ENVIRONMENTAL HEALTH
& ENGINEERING, INC.

Human Health Risk Assessment for Proposition 65: Crystalline Silica in Ceramic and Glass Tile

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PREFACE

This report entitled *Human Health Risk Assessment for Proposition 65: Crystalline Silica in Ceramic and Glass Tile* contains an analysis of tile as a source of exposure to respirable crystalline silica in the context of the Proposition 65 regulation in the state of California. The basis of the report is chemical properties and testing of ceramic and glass tile provided by approximately 180 manufacturers in North America, Italy, and Spain, representing nearly 315 brands, as well as interviews with 18 companies that employ over 830 professional tile installers.

This report supersedes the prior version with the same title that was issued on June 1, 2018. The distributions of chemical concentrations and corresponding potential exposures and health risks presented here reflect data from a larger set of tile products than the prior report. Consequently and necessarily, the distributions in this report are not identical to the distributions presented in the prior version of this report. However, the distributions are quite similar and therefore the conclusions regarding potential health risks presented in the current and prior reports are identical. These conclusions apply to brands of participating manufacturers and should not be generalized to brands of other manufacturers without additional analysis.

The research described in this report was commissioned by the Tile Council of North America (TCNA), with additional support from Confindustria Ceramica, Centro Ceramico Bologna, Spanish Ceramic Tile Manufacturers' Association (ASCER), and the TCNA Product Performance Testing Laboratory. The research was conducted by Environmental Health & Engineering, Inc., Newton, Massachusetts.

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LIST OF ABBREVIATIONS AND ACRONYMS

AER	air exchange rate
AIHA	American Industrial Hygiene Association
ASCER	Spanish Ceramic Tile Manufacturers' Association (Asociación Española de Fabricantes de Azulejos y Pavimentos Cerámicos)
BLS	Bureau of Labor Statistics
cm	centimeter
EF	emission factor
EH&E	Environmental Health & Engineering, Inc.
ft^2	square feet
HHRA	Human Health Risk Assessment
ICP-AES	inductively coupled plasma-atomic emission spectroscopy
in	inch
IUR	inhalation unit risk
kg	kilogram
Liberty	Liberty Mutual Industrial Hygiene Laboratory
m	meter
mg	milligram
mg/m^3	milligram per cubic meter
NIOSH	National Institute for Occupational Safety and Health
OEHHA	California Office of Environmental Health Hazard Assessment
OSHA	U.S. Occupational Safety and Health Administration
Prop 65	Proposition 65, Safe Drinking Water and Toxic Enforcement Act of 1986, California
SiO_2	silicon dioxide
SUD	Safe Use Determination
TCNA	Tile Council of North America
TWA	time-weighted average
USEPA	U.S. Environmental Protection Agency
XRD	x-ray diffraction
μm	micrometer
$\mu g/m^3$	micrograms per cubic meter

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LIST OF DEFINITIONS

Particulate Matter—a mixture of solid particles and liquid droplets suspended in air. Can contain organic and inorganic particles such as dust, pollen, soot, smoke, and liquid droplets. Also referred to as aerosol, or dust.

Respirable Particulate Matter—airborne particles measured with a DustTrak DRX Aerosol Monitor (TSI Incorporated) equipped with a 4 µm impactor or a sampling device designed to meet the characteristics for respirable particle size selective samplers specified in the International Organization for Standardization (ISO) 7708:1995: *Air Quality – Particle Size Fraction Definitions for Health-Related Sampling* (OSHA 29 CFR 1926.1153).

Respirable Crystalline Silica—quartz, cristobalite, and/or tridymite contained in airborne particles that are determined to be respirable by a sampling device designed to meet the characteristics for respirable particle size selective samplers specified in the International Organization for Standardization (ISO) 7708:1995: *Air Quality – Particle Size Fraction Definitions for Health-Related Sampling* (OSHA 29 CFR 1926.1153).

TOOLS

Angle Grinder—a handheld power tool used to grind, polish, or cut materials. Also known as a grinder or dry saw.

Core bit—a handheld power tool used to make round holes.

Dust Shroud—a type of dust control system for motorized cutting tools.

Nippers—a manual tool that looks like a pair of plyers and is used to remove small amounts of tile which needs to be fitted around an odd or irregular shape.

Manual Cutter—snap cutter and nippers.

Motorized Cutting Tool—wet saw or angle grinder.

Snap Cutter—a manual tile cutting tool that uses a scoring handle equipped with a blade to score the surface of tile and mechanical leverage to snap the tile along the scored line. Also called manual tile cutter, score and snap, or score and snap cutter.

Wet Saw—a motorized tile cutting saw equipped with an integrated water delivery system that continuously feeds water to the blade.

1.0 EXECUTIVE SUMMARY

Environmental Health & Engineering, Inc. (EH&E) assessed potential risks to human health from exposure to respirable crystalline silica during installation of ceramic and glass tile (hereafter “tile”) manufactured in Italy, Mexico, Spain, and the United States. Tile products are non-friable and as a result, there is no inhalation exposure to respirable crystalline silica from installed tile. During installation, however, cutting tile can release respirable size particles containing crystalline silica into the air.

The methods that we used conform with standard practice for Proposition 65 (Prop 65) in the state of California and the professional practice of environmental health science. Our assessment of potential tile-related exposures was based upon a robust set of information on work practices, measurements of emissions to air, and exposure concentrations that were developed from research conducted expressly for this assessment. The guideline value for cancer potency used in our analysis was obtained from reports published by the California Office of Environmental Health Hazard Assessment (OEHHA) related to two prior Safe Use Determinations (SUDs). One of those SUDs was submitted by the National Paint and Coatings Association for crystalline silica in interior flat latex paint. The other SUD was prepared by the Sorptive Minerals Institute for crystalline silica in sorptive mineral-based pet litter. We used inputs to the analysis recommended by OEHHA unless we had strong research-based evidence to rely upon. In cases where OEHHA had no recommended values, we developed conservative risk inputs based on recommendations from the U.S. Environmental Protection Agency (USEPA), scientific literature, and best professional judgement.

The results of our assessment indicate that the potential excess lifetime cancer risk (ELCR) associated with tile-related exposures for the average Californian who installs tile is 1.3 in 10 million (1.3×10^{-7}), or 0.013 per 100,000, a value that is 75-fold below the threshold of 1 in 100,000 established under the Prop 65 regulation. Sensitivity analyses demonstrated that reasonable alternative values and inputs to the analysis did not significantly influence our conclusions.

2.0 INTRODUCTION

This report describes our assessment of potential human health risks associated with crystalline silica in tile manufactured in Italy, Mexico, Spain, and the United States. The analysis considers information on tile provided by approximately 180 manufacturers, representing nearly 315 brands.[1] The research was commissioned by the Tile Council of North America (TCNA), with additional support from Confindustria Ceramica, Centro Ceramico Bologna, Spanish Ceramic Tile Manufacturers' Association (ASCER), and the TCNA Product Performance Testing Laboratory. The research was conducted by EH&E.

The objective of our risk assessment was to evaluate tile as a source of exposure to respirable crystalline silica in the context of the Prop 65 regulation in the state of California. We developed inputs for our evaluation from information published in the scientific literature, interviews with tile installers, and exposures during installation of tile. We combined that information following standard methods for human health risk assessment to characterize risk of cancer for the average Californian who installs tile.

Section 3 provides a fulsome background and overview of our assessment. In Section 4, we describe the scope of the assessment. The hazard characterization component of the assessment, including relevant health protective guideline values, is presented in Section 5. In Section 6, we present details of the exposure assessment for crystalline silica in tile, including exposure factors and exposure concentrations. The results from our assessment of potential health risks are presented in Section 7. The discussion of the findings from the assessment are presented in Section 8. The conclusions drawn from this analysis are provided in Section 9. Section 10 contains a bibliography of the literature and other data sources relied upon for this report. Lastly, Section 11 recognizes the participating manufacturers included in our study.

[1] The conclusions from this report apply to brands of participating manufacturers and should not be generalized to brands of other manufacturers without additional analysis.

3.0 BACKGROUND

In this section, we first discuss the aspects of the Prop 65 regulation that define the exposure scenarios targeted by this research. Next, we describe the types of tile installed in buildings and tile installation practices. In the remainder of this section, we summarize prior research on exposures to respirable crystalline silica associated with cutting of building materials.

3.1 PROPOSITION 65

Prop 65 is intended to inform consumers about products that contain chemicals known to the state of California where exposure to such chemicals pose potential risks of cancer, developmental, and/or reproductive effects in humans. If typical use of a product results in chemical exposures for the average Californian that are above thresholds established by the law, then the business is required to provide "clear and reasonable" warnings to individuals within the state of California.

The chemical-specific exposure thresholds, above which labeling is required are referred to as "safe harbor" levels. The need for labeling is generally evaluated by completing an exposure assessment that compares the magnitude of exposure for the average Californian to the appropriate safe harbor levels. For chemicals regulated by Prop 65 that do not have a safe harbor level defined, a risk assessment utilizing appropriate guideline values may be conducted.

In the next section, we describe the information in the literature that is available to evaluate exposures to chemicals regulated by Prop 65 that could occur during handling and installation of tile by the average Californian who installs tile.

3.2 DEFINITION OF TILE

The American National Standard Specifications for Ceramic Tile, ANSI (American National Standards Institute) A137.1 defines tile to be "*a ceramic surfacing unit, usually relatively thin in relation to facial area, having either a glazed or unglazed face and fired above red heat in the course of manufacture to a temperature sufficiently high to produce specific physical properties and characteristics* (ANSI, 2017). Similarly, the American National Standard Specifications for Glass Tile, ANSI A137.2 defines glass tile to be "*a tile having an overall non-crystalline microstructure with* SiO_2 *as the primary constituent and manufactured by one or more of three primary processes: cast, fused, or low temperature-coated*" (ANSI, 2014).

ANSI A137.1 identifies 4 different types of ceramic tile: porcelain tile, pressed floor tile, glazed wall tile, and quarry tile (ANSI, 2017). Certain tile types can be further distinguished by the color of clay used to manufacture the tile. For example, pressed floor and glazed wall tiles can be composed of either reddish or whitish clay and are therefore referred to as “red body” or “white body” tiles. Table 3.1 displays the different tile classifications.

Table 3.1 Ceramic and Glass Tile Types[1]

Tile Type		Description
Ceramic	Porcelain	• Ceramic tile with water absorption of 0.5% or less.[2] • Must be made with porcelain-grade clays and raw materials and fired in kilns set to firing temperatures of approximately 2000 °F to 2300 °F (1093 °C to 1260 °C). • May be pressed or extruded.
	Pressed Floor Tile Red Body	• Primarily used on floors but can also be used for walls and countertops. • Manufactured by having the body of the tile formed by pressure. • Can be vitreous, semi-vitreous, or non-vitreous.
	Pressed Floor Tile White Body	• Primarily used on floors but can also be used for walls and countertops. • Manufactured by having the body of the tile formed by pressure. • Can be vitreous, semi-vitreous, or non-vitreous.
	Glazed Wall Tile Red Body	• Non-vitreous and intended for use on walls.
	Glazed Wall Tile White Body	• Non-vitreous and intended for use on walls.
	Quarry	• Water absorption up to 5% and formed by an extrusion process from natural clay or shale.
Glass		A tile having an overall non-crystalline microstructure with SiO_2 as the primary constituent and manufactured by one or more of three primary processes: cast, fused or low temperature-coated (ANSI, 2014).

