Cutter 2 on September 26th was determined an outlier based on the lognormal distribution of the data, which made the validity of that datum questionable (a detailed discussion is in the Data Analyses section of this report). Excluding this data point, the 10-hour TWA respirable crystalline silica exposures ranged from 0.007 mg/m^3 to 0.012 mg/m^3 for the two cutters. They were all considerably lower than the NIOSH REL. The highest 10-hour TWA exposure was only 24% of the NIOSH REL. Similarly, the 8-hour TWA respirable crystalline silica exposures excluding Cutter 2's data on September 26th ranged from 0.008 mg/m^3 to 0.016 mg/m^3. The highest 8-hour TWA exposure was only 64% of the ACGIH® TLV®.

Weather Monitoring Results

During the three day survey, the air temperature at the site ranged from approximately 69°F to 90°F; and the relative humidity was from 43% to 84%. Matching the wind speed and direction to the workers' sampling periods resulted in the data shown in Table 5. Table 6 presents the wind speed and direction for the workers' sampling days (i.e., averaged over the total sampling periods). The standard deviation of the wind speed was about 98%, 156%, and 129% of the average wind speed for the three days. The variation of wind direction on each day was small, with the wind direction frequency within 90° of the average wind direction at about 45%, 49% and 48% of the three days.

Table 5 Wind speed and direction by worker and sample period.

Date	Sample period	Average wind speed (kph; mph)	Wind speed range (kph; mph)	Average wind direction (degrees)
9/24/2013	1	3.9; 1.4	0.0 to 10.9; 0.0 to 6.8	14
9/24/2013	2	1.5; 1.0	0.0 to 6.1; 0.0 to 3.8	173
9/25/2013	1	1.3; 0.8	0.0 to 5.5; 0.0 to 3.4	247
9/25/2013	2	0.9; 0.5	0.0 to 5.6; 0.0 to 3.5	221
9/26/2013	1	1.4; 0.9	0.0 to 5.1; 0.0 to 3.2	202
9/26/2013	2	1.5; 1.0	0.0 to 8.2; 0.0 to 5.1	211

Table 6 – Wind speed and direction by sampling day.

Date	Average wind speed (kph; mph)	Wind speed range (kph; mph)	Average wind direction (degrees)
9/24/2013	3.0; 1.8	0.0 to 10.9; 0.0 to 6.8	167
9/25/2013	1.1; 0.7	0.0 to 5.6; 0.0 to 3.5	232
9/26/2013	1.5; 0.9	0.0 to 8.2; 0.0 to 5.1	209

Productivity Results

The number of cuts, the length, the number of boards in the stack, and the board thickness of each cut were recorded during each sampling period. As mentioned above, the volume and mass of the material removed, and the estimated mass of quartz in the removed material were used as measures of productivity in this survey. The results are listed in Table 7.

Table 7 – Cutters' productivity by date and sample period.

Date	Cutter	Sample period	Volume of material removed (cm^3)	Mass of material removed (g)	Mass of Quartz in the removed material (g)
9/24/2013	1	1	461	650	243
9/24/2013	1	2	720	1011	375
9/24/2013	2	1	556	785	294
9/24/2013	2	2	879	1237	461
9/25/2013	1	1	460	642	237
9/25/2013	1	2	933	1291	470
9/25/2013	2	1	343	461	160
9/25/2013	2	2	872	1212	444
9/26/2013	1	1	404	571	214
9/26/2013	1	2	1396	1939	709
9/26/2013	2	1	597	845	317
9/26/2013	2	2	929	1314	493

Engineering Control Results

The two shop vacuums used in the survey were identified as SV1 and SV2, and they were used by Cutter 1 and Cutter 2, respectively. A new filter bag was installed in each shop vacuum every morning before the job started. Inspection of the shop vacuum conducted at the same time found that the cartridge filter was in good condition with little dust loading. Thus, the same cartridge filter was used in the shop vacuums throughout the survey.

Table 8 – Estimated operating flow rate of the shop vacuums.

Date	Flow rate of SV1 (m^3/s; CFM)	Flow rate of SV2 (m^3/s; CFM)
9/24/2013	0.036 – 0.042; 76.8 - 89.3	0.035 – 0.041; 75.2 - 87.8
9/25/2013	Not logged	Not logged
9/26/2013	0.033 – 0.037; 70.5 - 78.4	0.035 – 0.043; 75.2 - 90.9

As mentioned previously, the flow rate of the shop vacuums can be estimated based on the logged air pressure in the vacuums and the correlation between flow rate and pressure found in the laboratory study. The estimated operating flow rates of the two shop vacuums during the survey are listed in Table 8. For the most part, the flow rates remained relatively stable and were much higher than 0.014 m^3/s

(30 CFM), the flow rate which was found to provide effective dust control in the laboratory study. Neither data logger logged data on September 25th due to a technical issue with the data logging pressure transducers. The exposure and productivity data on September 25th, and the fact that the filters in both shop vacuums were found to be in good condition after the survey, indicated that both shop vacuums operated normally on that day, with a flow rate similar to the other two days.