°F degrees Fahrenheit
°C degrees Celsius
SiO_2 silicon dioxide
≤ less than or equal to
> greater than

1 Mosaics were not included within this table because they are smaller cuts of various tile types.
2 Water absorption is defined as the percentage of weight a tile gains when water soaks into the body and is an indication of the porosity of the tile. The industry generally recognizes four categories of water absorption capacity: impervious (≤0.5%), vitreous (0.5 – 3%), semi-vitreous (3 – 7%), or non-vitreous (>7%).

Sources:
ANSI. 2014. *ANSI A137.2-2013 American National Standard Specifications for Glass Tile*. Washington, DC: American National Standards Institute.
ANSI. 2017. *ANSI A137.1-2017 American National Standard Specifications for Ceramic Tile.* Washington, DC: American National Standards Institute.
UL Environment. 2014. *Ceramic Tile, Industry-wide Report Products Manufactured in North America, Environmental Product Declaration*. Marietta, GA: UL Environmental. Retrieved from http://www.tcnatile.com/images/pdfs/EPD-for-Ceramic-Tile-Made-in-North-America.pdf.

According to TCNA, approximately 3 billion square feet (ft^2) (280 million square meters [m^2]) of ceramic tile are purchased annually in the United States and used in multiple applications in commercial and residential buildings (TCNA, 2018). To meet this demand, manufacturers produce tile in numerous sizes, textures, and colors to appeal to consumer taste, style, preference, and trends (ANSI, 2018). Trends in tile are primarily aesthetically driven. The most commonly sold colors are neutral or earth tones. National retailers report that their top selling tiles are various shades of white, grey, and brown. Guidance on choosing tile is readily available to consumers on the internet and is consistent with the top sellers reported by retailers.[2] For example, soft hues and neutral colors are said to make a space feel big and hence are recommended for small spaces.[3]

3.3 COMPOSITION OF TILE

Tile products generally consist of two major components, the body and the surface application (UL Environmental, 2014). The body of the tile is largely made up of clay and other raw materials such as sand, scrap tile material from prior production, and silicate minerals (UL Environmental, 2014). The surface application of a tile typically consists of glaze and/or stain. Through the firing process the body and surface application fuse into a single material (ANSI, 2017).

Our literature search identified information on the composition of tile, and we further examined the composition of the raw materials from which most tile is made. Clays are primarily mixtures of amorphous minerals composed of aluminum, silicon, and oxygen, as well as crystals of quartz and other materials (Nayak and Singh, 2007; Alloway, 2013). Sand does not have a defined mineral composition, but its primary component is silica in the form of quartz (USGS, 2000). Tile production also uses various silicate minerals including feldspar, nepheline, granite, pyrophyllite, wollastonite, talc, and kaolin (UL Environmental, 2014). Minerals are categorized as silicate when the molecular composition contains silicon and oxygen (Panchuk, 2017).

Glaze is a thin, usually smooth, coating that is applied to tile products prior to being fired in a kiln to enhance performance or add color and other aesthetic properties (UL Environmental, 2014). The glazing materials are composed of water, glass frits, minerals, opacifiers, pigments, and/or stains (Casasola et al., 2012). The glaze is applied by pouring, spraying, printing, as well as other methods and then firing the tile to form a decorative layer (TCNA, 2006; American Tile & Stone, 2017).

3.4 TILE INSTALLATION

Tile installation consists of numerous tasks including cleaning and preparing the surface to be covered, measuring and cutting tile to fit the space, arranging or setting tile, applying grout, applying finishes, and clean up (BSL, 2015). Of these duties, the task of cutting tile poses the greatest potential for exposure to constituents in tile. Tile cutting releases dust by removing a narrow section of tile with a motorized tool or fracturing the tile with a manual cutter such as a score and snap cutter, i.e., “snap cutter.”

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[2] We reviewed tile selection guidance available at Wayfair.com and Lowes.
[3] We reviewed tile selection guidance available at Wayfair.com, homedit.com, and thespruce.com.

To understand the different methods of tile cutting, we reviewed literature and regulations, and conducted interviews with professionals in the tile industry. The interviewees included Five Star certified contractors, professional tile installers, and representatives of TCNA, the National Tile Contractors Association, and the Ceramic Tile Education Foundation.

Multiple tools are used to cut tile. The types of tools discussed in the literature are water (wet) saws, snap cutters, nippers, hole cutters, hole saws, drills, and grinders (Meehan and Meehan, 2005; Schweit and Nicholas, 2008; Home Improvement Group, 2010). The selection of a tile cutting tool is dependent on the type and dimensions of tile being cut, the type of cut being made, and preference of the installer. Manual cutters such as snap cutters and nippers are used to make simple straight and curved cuts on a variety of tile types (Schweit and Nicholas, 2008). Wet saws are well suited for making more intricate cuts such as miters or inside cuts, and working with stone, porcelain, and glass tiles (Meehan and Meehan, 2005; Schweit and Nicholas, 2008). Motorized dry cutting tools such as hole saws, drills and grinders are used less frequently and are generally limited to making curved and hole cuts in tile, usually to accommodate plumbing fixtures and pipes (Schweit and Nicholas, 2008). Overall, snap cutters and wet saws are the most frequently referenced tools for tile cutting in professional tile handbooks and job descriptions for tile installers (Meehan and Meehan, 2005; Schweit and Nicholas, 2008; Home Improvement Group, 2010; BSL, 2015).

Information on tool use gathered during our interviews with experts in the tile industry and tile installers was consistent with the literature. Interviewees indicated that most cuts required during a tile job can be completed with a snap cutter and/or a wet saw. They also indicated that snap cutters and wet saws are the most frequently used and preferred tile cutting tools. Interviewees also reported that motorized dry cutting tools are used infrequently, with uses limited primarily to specialized cuts that are often performed outdoors. Additional information from the interviews is presented in Section 6.

Information on tools used to cut tile is also available from the U.S. Occupational Safety and Health Administration (OSHA) standard for crystalline silica (OSHA 29 CFR 1926.1153). In that standard, OSHA recommends types of tools, work locations, and in some cases personal protection equipment, for cutting materials that contain crystalline silica. For example, the standard identifies motorized cutting with an integrated water delivery system, i.e., wet saw, as a method that produces exposure concentrations of respirable crystalline silica below levels that indicate the need for exposure monitoring (OSHA 29 CFR 1926.1153).

3.5 RELEVANT PRIOR STUDIES

We searched the peer-reviewed scientific literature and government or industry-sponsored research to identify sources of information relevant to assessing human exposure to respirable crystalline silica in tile. We then examined the utility of that information for identifying concentrations of crystalline silica in tile and assessing the level of tile-related exposure to respirable crystalline silica for the average Californian who installs tile.

3.5.1 Occupational Exposures / Concentrations

We identified and reviewed multiple studies relevant to cutting construction materials containing crystalline silica to help develop our study design. One study conducted by OSHA focused on occupational exposures to crystalline silica among U.S. workers in different occupational fields. Researchers determined that the arithmetic mean 8-hour time-weighted average (TWA) exposure to respirable crystalline silica among tile, marble, and mosaic workers was 0.036 milligram per cubic meter (mg/m^3) (Yassin et al., 2005). Notably, the measurements reported in this study are not specific to tile, but also include exposures for people working with natural stone materials. Nonetheless, the occupational exposure concentrations available in this paper were useful for understanding the approximate level of the respirable crystalline silica concentrations in typical workplaces where tile is being installed.

A study conducted by National Institute for Occupational Safety and Health (NIOSH) assessed exposures of roof installers to respirable crystalline silica during dry cutting and installation of cement roof tile (Hall et al., 2013). The continuous monitoring of particulate matter indicated that approximately 17% of particulate matter generated during dry cutting of cement roof tiles was in the respirable size fraction. The 8-hour personal breathing zone respirable crystalline silica concentrations ranged from 0.04 mg/m^3 to 0.44 mg/m^3 (40 to 440 micrograms per cubic meter [$\mu g/m^3$]). The percent weight of crystalline silica (quartz) of respirable particulate matter ranged from 9.5 to 21.7%. Quartz concentrations in bulk samples of the roof tiles ranged from 13 to 24% weight; other forms of crystalline silica (cristobalite and tridymite) were not detected. Although not specific to installation practices of ceramic or glass tile, the information on concentrations of airborne crystalline silica associated with cutting these construction materials was helpful for selecting sampling methods for our research.

3.5.2 Emission Rates

In another published study, investigators from NIOSH evaluated emission rates for respirable particulate matter and respirable crystalline silica from cutting fiber-cement siding in a laboratory-based test duct (Qi et al., 2016). They quantified the emission factor (EF) as the amount of particulate matter generated per standardized cut of cement board in a chamber, accounting for the flow rate and volume of the chamber, the sampling time during the cutting, and the width and number of cement boards that were cut. In addition to characterizing the emission rates, these authors demonstrated that emissions of respirable crystalline silica were proportional to the concentration of crystalline silica in the cement board.

Exposures to respirable dust and respirable crystalline silica have also been evaluated in relation to the type of tool used to cut stone, cement, and related materials. One study measured a 91% reduction in respirable crystalline silica exposure during block and brick cutting when using a stationary wet saw compared to dry cutting with no control (Meeker et al., 2009). Another study found respirable particulate matter concentrations generated from cutting curbs and slabs with a wet saw were at least 90% lower than concentrations generated from a motorized dry saw with no control system (Thorpe et al., 1999). In a controlled study of emissions generated by cutting cement roof tile, the authors reported that use of a wet saw reduced respirable particulate matter concentrations by 99% compared to a motorized dry saw (Carlo et al., 2010). According to OSHA's exposure profile for stationary masonry saws, wet cutting masonry resulted in a mean 8-hour TWA respirable crystalline silica exposure concentration of 34 μg/m^3 compared to a mean respirable crystalline silica exposure concentration of 329 μg/m^3 from dry cutting operations (Federal Register, March 25, 2016).

3.6 SUMMARY AND CONCLUSION

As described above, our search of the scientific literature did not identify any studies that specifically characterized exposures associated with installation of tile. However, the information did indicate that emissions and exposure concentrations are likely to be strongly related to the method used to cut tile. We also concluded that the information available at this time was not adequate for assessing potential exposures to respirable crystalline silica in tile for the average Californian who installs tile. However, the prior research was useful for identifying exposures of interest and evaluating alternative approaches for gathering information specific to tile. Information from the literature was also useful for selecting exposure scenarios to include in our research. As a result, we focused on developing EFs for respirable crystalline silica during motorized and manual tile cutting. The EFs provide a means for applying exposure modeling to different exposure scenarios to estimate lifetime average daily exposure and associated cancer risk of respirable crystalline silica.

4.0 SCOPE OF THE ASSESSMENT

In this section of the report, we describe the scope and objective of the risk assessment in the context of the background information presented above.

Tile products are non-friable and as a result, there is no inhalation exposure to respirable crystalline silica from installed tile. During installation, however, cutting tile can release respirable size particles of tile into the air. The particles provide a pathway of potential exposure to chemical substances in tile, such as respirable crystalline silica. Respirable crystalline silica is identified as a human carcinogen in the scientific literature and by numerous regulatory and other authoritative organizations.

People in proximity to tile cutting have the greatest potential to be exposed to respirable particles generated from tile. This population includes people who cut tile and people who spend time near where tile is being cut. For those reasons, our assessment focused on professional and non-professional tile setters.

The U.S. Department of Labor (DOL) identifies professional tile setters by occupational code 47-2044 (BSL, 2018a). People in this occupation prepare surfaces to be covered, measure and cut tile to fit the space, arrange or set tile, apply grout, apply finishes, and clean up (BSL, 2015). Statistics published by DOL indicate that 7,150 professional tile setters worked in California in 2017 (BSL, 2018a).

Non-professional tile setters are people who set tile but are not employed in the field. A representative sample of the United States for calendar year 2015, the latest data available, indicated that 1.4% of owner-occupied households completed a non-professional bathroom renovation or remodeling project in the prior year (Census Bureau, 2015). Not all of these projects would necessarily involve cutting or setting tile. If they did, however, non-professionals would set tile in approximately 106,500 California households each year (Census Bureau, 2017). On average, 2.95 people live in each California household (Census Bureau, 2017). Tile installation could be completed by 1 or more people living in each household. In consideration of the average number of residents per household, our base case analysis assumed that 2 non-professionals participated in each tile installation on average. Based on that value, approximately 213,000 non-professionals in California install tile each year while completing a home renovation or remodeling project.

These two groups, the professionals and non-professionals, comprise the population of people who install tile in California. For that population, we assessed potential risks of cancer associated with lifetime average exposure to respirable crystalline silica in tile during installation following standard methods for human health risk assessment (USEPA 2009; WHO 2010).

5.0 HAZARD CHARACTERIZATION

OEHHA and USEPA publish quantitative estimates of cancer potency for specific compounds. These guideline values represent conservative, i.e., health protective, estimates of the potential risk of cancer per unit of exposure averaged over a lifetime (Castorina and Woodruff 2003; USEPA 2018).

However, neither OEHHA nor USEPA has developed a cancer potency value or No Significant Risk Level (NSRL) for respirable crystalline silica. Instead, the guideline value for cancer potency used in our analysis was obtained from reports published by OEHHA related to 2 prior SUDs. One of those SUDs was submitted by the National Paint and Coatings Association for respirable crystalline silica in interior flat latex paint (OEHHA, 2003). The other SUD was prepared by the Sorptive Minerals Institute for respirable crystalline silica in sorptive mineral-based pet litter (OEHHA, 1999). The cancer potency value also known as inhalation unit risk (IUR) for respirable crystalline silica reported in the latex paint and pet litter SUDs ranged from 6.8×10^{-7} to 1.85×10^{-5} per $\mu g/m^3$ (Goldsmith et al., 1995). To be health protective, we used the more conservative upper bound IUR value of 1.85×10^{-5} in our analysis (Goldsmith et al., 1995).[4]

[4] The USEPA defines inhalation unit risk as "the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 $\mu g/m^3$ in air." Source: https://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/glossariesandkeywordlists/search.do?details=&glossaryName=IRIS%20Glossary

6.0 EXPOSURE ASSESSMENT

6.1 OVERVIEW

We evaluated several different approaches to assess potential tile-related exposure to respirable crystalline silica. Ultimately, we chose to employ a microenvironmental modeling approach that combines information on respirable crystalline silica emissions during tile cutting and exposure factors for tile setters. We developed inputs for the model from interviews of tile setters, measurements of chemical concentrations in commonly sold tile products, controlled experiments to quantify emissions of chemicals when a tile is cut, and searches of the relevant literature. We corroborated the modeling results with observations and measurements made at construction sites during times when tile was being installed.

6.2 EXPOSURE FACTORS

In this section of the report, we describe the results of the interviews conducted to develop exposure scenarios and exposure factors.

To gather information on exposure scenarios and exposure factors, we interviewed a representative from each of 18 companies that in total employ 830 tile setters and tile helpers. The companies install tile in California and 17 other states including: Arizona, Florida, Georgia, Idaho, Illinois, Indiana, Michigan, Minnesota, Mississippi, Nevada, New Jersey, North Carolina, Pennsylvania, Texas, Utah, Virginia, and Wisconsin. The responses represent the average tile setter at each company.

We collected exposure factor inputs such as frequency of tool use, time spent in various tile-related microenvironments, and the years, weeks, days, and hours spent setting tile over a lifetime. We utilized the information obtained from interviews to develop exposure factor inputs for characterizing lifetime average daily exposure.

Over the course of a job, tile setters spend time in three main microenvironments; the installation site, the adjacent room (indoor cutting area), and outdoors. The tile setting area is the space where the tile is being installed. The indoor satellite cutting area is a space adjacent to the tile setting area, where tile setters generally locate and operate stationary tools such as a wet saw. When conditions permit, tile setters occasionally use motorized cutting tools in outdoor locations as indicated in the table. A summary of the information on tool use and microenvironmental time-location patterns obtained from our interviews is shown in Tables 6.1 and 6.2.

All interviewees reported using snap cutters and wet saws on a regular basis. Because these tools are used daily at work, the interviewees were able to provide precise information on the frequency and location with which they used snap cutters and wet saws. For example, snap cutters are always used in the installation site, directly adjacent to the work of the tile setter because they are compact and produce minimal dust. Wet saws are typically set up in one location, which does not usually change throughout the day. They can be set up in the installation site but because of their size are generally used in a room adjacent to the tile installation or outside.

Interviewees reported using handheld tools, such as core bits, nippers, and angle grinders, less frequently than wet saws and snap cutters. Several of the interviewees indicated they only use 1 or 2 types of handheld tools. For example, 6 interviewees representing 570 installers said they do not use angle grinders at all. Consequently, we had fewer responses to analyze for handheld tools than for wet saws and snap cutters. Distinct use patterns were evident for handheld tools nonetheless. Principally, handheld motorized cutting tools, with or without dust control systems in place, are most commonly used outdoors or an indoor space near the installation area.

Table 6.1 Relative Frequency of Tools Used to Cut Tile[1]

Cutting Method	Tool	Percentage of total cuts with each tool
Manual Cutting	Snap Cutter	76%
	Nippers	0.25%
Wet Cutting	Wet Saw	17.5%
	Angle Grinder with Wet Sponge	0.4%
	Core bit with Wet Sponge	2%
Dry Cutting	Angle Grinder	1%
	Core bit	0.15%
Dry Cutting with control other than water	Stationary Saw with Dust Capture	1%
	Angle Grinder with Dust Shroud	1.7%
Total		100%

1 Based on interviews of professional tile installers as well as literature on tile installation referenced in Sections 3 and 6 of this report.

Table 6.2 Location of Tool Use[1]

Cutting Method	Tool	Percentage of Uses by Microenvironment[2]		
		Installation Site	Adjacent Room	Outside
Manual Cutting	Snap Cutter	100%	0%	0%
	Nippers	100%	0%	0%
Wet Cutting	Wet Saw	5%	50%	45%
	Angle Grinder with Wet Sponge	15%	35%	50%
	Core bit with Wet Sponge	10%	50%	40%
Dry Cutting	Angle Grinder	15%	30%	55%
	Core bit	20%	30%	50%
Dry Cutting with control other than water	Stationary Saw with Dust Capture	25%	35%	40%
	Angle Grinder with Dust Shroud	10%	50%	40%

1 Based on interviews of professional tile installers as well as literature on tile installation referenced in Sections 3 and 6 of this report.
2 Rows total to 100 percent.

To gather information on the typical amount of tile cut during an installation, we asked tile professionals about two common types of tile installations: bathrooms and kitchens. For a bathroom with 50 square feet of floor tile and 150 square feet of wall tile, interviewees reported that on average this space would require approximately: 2.75 days for an individual installer to complete (22 hours), 60 lineal feet of tile cut, and 2 hours of cutting. On average, for a room with 200 square feet of floor tile, interviewees reported that the space would require approximately: 1.75 days to complete (14 hours), 50 lineal feet of tile cut, and 1.1 hours of cutting.

Inputs for the lifetime frequency and duration of tile setting work for professional and non-professional tile setters were gathered from interviews. Professionals generally reported spending 25 years in the field; 3 as a helper and 22 as a tile setter. On average, they work 49 weeks per year, 5 days per week, and 7.5 hours per day.

In contrast, non-professionals set tile much less frequently than professionals. As noted in Section 4, data from the U.S. Census Bureau indicate that bathrooms are renovated or remodeled in approximately 106,500 owner-occupied households per year in California. To be conservative, we assumed that new tile is set on the floor and walls of the room for each renovation and remodeling job. This input will lead to overestimates of actual exposures because some remodeling and renovation jobs consist solely of installing natural stone or replacing plumbing fixtures, cabinetry, paint, or wallpaper. The census data are silent on the number of tile jobs that a non-professional tile setter will undertake over their lifetime. To fill that information gap, we made a set of reasonable, but conservative assumptions. First, we assumed that non-professionals perform an average of 1 tile setting job in each residence that they occupy. According to human activities exposure factors published by USEPA, Americans relocate their residence every 12 years on average (USEPA, 2011). We further assumed that non-professionals set tile between the ages of 18 and 68, a period of 50 years. Combining these assumptions, we estimate that the average non-professional tile setter completes 4.2 projects, which we rounded up to 5, over their lifetime. We also conducted a sensitivity analysis in which the average non-professional completed one tile installation job every year for 50 years.

6.3 EXPOSURE CONCENTRATIONS

6.3.1 Overview

In this section of the report, we describe the tile products and the process used to characterize exposure concentrations.

6.3.2 Tile Inventory

Through TCNA, we requested that manufacturers in Italy, Mexico, Spain, and the United States provide us with samples of their most commonly sold porcelain, pressed floor red body, pressed floor white body, quarry, wall tile red body, wall tile white body, and glass tile products. Table 6.3 displays a summary of the number of unique tile products we received by tile type.

Table 6.3 Number of Tile Products Received by Tile Type

Tile Type	Total by Type
Glass Tile	8
Porcelain Tile	15
Pressed Floor Tile Red Body	11
Pressed Floor Tile White Body	4
Quarry Tile	11
Wall Tile Red Body	6
Wall Tile White Body	8
Total	63

In addition to representing seven different types of tile, the tile products received had diverse physical characteristics. Tiles ranged in size from 0.0026 to 6.0 ft^2 (0.00024 to 0.56 m^2) with a median of 0.96 ft^2 (0.089 m^2). The tile products also varied in thickness from 0.18 to 0.66 inches (0.46 to 1.68 centimeters [cm]). As illustrated by the photo in Figure 6.1, the collection of tile products gathered for this research consists primarily of neutral tones and is consistent with the "top sellers" described above in Section 3.2.