Data analyses

A total of 12 air samples were taken during this survey, with 6 samples for each cutter. Data analysis was performed for the 12 samples. The exposure data were found to be log-normally distributed for both respirable dust TWA concentration and respirable crystalline silica TWA concentration. However, one of the two samples for Cutter 2 on September 26th (listed in Table A2 of the Appendix) resulted in a respirable crystalline silica concentration of 0.0516 mg/m^3, which fell more than 1.5 times the inter-quartile-range (IQR) above the third quartile (0.0375 mg/m^3) of the 12 samples. Thus, this sample was determined to be an outlier based on Tukey's method identifying outliers [1977]. Thus, only the other 11 samples were used in the statistical calculation for respirable crystalline silica TWA concentrations. The summary statistics are listed in Table 9.

Table 9 - Summary Statistics and 95% Confidence Limits of the Geometric Means

Exposure Variables	Job Type	Number of Samples	Geometric Mean	95% Confidence Limits of Geometric Mean		Geometric Standard Deviation
Respirable dust TWA concentration (mg/m^3)	Cutter	12	0.110	0.083	0.145	1.55
Respirable crystalline silica TWA concentration (mg/m^3)	Cutter	11	0.0124	0.0097	0.0158	1.43

As listed in Table 9, the two cutters' exposures were well under control, with the 95% upper confidence limits of both analyzed cases considerably lower than either the NIOSH REL of 0.05 mg/m^3 for respirable crystalline silica TWA concentration or OSHA PEL of 1.38 mg/m^3 for respirable dust concentration (with a mean of 13.1% quartz for all the samples). The 95% upper confidence limit of respirable crystalline silica TWA concentration was also below the ACGIH® TLV® of 0.025 mg/m^3. It should be noted that the aforementioned outlier was not included in the statistical calculation for respirable crystalline silica TWA concentrations. If the outlier was included in the calculation, the geometric mean of the respirable crystalline silica

TWA concentration for all the 12 samples would become 0.0139 mg/m^3, and the corresponding 95% upper confidence limit would become 0.0196 mg/m^3. They are still lower than both the NIOSH REL and the ACGIH® TLV®.

A Pearson correlation analysis was also performed to investigate the possible correlation between the cutters' exposure levels and the mass of material removed per unit time during each sampling period. The exposure to respirable dust was tested for correlation with the mass of material removed (data in Table 7) per unit time; and the exposure to respirable crystalline silica was tested for correlation with the mass of quartz in the removed material (data in Table 7) per unit time. The analysis was done for 12 samples of respirable dust and 11 samples of respirable crystalline silica. The Pearson Correlation Coefficients of the two pairs of variables of interest were 0.005 and -0.16, which are not statistically significant. This indicates that there is no statistically significant evidence for a positive linear relationship between the cutters' exposure levels and the mass of material removed per unit time. This is possibly due to the small number of samples analyzed and the influence of other factors, such as wind, the cutters' standing positions, etc.

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 (PPE, 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, the 8-hour TWA exposures to respirable dust were below 14.6% of the OSHA PEL, and the 10- hour TWA exposures to respirable crystalline silica were below 24% of the NIOSH REL. These results indicate that the engineering control measure used in this survey effectively controlled the dust emissions and reduced the workers' exposures. The use of this type of engineering control technology for the dust-collecting circular saws is a preferred solution and adheres to the hierarchy of controls.

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Appendix

Table A1 - Respirable Dust Sampling Results

Date	Worker	Sampling Period	Duration (min)	Volume (L)	Respirable Particulate (µg/sample)	Respirable Concentration (mg/m^3)
9/24/2013	Cutter 1	1	217	900	67	0.074
9/24/2013	Cutter 1	2	269	1134	77	0.068
9/24/2013	Cutter 2	1	193	809	120	0.148
9/24/2013	Cutter 2	2	263	1108	180	0.163
9/25/2013	Cutter 1	1	260	1115	57	0.051
9/25/2013	Cutter 1	2	253	1081	150	0.139
9/25/2013	Cutter 2	1	244	1042	170	0.163
9/25/2013	Cutter 2	2	255	1092	110	0.101
9/26/2013	Cutter 1	1	156	661	87	0.132
9/26/2013	Cutter 1	2	254	1083	67	0.062
9/26/2013	Cutter 2	1	155	659	97	0.147
9/26/2013	Cutter 2	2	256	1088	190	0.175

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

Table A2 – Silica Sampling Results

Date	Worker	Sampling Period	Duration (min)	Volume (L)	Quartz (µg/sample))	Quartz Concentration (mg/m^3)
9/24/2013	Cutter 1	1	217	900	13.3	0.0099
9/24/2013	Cutter 1	2	269	1134	14.3	0.0097
9/24/2013	Cutter 2	1	193	809	8.1	0.0120
9/24/2013	Cutter 2	2	263	1108	10.0	0.0163
9/25/2013	Cutter 1	1	260	1115	19.3	0.0099
9/25/2013	Cutter 1	2	253	1081	8.0	0.0111
9/25/2013	Cutter 2	1	244	1042	10.6	0.0173
9/25/2013	Cutter 2	2	255	1092	12.7	0.0128
9/26/2013	Cutter 1	1	156	661	11.5	0.0151
9/26/2013	Cutter 1	2	254	1083	10.1	0.0063
9/26/2013	Cutter 2	1	155	659	35.1	0.0516
9/26/2013	Cutter 2	2	256	1088	13.7	0.0239

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

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