Figure 6.1 Photograph of Tile Inventory Representing Products for Research

6.3.2.1 Analytical Method for Crystalline Silica in Tile

We selected 5 to 8 products from each type of tile for chemical analysis. We removed 12 square inches (77.42 square centimeters) from the corner of one tile of each product to obtain a bulk sample that would result in approximately 60 milliliters of dust after being pulverized to be suitable for analysis. For quality control purposes, a replicate section of tile was obtained from three of the products to create duplicate samples, which received the same analysis as the primary sample.

The sections of tile were shipped to the National Brick Research Center at Clemson University (Anderson, South Carolina) and pulverized in a puck mill to a nominal grain size of 200 micrometers (µm). The pulverized tile samples were shipped to Liberty Mutual Industrial Hygiene Laboratory (Liberty) (Hopkinton, Massachusetts) for analysis.

A subsample of the pulverized tile was analyzed at Liberty for concentrations of crystalline silica according to NIOSH 7500. Prior to analysis, the pulverized tile was screened with a 10 µm sieve to obtain respirable sized particles. The samples were weighed and then transferred to small glass vials, mixed with isopropanol, and sonicated to disperse the sample. The samples were then deposited onto silver membrane filters and assayed for crystalline silica (quartz, cristobalite, and tridymite) by X-ray diffraction (XRD).

When testing samples for crystalline silica, a qualitative XRD scan is done to determine the presence of silica polymorphs by their characteristic diffraction peaks. Liberty's XRD analysis for every sample includes diffraction angle scans in a "low region" (20 to 22.5°) and a "high region" (26 to 27.5°). The primary diffraction peaks for quartz are detectable in the high region and the primary diffraction peaks for cristobalite and tridymite are detectable in the low region. Tridymite is an uncommon form of crystalline silica; therefore, Liberty's standard practice is to conduct a qualitative XRD scan for the presence of tridymite and follow up with further analysis if present in the sample. Quartz and cristobalite were further quantified by XRD in accordance with NIOSH Method 7500. The detection limits were 0.02% weight for cristobalite and quartz in bulk samples.

6.3.2.2 Analytical Results for Crystalline Silica in Tile

We analyzed a total of 46 samples of tile, including 40 primary samples and 6 duplicate samples, for three forms of crystalline silica. Crystalline silica in the form of quartz was detected in all but 6 of the 40 (85%) tile samples, with glass tile being the exception. Cristobalite and tridymite, less abundant forms of crystalline silica, were not detected in any of the tile products. The detected concentration of quartz ranged from 2.9 to 25% weight.

6.3.2.3 Survey of Tile Manufacturers

We administered surveys to tile manufacturers in North America, Italy, and Spain to collect information of the content of silica (SiO_2) in ceramic tile. Tile manufacturers obtain information on the total silica content (including amorphous and crystalline silica) of tile products for quality control. We received 246 survey responses. The median concentration of silica (including amorphous and crystalline forms) reported by tile manufacturers was 67% by weight. There were some tile manufacturers from Spain who quantified crystalline silica in respirable size fraction of pulverized tile. The median concentration of crystalline silica in the respirable size fraction reported by certain Spanish tile manufacturers was 4%.

6.3.3 Emissions Tests

6.3.3.1 Overview

In this section of the report, we describe the process used to characterize emissions of crystalline silica in air during cutting of tile. Here, we provide a brief overview of the methods that are detailed in the remainder of this section.

We conducted simulations of tile cutting and analyzed the data from the simulations to determine emissions of crystalline silica. The simulations focused on particulate matter emissions generated by tools that are representative of use practices of tile installers and are also permitted by the OSHA respirable crystalline silica standard; specifically, an electric-powered wet saw and a manually operated snap cutter. The experimental design was adapted from approaches recommended by governmental organizations, such as the California Department of Public Health, for evaluating chemical emission rates from surface finish materials in buildings (OEHHA, 2003; OEHHA, 2016).

We developed EFs (emissions per standard tile cut) for crystalline silica in respirable particulate matter. The objective of this analysis was to assess the feasibility of estimating potential inhalation exposure concentrations based on the crystalline silica composition of a tile product.

6.3.3.2 Experimental Design for Emissions Tests

We quantified airborne emissions of respirable particulate matter during the cutting of tile products for which we also determined the concentrations of crystalline silica. A brief description of the experimental design and methods are provided here.

The testing was conducted in a 23.1 cubic meter chamber (Clean Air Products Inc., Model CAP591) located at EH&E's facility in Needham, Massachusetts. The chamber is finished with painted aluminum walls and linoleum floor tiles. A small oscillating fan, set to high, was operated within the chamber to promote mixing. A second fan, referred to as the make-up air fan, was used to draw air into the chamber at a flow rate of 5.8 cubic meters per hour, which provided an air exchange rate (AER) of 0.25 per hour.

Emissions were characterized during cutting of tile with both a wet saw and a snap cutter. The model of the wet saw was a MK Diamond HD-101R tile saw, which was rented from a home improvement store that has operations in most of the United States and offers similar rentals, if not the same equipment. The wet saw was fitted with a new Ridgid 10-inch Premium Tile Diamond Blade. The model of the snap cutter was a QEP 10600BR 24-inch Brutus, which was also rented from a home improvement store. We determined the wet saw and snap cutter used for the trials were representative of cutting tools utilized by professional tile installers indicated from our interviews. In addition, these cutting tools are readily available for rental from common home improvement stores for use by non-professional tile installers.

The length of tile cut and frequency of cuts made during each trial was designed to produce concentrations of respirable dust that were quantifiable with a continuous-reading nephelometer (DRX Aerosol Monitor 8533, TSI Inc.) over the course of each test. The wet saw trials were also designed to yield quantifiable concentrations of crystalline silica in time-integrated respirable dust samples that were collected over the duration of each trial. Based on the results of pilot testing conducted to inform the ultimate protocols, trials involved cutting 1 foot (0.30 m) of tile (if possible) every minute for a total of 25 minutes with the wet saw and every 30 seconds over 30 minutes with the snap cutter. This methodology was chosen because we could reach steady state in the chamber relatively quickly and collect a quantifiable concentration of crystalline silica in respirable particulate matter samples.

6.3.3.3 Analytical Method for Respirable Crystalline Silica

Particles in the respirable size range were deposited onto pre-weighed PVC filters using Sensidyne FSP-10 large capacity size selection cyclones in accordance with NIOSH 0600. Samples were shipped to Liberty and analyzed for particle mass concentrations and crystalline silica content according to NIOSH 7500. The filters were first weighed for gravimetric determination of respirable particulate and then placed into crucibles and ashed at 600 °C in a muffle furnace. The residual material was mixed with isopropanol, sonicated to disperse the samples, and deposited onto a silver filter membrane and assayed for quartz, cristobalite, and tridymite by XRD. The detection limit for respirable particulate was 1.8 x 10^{-4} mg/m^3. The detection limit for cristobalite and quartz was 3.5 x 10^{-5} mg/m^3.

6.3.3.4 Analytical Results for Respirable Crystalline Silica During Wet Saw Cutting

During 30 tile cutting trials with the wet saw, we collected a total of 36 filter samples (24 primary samples and 12 duplicates). Filter samples were analyzed for respirable dust and three forms of crystalline silica in the respirable particle size fraction. Crystalline silica in the form of quartz was detected in all the samples of respirable dust. Cristobalite and tridymite, less abundant forms of crystalline silica, were not detected in any of the samples. Crystalline silica in the form of quartz was present in respirable particulate matter with detected concentrations ranging from 4.9 to 22%.

6.3.3.5 Analytical Results for Respirable Crystalline Silica During Snap Cutting

During 9 tile cutting trials with the snap cutter, we collected a total of 14 filter samples (9 primary samples and 5 duplicates). Filter samples were analyzed for respirable particulate matter and three forms of respirable crystalline silica. The concentration of respirable particulate matter was only detected for 1 out of the 9 tile cutting trials using the snap cutter. Quartz, cristobalite, and tridymite were not detected in any of the filter samples.

6.3.4 Quality Assurance

Our technical teams made planned efforts in each phase of the project to ensure completeness and accuracy of data collection, analytical methods, data entry, calculations, and reporting of results. David L. MacIntosh, Sc.D., C.I.H., Principal Investigator, was responsible for technical oversight of the overall project and for ensuring that high data quality objectives were met by the project team.

All sampling and analytical procedures for the project utilized appropriate and valid monitoring procedures approved and recommended in relevant published sources from regulatory agencies, such as OSHA and NIOSH (refer to Table 6.4).

Table 6.4 Sampling Equipment and Analysis Method by Exposure Measure

Sample Type	Sampling Equipment	Analysis
Temperature and Relative Humidity	Q-Trak Indoor Air Quality Monitor 757 (TSI Incorporated, Shoreview, MN)	Not applicable; direct read device
Area Respirable Particulate Matter	Particulate matter Trak DRX Aerosol Monitor 8533 with a heated inlet (TSI Incorporated, Shoreview, MN)	Not applicable; direct read device
Crystalline Silica in Tile	Bulk Sample (National Brick Research Center at Clemson University, Anderson, SC, & Liberty Mutual Industrial Hygiene Lab, Hopkinton, MA)	NIOSH 7500
Respirable Crystalline Silica in Air	PVC 3-piece cassette, 37 mm pre-weighed with Sensidyne FSP-10 large capacity size selection cyclone and GAST high flow rate pump (Liberty Mutual Industrial Hygiene Lab, Hopkinton, MA)	NIOSH 7500
Respirable Particulate Matter in Air	PVC 3-piece cassette, 37 mm pre-weighed with Sensidyne FSP-10 large capacity size selection cyclone (Liberty Mutual Industrial Hygiene Lab, Hopkinton, MA)	NIOSH 0600

NIOSH National Institute for Occupational Safety and Health
mm millimeter

Source:
NIOSH. 1994. *NIOSH Manual of Analytical Methods* (NMAM) Fourth Edition. Washington, DC: Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

The quality assurance program included criteria for determining acceptable data quality, sampling handling and custody procedures, calibration and performance evaluation procedures, and data reduction and reporting procedures. We checked sample log sheets against chain of custody forms, reviewed chamber and laboratory blank results, checked instrument and laboratory reports against chain of custody forms and field notes, checked compiled data against laboratory reports, screened compiled data for improbable extreme values, generated preliminary plots of results by sample for review, and checked units in compiled data against units in field instrument and laboratory reports. If differences were found between two or more data sources, we evaluated the available records to determine which source was correct.

As part of the quality assurance program, we assessed blank values and method precision. Precision, as the root mean square error of duplicate measurements, was targeted to be less than or equal to 30%. The level of precision for analyzed crystalline silica in tile and respirable particulate matter met the target of less than or equal to 30%.

6.3.5 Emissions Analysis

6.3.5.1 Overview

We analyzed data generated from the measurements of bulk tile and measurements during the tile cutting trials to derive EFs for respirable crystalline silica when cutting tile with a wet saw and a snap cutter. In brief, we fit data from the chamber tests to a first-order compartment model to determine emission rates of respirable particulate matter while cutting tile. Because tiles of different lengths and thicknesses were cut during the trials, we standardized the emissions to a fixed length of cut and thickness of tile following the methodology used by NIOSH when characterizing respirable crystalline silica emissions from cutting cement board (Qi et al., 2016). We defined a standard cut as a 1-foot (0.30-m) long cut of a 3/8-inch (0.95-cm) thick tile. We calculated emissions of respirable crystalline silica by multiplying the respirable particulate emissions by the corresponding concentrations of crystalline silica. In the final step of the analysis, we examined the relationships of crystalline silica concentrations in bulk tile with the corresponding emissions to develop EFs for a standard cut of tile. Details of this analysis are provided in the remainder of Section 6.3.5.

6.3.5.2 Emission Rates

As expected, plots of particulate matter data from the chamber tests demonstrated that respirable particulate matter concentrations during each trial increased approximately linearly initially and then approached steady-state levels during the trial. The pattern was consistent with accumulation according to first-order dynamics. We therefore used a first-order compartment model to calculate the emission rates of respirable particulate matter during each trial.

Before fitting the models, we calibrated the continuous particle readings made with the nephelometer. This calibration was necessary because although nephelometers are convenient for measuring airborne particle concentrations over short time scales, the mass concentrations reported by these devices are dependent upon the light scattering characteristics of the particulate matter being measured (Yanosky et al., 2002). To account for this effect, nephelometer readings are calibrated with collocated gravimetric measurements (TSI Incorporated, 2012). We used results from the filter samples to derive a calibration factor for calculating mass-based concentrations of particulate matter levels over time during each trial. The calibration factor was the ratio of the TWA particulate matter concentration determined gravimetrically to the corresponding TWA determined with the nephelometer.

After calibrating the continuous particle readings, we used non-linear least squares regression to fit the parameters of a first-order compartment model to data from the accumulation period of each test. The accumulation period was defined as the time over which tile was cut with the pre-specified length and frequency. The modeling software uses an iterative process to solve Equation 6.1 for emission rate and removal rate. Because particulate matter concentrations within the chamber reached levels that were at least 100-fold higher than background levels in the chamber at the start of each trial, C_o can be assumed to be effectively zero.

$$C_t = C_o + \left(\frac{ER}{k \bullet V}\right)(1 - e^{-kt}) \qquad \textit{(Equation 6.1)}$$

C_t airborne particulate matter concentration at time t (milligram per cubic meter, mg/m^3)
C_o background airborne particulate matter concentration (mg/m^3)
ER airborne particulate matter emission rate in the test chamber (mg per second, mg/s)
k airborne particulate matter removal rate estimated for each trial (per second)
V volume of the test chamber (m^3)
t time (seconds)

6.3.5.3 Emissions per Standard Cut

We followed methods reported in the literature to standardize the emission rates across the tile products to the material released during a 1-foot (0.30-m) long cut of a 3/8-inch (0.95-cm) thick tile first-order compartment model (Qi et al., 2016). These dimensions were selected to represent a typical tile. Emissions of respirable particulate per standard cut were calculated as shown in Equation 6.2.

$$E = \frac{ER}{f * l * h} \qquad \textit{(Equation 6.2)}$$

E airborne particulate matter emission per standard cut (mg per 1-foot [0.30-m] of 3/8-inch [0.95-cm] tile)
ER airborne particulate matter emission rate in the test chamber (mg per second, mg/s)
f frequency of cuts (cuts per second)
l $\frac{\text{length of cut (ft)}}{\text{1 standard cut (12 in [0.30 m])}}$
h $\frac{\text{thickness of tile cut (in)}}{\text{1 standard cut (0.375 in [0.95 cm])}}$

After standardizing the particulate emissions for each trial, we then calculated the corresponding emissions of crystalline silica. We multiplied E for respirable particulate by the fraction of crystalline silica present in the sample of respirable particulate matter from that trial.

6.3.5.4 Emission Factors

The final step of the data analysis was to determine an EF for respirable crystalline silica when making a standard cut. An EF is a representative value that relates the quantity of a substance emitted to air with an activity that is associated with the emission (USEPA, 1995). For example, an EF for tile would describe the amount of silica released to the air per foot of tile cut. EFs are typically averages derived from the relevant and applicable data (USEPA, 1995). According to this framework, emissions for a constituent of tile are linearly related to the concentration of the constituent in bulk tile. In that case, the EF is the slope of the line between respirable crystalline silica emissions per standard cut and crystalline silica concentrations in tile.

We derived an EF for respirable crystalline silica. Respirable crystalline silica emissions and concentrations in tile fit key assumptions for linear regression, thus, we analyzed the relationship between the crude values for each. For example, emissions of respirable crystalline silica were approximately normally distributed for a given concentration of crystalline silica in tile and of approximately equal variance across the range of crystalline silica levels in tile, i.e., homoscedastic. We then used ordinary least squares regression to derive an EF for respirable crystalline silica as well as to characterize the strength of the association between the emissions and concentrations in tile.

6.3.6 Tool-Specific Concentrations

We used a standard one-compartment model to characterize steady-state concentrations of respirable crystalline silica in indoor air of tile installation work spaces identified in Section 6.2. Exposure concentrations in outdoor areas were assumed to be zero. The form of the model and inputs to the model are shown in Equation 6.3.

$$C_t = \frac{S_t * x * y * \frac{1}{w}}{(k_{dep} + k_{AER})\, V} \qquad \textit{(Equation 6.3)}$$

C_t steady-state concentration of respirable crystalline silica in air for cutting tool *t* (mg/m^3)
S_t emission of respirable crystalline silica per standard 1-foot cut using cutting tool *t* (mg)
x total number of 1-foot (0.30-m) cuts per tile job (ft/m)
y fraction of standard cuts made with cutting tool *t* (unitless)
w number of working hours per tile job (hours)
k_{dep} particulate matter deposition rate (per hour)
k_{AER} air exchange rate (per hour)
V volume of room (m^3)

Inputs to the exposure model were derived from measurements, scientific literature, and recommendations from OEHHA. The inputs to the exposure model are described below.

We developed the emission terms (S_t) in Equation 6.3 from simulations of tile cutting under controlled testing conditions. In brief, we found that emissions of respirable crystalline silica were directly related to their concentration in bulk tile. We also found that emissions differed by the type of cutting tool. We calculated tool-specific S_t for crystalline silica by multiplying the median concentration of crystalline silica measured in bulk tile by the corresponding tool-specific EF.

The total length of tile cut per installation, fraction of cuts made with each cutting tool, and number of working hours per tile job were determined from interviews of tile installers. We used a measured deposition rate (k_{dep}) of 3.6 per hour for the wet saw and 1.1 per hour for the snap cutter. We applied the same atmospheric deposition rates for respirable particulate matter measured during our testing of wet saws to handheld, powered cutting with no controls or with a dust shroud in our exposure concentration modeling. We used an air exchange rate (k_{AER}) recommended by USEPA of 0.45 per hour (USEPA, 2011). This value is conservative compared to a prior SUD for latex paint which used a value of 0.50 per hour (NPCA, 2002) and the median air exchange rate measured in California homes of 0.87 per hour reported in the scientific literature (Yamamoto et al., 2010).

Based on information from the interviews and observations from installation sites, each use of a stationary cutting tool, i.e., snap cutter, wet saw, and stationary saw with integrated shroud and vacuum for dust control, was estimated on average to make a 1-foot (0.30-m) long, straight or gently arced cut through the body of a tile. However, handheld tools such as angle grinders, core bits, and nippers, are used to make substantially different types of cuts.

The tile setters we interviewed indicated that they typically use handheld tools to shave or touch-up the edge of a cut made with another tool, or to make a curved cut to accommodate doorframes, cabinetry, or plumbing penetrations. Consider, for example, the cut-out for a standard 3/4-inch (1.91-cm) diameter shower or sink pipe surrounded by a 3-inch (7.63-cm) diameter flange. The cut-out for this penetration will necessarily be smaller than 1.5 inches (3.81 cm) in diameter with a corresponding circumference no greater than approximately 4.5 inches (11.43 cm). In comparison, touch-up work is generally limited to lengths of 1 to 2 inches (2.54 to 5.08 cm) or less. Therefore, touch-ups made with an angle grinder or nipper would remove even less tile material than a typical cut-out. Based on these considerations and to be conservative, we set the length of each cut made with a handheld tool to 6 inches (15.24 cm).

6.3.7 Tile Setting Microenvironments

Using the tool-specific emission rates and other results of the tile cutting research, we estimated steady-state concentrations of respirable crystalline silica in each microenvironment.

We summed the tool-specific results to obtain the exposure concentration for each tile setting work area or microenvironment (Equation 6.4), following the superposition principle.

$$C_n = \sum C_{ws} + C_{ss} + C_{ds} \qquad \text{(Equation 6.4)}$$

C_n concentration of respirable crystalline silica in microenvironment *i* (µg/m^3)
C_{ws} concentration of respirable crystalline silica from wet saw emissions (µg/m^3)
C_{ss} concentration of respirable crystalline silica from snap cutter emissions (µg/m^3)
C_{ds} concentration of respirable crystalline silica from handheld power tool without dust control (µg/m^3)

6.3.8 Time-Weighted Average Concentrations

We calculated the time-weighted average exposure concentration for a tile setter as shown in Equation 6.5, following the standard microenvironmental modeling approach (USEPA, 2009).

$$EC = (\sum_{i=1}^{n} t_1 C_1 + t_2 C_2 + \cdots + t_i C_i) \qquad \text{(Equation 6.5)}$$

EC 8-hr time weighted average exposure concentration (µg/m^3)
t fraction of time spent in microenvironment (refer to Table 6.5) (unitless)
C_n steady-state concentration of respirable crystalline silica in microenvironment *i* (µg/m^3)
n number of microenvironments (unitless)

The three microenvironments in our assessment included the installation site, adjacent room (indoor cutting area), and outdoors. We calculated the concentration of respirable crystalline silica in the installation site and adjacent room. Because tile installers position themselves away from dust produced by a cutting tool and because dilution is rapid outdoors, we assumed that exposure concentrations outdoors were negligible. The fraction of time spent in each microenvironment is shown in Table 6.5.

Table 6.5 Average Percentage of Time Spent in Tile Setting Microenvironments During a Tile Installation Project

Location	Helper	Setter
Installation Site	56%	81%
Adjacent Room	25%	6%
Outside	19%	13%

6.3.9 Lifetime Average Daily Exposure

We calculated lifetime average daily exposure (LADE) for tile-related inhalation exposures following guidance from USEPA for human health risk assessment (Equation 6.6) (USEPA, 2001).

$$\mathrm{LADE} = \mathrm{EC} \times \frac{\mathrm{ET} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{AT}} \qquad \textit{(Equation 6.6)}$$

LADE	Lifetime Average Daily Exposure (µg/m^3)
EC	Exposure Concentration (µg/m^3)
ET	Exposure Time (hours/day)
EF	Exposure Frequency (days/year)
ED	Exposure Duration (years)
AT	Averaging Time (hours)

We calculated LADE for the average Californian who installs tile as the population-weighted average of professional and non-professional tile setters in California. For professional tile installers, we used an exposure time of 7.5 hours per day, an exposure frequency of 245 days per year and an exposure duration of 25 years. For non-professional tile installers we used an exposure time of 7.5 hours per day, an exposure frequency of 2 days per year and estimated that non-professional tile installers complete 5 tile installations over a lifetime. As noted in Section 4, data from the U.S. Department of Labor indicates that 7,150 people in California install tile as a profession (BSL, 2018b). Similarly, based on data published by the U.S. Census Bureau, we conservatively estimated that 213,000 non-professionals install tile as part of 5 separate home renovation or remodeling projects over their lifetime (USEPA, 2011; U.S. Census Bureau, 2015; U.S. Census Bureau, 2017). We averaged exposure to respirable crystalline silica over a 70-year lifetime, recommended by the California Office of Human and Ecological Risk (HERO, 2014) and USEPA (USEPA, 2011).

7.0 RISK CHARACTERIZATION

To express cancer risk quantitatively, we followed standard methods and calculated excess lifetime cancer risk (ELCR) as the product of the LADE for respirable crystalline silica and its guideline value for cancer potency (Equation 7.1). We calculated ELCR for the population of tile setters in California.

$$\text{ELCR} = \text{LADE} * \text{IUR} \qquad \textit{(Equation 7.1)}$$

ELCR Excess Lifetime Cancer Risk (unitless)
LADE Lifetime Average Daily Exposure (µg/m^3)
IUR Inhalation Unit Risk (per µg/m^3)

We compared the cancer risks to the threshold of 1 in a 100,000 (10^{-5}) for risk management established by Prop 65. Guideline values for cancer potency include science policy decisions that are intended to ensure that actual risks are not underestimated. As a result, for compounds with ELCR less than 10^{-5}, the exposure is not likely to be associated with a substantive increase in the probability of cancer. Similarly, an ELCR greater than 10^{-5} does not indicate that formation of a malignant tumor is imminent, but instead denotes conditions that may warrant additional evaluation of the risk posed by the substance (USEPA, 2018).

The potential LADE, IUR, and ELCR associated with respirable crystalline silica from our analysis for the average Californian who installs tile are shown in Table 7.1. The potential ELCR is 1.3 x 10^{-7}, or 0.013 per 100,000. This level of potential cancer risk is 75-fold below the threshold of 10^{-5} for ELCR under Prop 65.

Table 7.1 Potential Excess Lifetime Cancer Risk for Respirable Crystalline Silica from Tile Installation for the Average Californian Who Installs Tile

Chemical	IUR (µg/m^3)$^{-1}$	LADE (µg/m^3)	ELCR
Respirable Crystalline Silica	1.85 x 10^{-5}	7.0 x 10^{-3}	0.013 in 100,000 (1.3 x 10^{-7})

IUR Inhalation Unit Risk Factor. Upper bound of cancer potency (Goldsmith et al., 1995)
µg/m^3 microgram per cubic meter
LADE Lifetime Average Daily Exposure
ELCR Excess Lifetime Cancer Risk

Source:
Goldsmith DF, Ruble RP and Klein CO. 1995. Comparative Cancer Potency for Silica from Extrapolations of Human and Animal Findings. *Scandinavian Journal of Work, Environment & Health* 21(Suppl 2):104-107.

8.0 DISCUSSION

The results of our human health risk assessment indicate that potential cancer risk associated with respirable crystalline silica tile-related exposures for the average California who installs tile is 75-fold below the Prop 65 threshold of 10^{-5}. This finding is based upon a robust set of information on work practices, measurement of emissions to air, and exposure concentrations that were developed from research conducted expressly for this assessment. We used inputs to the exposure and risk assessment recommended by OEHHA unless we had strong research-based evidence to rely upon. In some cases, however, certain types of detailed information were not available from OEHHA or USEPA. In those situations, we relied upon the scientific literature and best professional judgement to fill the information gap.

For example, OEHHA does not publish recommended exposure factors for installation of tile. In the absence of such data, we estimated that the average non-professional tile setter completes a room-scale tile installation project five times over their lifetime. This input was based on duration of residency data recommended by USEPA, the proportion of U.S. households that completed a "do-it-yourself" bathroom renovation or remodeling projects reported by the U.S. Census Bureau, and best professional judgement (refer to Section 6.2 for details). To evaluate the sensitivity of the risk assessment results to the input for number of tile installations completed over a lifetime, we re-calculated ELCR using an alternative worst-case input that non-professionals complete one tile setting project every year for 50 years. The resulting cancer risk for the population of tile installers in California increased approximately 40% over the baseline ELCR of 0.013 per 100,000, but was still more than an order of magnitude below the Prop 65 threshold of 10^{-5}, indicating that our base case findings are not sensitive to the tile installation frequency for non-professionals.[5]

Similarly, OEHHA does not have default values for the frequency with which the various types of tools are used to cut tile and the length of those cuts. To fill that gap, we gathered information on tool use and cuts from interviews of tile installers. To be conservative in the analysis, we assumed that each use of every handheld tool produced a 6-inch (15.24-cm) cut through the entire body of a tile. However, the tile setters we interviewed indicated that in practice, handheld tools are primarily used to shave the edge of a cut made with another tool or to make a curved cut to accommodate plumbing penetrations or corners of door frames and cabinetry. We made visits to multiple construction sites and our observations corroborated the responses from the interviewees. We expect that emissions to air will be lower when an angle grinder, core bit, and nipper are used in those ways compared to making a 6-inch (15.24-cm) long cut through the body of a tile. Had we incorporated a more realistic use case for handheld tools into our analysis,

[5] The resulting ELCR for respirable crystalline silica under the assumption of 50 tile installations over a lifetime for a non-professional tile installer is 0.018 per 100,000.

the potential ELCR for respirable crystalline silica would have been further below the Prop 65 threshold of 1 in 100,000.

We also used a conservative input to account for limited information available on the effectiveness of an integrated shroud and vacuum system for controlling emissions of respirable particulate from powered handheld cutting tools, such as an angle grinder. Specifically, we assumed that such a system has no efficacy for controlling emissions from handheld tools. In practice however, we expect that emission control technique has some efficacy for handheld tools. If a control efficiency greater than zero for integrated shroud and vacuum systems was incorporated into our analysis, the estimated exposures and cancer risks would be lower than our base case results.

OEHHA also does not provide default values for atmospheric deposition rates of respirable particles generated during tile cutting. To fill this gap, we relied upon data from our tile cutting testing. Even then, some information gaps remained, and we relied upon best professional judgment to develop the necessary inputs. For example, we applied the same atmospheric deposition rates for respirable particulate matter measured during our testing of wet saws to handheld, powered cutting with no controls or with a dust shroud in our exposure concentration modeling. The rationale for using the same deposition rate for wet saws and dry saws is supported by the literature on particle characteristics and removal processes. The deposition rate for particles is primarily based on the aerodynamic size and density of the particulate matter although it can also be affected by humidity if the particles are soluble in water (USEPA, 1998; Shaughnessy and Sextro, 2006). The aerodynamic size distribution of particles emitted while cutting tile is primarily determined by the cutting mechanism of the tool, i.e., motorized cutting with a diamond blade or scoring and manually snapping tile. Tile cutting with a motorized tool, using a diamond blade, releases particles by removing a narrow section of tile. The particles generated from different motorized cutting tools with a diamond blade should have approximately the same size distribution. Additionally, as crystalline silica is not soluble in water, the particle size distribution should not be affected by humidity associated with wet cutting (Kotz et al., 2008; Shaughnessy and Sextro, 2006). Based on these reasons, we determined from the literature that the deposition rate of particles generated from motorized cutting would not be affected by the controls in place such as water delivery or vacuum systems.

The exposure assessment conducted for this analysis indicates that tile-related concentrations of respirable particulate matter in locations where tile is set are strongly associated with the type of tool used to cut tile and the dust control systems used. This finding is consistent with the results of prior research conducted by other investigators. For example, wet cutting, i.e., motorized cutting with integrated water delivery system, has been shown to be effective at reducing exposures to respirable crystalline silica compared to dry cutting. One study measured a 91% reduction in respirable crystalline silica exposure during block and brick cutting when using a stationary wet saw compared to dry cutting with no control (Meeker et al., 2009). Another study found respirable particulate matter concentrations generated from cutting curbs and slabs utilizing a wet saw were reduced by at least 90% when compared to concentrations generated from using a motorized dry saw with no control system (Thorpe et al., 1999). In a controlled study of emissions generated by cutting cement roof tile, the authors reported that use of a wet saw reduced particulate matter concentrations by 99% compared to a motorized dry saw (Carlo et al., 2010). According to OSHA's exposure profile for stationary masonry saws, wet cutting resulted in a median 8-hour TWA respirable crystalline silica exposure concentration of 34 $\mu g/m^3$ and a mean exposure concentration of 41 $\mu g/m^3$ (Federal Register, 2016). These exposure concentrations were substantially lower than the mean respirable crystalline silica exposure concentration of 329 $\mu g/m^3$ from dry cutting operations.

Our testing also indicates that manual cutting tools produce lower emissions of crystalline silica compared to wet and dry saws. For example, we found that emissions of respirable particulate matter during use of a snap cutter are approximately 50-fold lower than during use of a stationary powered saw equipped with an integrated water delivery system. We also found that score and snap emissions are approximately 1,000-fold lower than emissions from a handheld saw without emission controls. Clearly then, work practices that favor the use of manual cutting tools and wet saws, and avoid use of motorized dry cutting without a dust control system, are effective at minimizing tile-related exposures to respirable crystalline silica.

Our interviews of tile installers indicate that the use of motorized dry cutting is decreasing in the tile industry. The change in behaviors appears to be partly in response to the availability of more information and research on health risks associated with respirable crystalline silica exposures from cutting building materials. In 2017, OSHA established a new permissible exposure limit and action level (AL) under the respirable crystalline silica standard for the construction industry. In the new standard, OSHA recommends the types of tools that can be used to cut materials containing crystalline silica as well as where those tools can be used (indoors or outdoors) and what personal protective equipment is appropriate for maintaining exposures below the AL. The standard indicates that motorized cutting with an integrated water delivery system, i.e., wet saw, produces exposure concentrations of respirable crystalline silica that generally do not warrant exposure monitoring (OSHA 29 CFR 1926.1153). OSHA also indicates that employee exposures should be evaluated over the workday when other cutting practices, such as motorized dry cutting, are applied to materials that contain crystalline silica. Our research indicates that eliminating the use of dry cutting without dust controls will reduce exposure to respirable crystalline silica for the population of tile installers in California. After eliminating the use of dry cutting without dust controls from our analysis, the potential ELCR for the average tile installer was reduced to 0.011 per 100,000, over 90-fold below the threshold of 1 in 100,000 for ELCR under Prop 65.

9.0 CONCLUSION

Our human health risk assessment indicates that potential risks of cancer associated with tile-related exposures to respirable crystalline silica for the average Californian who install tile are below thresholds established under the Prop 65 regulation. The potential excess lifetime cancer risk of approximately 1.3 in 10 million (1.3×10^{-7}), or 0.013 per 100,000, is 75-fold below the Prop 65 threshold of 1 in 100,000.

10.0 REFERENCES

Alloway BJ. 2013. Sources of Heavy Metals and Metalloids in Soils. *Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability*. Alloway BJ. Dordrecht: Springer Netherlands 11-50.

American Tile & Stone. 2017. *Tile: How It's Made*. Retrieved from http://www.americantileandstone.com/contentpage.aspx?Id=19765.

ANSI. 2014. *ANSI A137.2-2013 American National Standard Specifications for Glass Tile*. Washington, DC: American National Standards Institute.

ANSI. 2017. *ANSI A137.1-2017 American National Standard Specifications for Ceramic Tile*. Washington, DC: American National Standards Institute.

ANSI. 2018. *ANSI A137.1:2017 American National Standards Specifications for Ceramic Tile Revised*. Washington, DC: American National Standards Institute. https://blog.ansi.org/2018/01/ansi-a1371-2017-specifications-ceramic-tile/#gref

BSL. 2015. *Flooring Installers and Tile and Marble Setters*. Washington, DC: U.S. Bureau of Labor Statistics, Division of Occupational Employment Statistics. Retrieved from https://www.bls.gov/ooh/construction-and-extraction/tile-and-marble-setters.htm#tab-2.

BSL. 2018a. *Occupational Employment Statistics: 47-2044 Tile and Marble Setters*. Washington, DC: U.S. Bureau of Labor Statistics, Division of Occupational Employment Statistics. Retrieved from https://www.bls.gov/oes/current/oes472044.htm.

BSL. 2018b. *State Occupational Employment and Wage Estimates California*. Washington, DC: U.S. Bureau of Labor Statistics, Division of Occupational Employment Statistics. Retrieved from https://www.bls.gov/oes/current/oes_ca.htm.

Carlo RV, Sheehy J, Feng HA and Sieber WK. 2010. Laboratory evaluation to reduce respirable crystalline silica dust when cutting concrete roofing tiles using a masonry saw. *Journal of Occupational and Environmental Hygiene* 7(4):245-251.

Casasola R, Rincón J and Romero M. 2012. Glass-Ceramic Glazes for Ceramic Tiles - A Review. *Journal of Material Science* 47:553-582.

Castorina R and Woodruff T. 2003. Assessment of potential risk levels associated with U.S. Environmental Protection Agency reference values. *Environmental Health Perspectives* 111(10):1318-1325.

Federal Register. 2016. Occupational Exposure to Respirable Crystalline Silica. Occupational Safety and Health Administration, Department of Labor. 81 Fed. Reg. 16714 (March 25, 2016).

Goldsmith DF, Ruble RP and Klein CO. 1995. Comparative Cancer Potency for Silica from Extrapolations of Human and Animal Findings. *Scandinavian Journal of Work, Environment & Health* 21(Suppl 2):104-107.

Hall RM, Achutan C, Sollberger R, McCleery RE and Rodriguez M. 2013. Case Study: Exposure Assessment for Roofers Exposed to Silica during Installation of Roof Tiles. *Journal of Occupational and Environmental Hygiene* 10(1):D6-D10.

HERO. 2014. *Recommended DTSC Default Exposure Factors for Use in Risk Assessmnet at California Hazardous Waste Sites and Permitted Facilities.* California Department of Toxic Substances, Office of Human and Ecological Risk.

Home Improvement Group. 2010. *The Complete Guide to Ceramic Tile*. Minneapolis, MN: Creative Publishing International, Inc.

Kotz JC, Treichel PM and Townsend JR. 2008. *Chemistry and Chemical Reactivity*. Belmont, CA: Brooks/Cole.

Meehan T and Meehan L. 2005. *Working With Tile*. Newton, CT: The Taunton Press, Inc.

Meeker JD, Cooper MR, Lefkowitz D and Susi P. 2009. Engineering Control Technologies to Reduce Occupational Silica Exposures in Masonry Cutting and Tuckpointing. *Public Health Reports* 124(Suppl 1):101-111.

Nayak PS and Singh B. 2007. Instrumental characterization of clay by XRF, XRD and FTIR. *Bulletin of Materials Science* 30(3):235-238.

NIOSH. 1994. *NIOSH Manual of Analytical Methods* (NMAM) Fourth Edition. Washington, DC: Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

NPCA. 2002. *Application RE: Safe Use Determination Under the California Safe Drinking Water and Toxic Enforcement Act of 1986; Crystalline Silica in Latex Paints*. Washington, DC: National Paint and Coating Association.

OEHHA. 1999. *Supporting Materials for a Safe Use Determination For Crystalline Silica in Sorptive Mineral-Based Pet Litter*. Oakland, CA : California Environmental Protection Agency, Office of Environmental Health Hazard Assessment.

OEHHA. 2003. *Supporting Materials for a Safe Use Determination For Crystalline Silica in Interior Flat Latex Paint*. Oakland, CA: California Environmental Protection Agency, Office of Environmental Health Hazard Assessment.

OEHHA. 2016. *Supporting Materials for a Safe Use Determination for Exposure to Residents to Diisononyl Phthalate (DINP) in Vinyl Flooring Products*. Oakland, CA : California Environmental Protection Agency, Office of Environmental Health Hazard Assessment.

OSHA 29 CFR 1926.1153. Safety and Health Regulations for Construction. *Code of Federal Regulations*. Title 29, Part 1926, Section 1153, Respirable crystalline silica. Washington, DC: U.S. Occupational Safety and Health Administration.

Panchuk K. 2017. *Physical Geology, Second Adapted Edition*. Retrieved from https://opentextbc.ca/geology/chapter/2-4-silicate-minerals/.

Qi C, Echt A and Gressel MG. 2016. On the characterization of the generation rate and size-dependent crystalline silica content of the dust from cutting fiber cement siding. *Annals of Occupational Hygiene*.

Schweit M and Nicholas R. 2008. *Tiling Complete Expert Advice From Start to Finish*. Newton, CT: The Taunton Press, Inc.

Shaughnessy RJ and Sextro RG. 2006. What is an Effective Portable Air Cleaning Device? A review. *Journal of Occupational & Environmental Hygiene* 3:169-181.

TCNA. 2006. *Glazed and Confused? Here's a Look at the Terminology and Technology*. Tile Council of North America, Inc.Retrieved from https://www.tcnatile.com/images/pdfs/Glazed%20and%20Confused%20-%20Heres%20a%20Look%20at%20the%20Terminology%20and%20Technology.pdf.

TCNA. 2018. *U.S. Ceramic Tile Industry Update*: Tile Council of North America, Inc. Retrieved from http://www.tcnatile.com/component/content/index.php?option=com_content&view=article&id=321.

Thorpe A, Ritchie A, Gibson M and Brown R. 1999. Measurements of the effectiveness of dust control on cut-off saws used in the construction industry. *Annals of Occupational Hygiene* 43(7):443-456.

TSI Incorporated. 2012. *DustTrak™ DRX Aerosol Monitor Calibration Methods*.

UL Environment. 2014. *Ceramic Tile, Industry-wide Report Products Manufactured in North America, Environmental Product Declaration*. Marietta, GA: UL Environmental. Retrieved from http://www.tcnatile.com/images/pdfs/EPD-for-Ceramic-Tile-Made-in-North-America.pdf.

U.S. Census Bureau. 2015. *American Housing Survey*. Washington, DC: U.S. Department of Commerce, U.S. Census Bureau. Retrieved from https://www.census.gov/programs-surveys/ahs/.

U.S. Census Bureau. 2017. *Quick Facts California*. Washington, DC: U.S. Department of Commerce, U.S. Census Bureau. Retrieved from https://www.census.gov/quickfacts/CA.

USEPA. 1995. *AP 42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources*. Washington, DC: U.S. Environmental Protection Agency.

USEPA 1998. *Guideline on Speciated Particulate Monitoring*. Washington, DC: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards.

USEPA. 2001. *Risk Assessment Guidance for Superfund: Volume I Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments)*. Washington, DC: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response.

USEPA. 2009. *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment)*. Washington, DC: U.S. Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation.

USEPA. 2011. *Exposure Factors Handbook: 2011 Edition (Final Report)*. Washington,DC: U.S. Environmental Protection Agency, National Center for Environmental Assessment, Office of Research and Development.

USEPA. 2018. *Regional Screening Levels Frequent Questions*. Retrieved from https://www.epa.gov/risk/regional-screening-levels-frequent-questions.

USGS. 2000. *Silica Sand*: United States Geological Survey. Retrieved from https://geomaps.wr.usgs.gov/parks/coast/sand/sand.html.

WHO. 2010. *WHO Human Health Risk Assessment Toolkit: Chemical Hazards*. Geneva, Switzerland: International Programme on Chemical Safety Harmonization Project No. 8.

Yamamoto N, Shendell DG, Winer AM and Zhang J. 2010. Residential Air Exchange Rates in Three Major US Metropolitan Areas: Results from the Relationship Among Indoor, Outdoor, and Personal Air Study 1999-2001. *Indoor Air* 20(1):85-90.

Yanosky JD, Williams PL and MacIntosh DL. 2002. A comparison of two direct-reading aerosol monitors with the federal reference method for PM 2.5 in indoor air. *Atmospheric Environment* 36(1):107-113.

Yassin A, Yebesi F and Tingle R. 2005. Occupational exposure to crystalline silica dust in the United States, 1988-2003. *Environmental Health Perspectives* 113(3): 255-260.

11.0 PARTICIPATING MANUFACTURERS

The conclusions from this report apply to brands of participating manufacturers from whom we received data as of May 31, 2019, including tile products and completed surveys and should not be generalized to other tile products without additional analysis.

11.1 NORTH AMERICA

Alcobe Ceramicos S.A. de C.V., ALCESA
American Wonder Porcelain
ARTO, Monrovia, Oleson, Studio, California Revival, 2D Impressions, Decos
Atlas Concorde USA, Inc., Atlas Concorde USA
Caesar Ceramics USA, Caesar USA
Ceramiche Marca Corona USA LLC, 1741 Di Marca Corona, Marca Corona Contract
Crossville Inc., Crossville (including products made for Crossville by Ilva S.A. and Eliane S.A. - Revestimentos Ceramicos)
Dal-Tile Corporation, Daltile, American Olean, Marazzi, Ragno, Mohawk Hard Surfaces
Del Conca USA, Inc., Del Conca USA
Florida Tile, Inc.
Florim USA, Inc.
Interceramic
Ironrock Capital Inc., Metropolitan Ceramics®, METROBRICK®, Royal Thin Brick®
Manufacturas Vitromex S.A. de C.V. & Vitromex USA, Inc., Vitromex, ARKO, Artemis, Oem Brands and Unbranded Products
Mirage Granito Ceramico U.S.A. Inc., Mirage USA
Nitropiso S.A. de C.V., Tecnopiso, Nitropiso, Nitrotile
Porcelanite Lamosa S.A. de C.V., Porcelanite, Lamosa, Firenze
Sonoma Tilemakers
Stonepeak Ceramics, Inc., Stonepeak Ceramics, Fiandre USA, Iris US
Summitville Tiles, Inc.
UST Inc., Landmark Ceramics

11.2 ITALY

Abk Group Industrie Ceramiche S.P.A., Abk, Ariana, Casa Tua, Flaviker
Abm S.R.L., Candia Valpanaro, Art Casa
Altaeco S.P.A., Appiani, Ceramica Vogue
Armonie by Arte Casa Ceramiche S.P.A., Armonie
Casalgrande Padana S.P.A., Casalgrande Padana
Cedir Ceramiche di Romagna S.P.A., Cedir, Imolagres
Ceramica Colli Di Sassuolo S.P.A., Ceramica Colli Di Sassuolo

Ceramica Del Conca S.P.A., Del Conca, Pastorelli
Ceramica Euro S.P.A., Ceramica Euro S.P.A., Fly Zone
Ceramica Faetano S.P.A., Faetano, Fondovalle
Ceramica Mediterranea S.P.A., Mediterranea
Ceramica Sant'Agostino S.P.A., Ceramica Casamia, Ceramica Gresitalia, Ceramica Sant'Agostino
Ceramica Valsecchia S.P.A., Valsecchia
Ceramiche Ascot S.P.A., Ascot Ceramiche, Dom Ceramiche
Ceramiche Atlas Concorde S.P.A., Atlas Concorde, Atlas Concorde Solution, Ceramiche Keope/Keope contract, Supergres
Ceramiche Caesar S.P.A., Caesar, Fap Ceramiche
Ceramiche Ccv Castelvetro S.P.A., Ceramiche Ccv Castelvetro
Ceramiche Mac3 S.R.L., Mac3
Ceramiche Marca Corona S.P.A., 1741 Di Marca Corona, Marca Corona, Marca Corona Contract
Ceramiche Mariner S.P.A., Mariner
Ceramiche Moma S.P.A., Idea Ceramiche, Paul & Co.
Ceramiche Refin S.P.A., Ceramiche Refin
Ceramiche Serra S.P.A., Ceramiche Serra
Ceramiche Settecento Valtresinaro S.P.A., Settecento - Mosaici e Ceramiche D'Arte
Cerindustries S.P.A., Cerdomus, Porcellana Di Rocca
Coem S.P.A., Blu Art Stone, Ceramica Fioranese, Ceramiche Coem Manifattura
Cooperativa Ceramica d'Imola S.C., Imola, Lafaenza, Leonardo
Eco Ceramica S.P.A., Eco Ceramica, Arkadia
Elios Ceramica S.P.A., Elios Ceramica
Emilceramica S.R.L., Emilceramica, Emilgroup, Ergon, Viva, Provenza, Acif
Etruria Design S.R.L., Etruria Design
Faro Ceramiche S.R.L., Faro Ceramiche, Dolcevita, Basilica
Fincibec S.P.A., Century, Fincibec, Fire, Monocibec, Naxos
Florim Ceramiche S.P.A, Casamood, Cedit Ceramiche d'Italia, Cerim, Floor Gres, Rex Ceramiche Artistiche, Casadolcecasa, Florimstone
Gambinigroup S.P.A., Gambini Tile On Time
Gamma Due S.P.A., Ornamenta
Gold Art S.P.A., Energie Ker
Gruppo Beta S.P.A., Astor, Edimax
Gruppo Ceramiche Gresmalt S.P.A., Abitare La Ceramica, Materia Design, Sintesi Ceramiche
Gruppo Ceramiche Ricchetti S.P.A., Cerdisa, Cisa, Ricchetti
Gruppo Romani S.P.A., Cerasarda, Cercom, Cir, Ngt, Seremissima
Gs Luxury Group S.P.A., Ducati, Gs Luxury, Tonino Lamborghini Tiles X Style
Happy House S.R.L., Happy House
Herberia S.P.A., Herberia
Horus Art Ceramiche S.R.L., Horus Art Ceramiche

Industrie Ceramiche Piemme S.P.A., Ceramiche Piemme Floor And More, Valentino Lifestyle By Ceramiche Piemme
Italgraniti Group S.P.A., Impronta, Italgraniti
Keradom S.R.L., Keradom
Kronos 2 Ceramiche S.P.A., Kronos Ceramiche
La Fabbrica S.P.A., Ava
La Fenice S.R.L., La Fenice
Laminam S.P.A., Laminam, Restile
Marazzi Group S.R.L., En Place, Forme, Gallery, Marazzi, Masterker, Ragno, Unika, Villa
Mirage Granito Ceramico S.P.A., Infinity, Mirage
Novabell S.P.A., Novabell
Nuova Ri.Wal Ceramiche S.R.L., Saime e Alfalux
Nuovocorso S.P.A., Nuovocorso
Panariagroup Industrie Ceramiche S.P.A., Blustyle By Cotto D'este, Fiordo Industrie Ceramiche, Lea Ceramiche, Love Tiles, Margres, Panaria Ceramica
Rondine S.P.A., Rondine
San Valentino Manifatture Ceramiche S.P.A., San Valentino Manifatture Ceramiche
Santa Marla S.R.L., Capri
Savoia Italia S.P.A., Savoia Italia, A.L.CO Ceramiche
Sichenia Gruppo Ceramiche S.P.A., Phorma, Sichenia
Sicis S.R.L., Sicis
Sima Ceramiche S.R.L., Simagres
Stile Italia S.R.L., Stile Italia
Terratinta Group S.R.L., Terratinta Ceramiche, Ceramiche Magica
Unicom S.R.L., Unicom Starker
Vallelunga & Co S.R.L., Vallelunga
Verde 1999 S.R.L., Verde 1999, Ceramiche Campogalliano, Ceramicasa
41zero42 S.R.L., 41zero42

11.3 SPAIN

Argenta Cerámica S.L., Argenta, Cifre, Silber
Alcalagres, SA, Alcalagres
Alttoglass, SA, Alttoglass
Apavisa Porcelánico, S.L., Cerámicas Aparici, S.A., Habitat Ceramics, S.A., Land Porcelánico, S.L., Veneto Cerámicas, S.A., Apavisa Porcelánico, Cerámicas Aparici, Habitat Ceramics, Land Porcelánico, Veneto Cerámicas
Azteca Products & Services, S.L.U., Azteca
Azulejera Alcorense 1, S.L., Azulejera Alcorense / Azalgres
Azulejo Decorado y Exportación, S.L., Adex
Azulejos Plaza, S.A., Plaza Cerámicas

Azulev, S.A.U., Azulev, Milania, Sanchis, XLAM
Azuliber 1, S.L., Keralco, Azuliber
Baldocer, S.A., Azulejos Benadresa, S.A., Dilmun Empresarial, S.L., Azulejos Benadresa, Baldocer, Dilmun, Etile, Elam
Bestile, S.L., Bestile
Ceracasa, S.A., Ceracasa
Cerámica Elias, S.A., Cerámica Elias
Cerámica Gomez, S.A., Cerámica Gomez, Oneker
Cerámica Mayor, S.A., Cerámica Mayor, Mayor Pool Solutions, Tempio
Cerámica Nulense, S.A.U., Azulmed, S.L.U., Cerámica Nulense, Azulmed, Spanish tile from Nules, Nueva Alaplana, Keratiles, Cerámicas Tesany, Cerámicas de Moncofar
Cerámica Ribesalbes, S.A., Cerámica Ribesalbes, Ribecer
Cerámica Saloni, S.A.U., Saloni
Cerámica Vilar Albaro, S.L., Salcamar CVA
Cerámicas Belcaire, S.A., Roca, Bellavista, Gala, Madison
Cerámicas Fanal, S.A., Cerámicas Fanal
Cerámicas Myr, S.L., Myr Cerámica, Myr Porcelánico
Cerlat, S.A., Cerlat, Azulejos Mijares, Silver Fox
Cevica, S.L., Cevica
Cicogres, S.A., Cicogres
Colorker, S.A., Colorker, ZYX
Cristal Cerámicas, S.A., Cristacer
Decocer, S.A., Decocer
Dualgres, S.A., Dualgres, Cerámica Belmar
El Barco, S.L., El Barco
Equipe Cerámicas, S.L., Equipe Cerámicas
Estudio Cerámico, S.L., Estudio Cerámico, Dune Cerámica
Evoque Living Ceramic, S.L., Living Ceramics
Exagres, S.A., Gres de Andorra, S.L., Exagres, Gres de Andorra, Gresan
Fabricacion Española Sanitaria, S.A., Fabresa
Gres de Aragón, S.A., Gres Aragón
Grespania, S.A., Grespania, Bellacasa, Coverlam
Grupo Industrial Pamesa, Pamesa, Geotiles, Prissmacer, Navarti, Ecoceramic, Tau
Halcón Cerámicas, S.A., Halcón Cerámicas, Attom, Emotion Ceramics, Onice, Millenium
Hijos de Cipriano Castelló Alfonso, S.L., El Molino
Hijos de Francisco Gaya Fores, S.L., Gayafores, Marquis
Iberoalcorense, S.L., Ibero Porcelánico
Industrias Alcorenses Confederadas, S.A., Inalco
Incoazul, S.L., Porcelanite, S.L., Incoazul, Porcelanite Dos
Jose Oset y Cia, S.L., Oset
Keraben Grupo, S.A.U., Keraben, Metropol, Casa Infinita

Keros Cerámica, S.L., Keros
La Platera, S.A., La Platera, Alcotile, Contract Tile
Levantina y Asociados de Minerales, S.A., Techlam
Manufactura Industrial Azuelejra, S.L., Mainzu
Mayolica Azulejos, S.L., Mayólica
Natucer, S.L., Natucer
Novogres, S.A., Novogres, Donnaker
Onix Cerámica S.L., Onix Mosaic
Peronda Group, S.A., Peronda, Duomo, Museum, Harmony
Porcelánicos HDC, S.A., Porcelánicos HDC
Porcelanosa, S.A., Venis, S.A. Porcelanosa, Urbatek, Venis
Realonda, S. A., Realonda
Roig Cerámica, S.A., Roig Cerámica, Rocersa
Rosagres, S.L.U., Rosa Gres
Tendencias Cerámicas, S.L.U., WOW Design
Terracota Pavimentos de Gres, S.A.., Terracota
The Size Surface, S.L., The Size, Neolith
Todagres, S.A., Todagres
Togama, S.A.U., Togama More Than Mosaic
Undefasa, S.A., Undefasa, Addictile, Yourtile
Universal Cerámica, S.L., Unicer
Vives Azuejos y Gres, S.A., Vives Azuelos y Gres, Arcana Cerámica