Report to the Natural Resources Board: Silica Study

August 2011

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Executive Summary

This special study of crystalline and amorphous forms of silica was done in accordance with the Wisconsin Air Toxics rule (Ch. NR 445, Wis. Adm. Code). The language in the Wisconsin Air Toxics rule is as follows:

> "NR 445.14(2). The department staff shall, in consultation with affected industry, public health officials and other interested parties, undertake 2 separate studies of the emissions of amorphous and crystalline silica and wood dust. The studies shall evaluate the sources and amounts of emissions and alternative strategies for minimizing public health risks. The department staff shall report progress on the studies to the natural resources board by July 1, 2006. "

The study describes what is currently known about sources, health effects, exposures, controls and the regulatory status of silica in Wisconsin as well as in other states and countries. This study does not recommend policy actions, because that is not the purpose of the study. It does provide options to policy makers regarding potential alternative strategies for enhancing the regulation of and/or further minimizing public health risks.

Comments received during the public comment period for the draft version have been reviewed and addressed in the study.

Based on a review of available literature and other information, as well as a survey of state and local officials from across the U.S., the following are the major findings to date regarding sources, health effects, monitoring, and regulation of ambient silica air emissions:

- Sources of crystalline silica are ubiquitous and include paved and unpaved roads, wind blown soil and agricultural activities (e.g., tilling and harvesting).
- Industrial sources of crystalline silica include construction, foundries, glass manufacturing, abrasive blasting or any industrial or commercial use of sand and quartz, and mining and rock crushing operations.
- Crystalline forms of silica (such as quartz) meet the definition of a known carcinogenic hazardous air pollutant (HAP)[1] as defined in Wisconsin's Air Toxics Rule, Ch. NR 445, Wis. Adm. Code. Wisconsin statutes have specific criteria which must be met in order for a hazardous air pollutant standard to be established.
- Amorphous forms of silica do not currently meet the decision rules for defining amorphous silica as a HAP because they have been delisted by the American Conference of Governmental Industrial Hygienists (ACGIH).
- No federal air quality standards for silica currently exist. Federal standards for particulate matter (PM), a component of which is silica, are in effect for PM 10 and PM2.5.
- The size of crystalline silica particles of most concern are those that are smaller than four microns (millionths of a meter), also called particulate matter 4 (PM4). There are no generally accepted methods for monitoring PM4 in ambient air.
- Controls for crystalline silica are the same controls typically used for particulate matter (PM). The extent of reduction from existing particulate matter (PM) controls is not currently known and will

[1] The Air Toxics Rule uses the term "Hazardous Air Contaminants." For the purposes of this report, the more common term, "Hazardous Air Pollutant" (HAP) is used throughout the report.

vary from source to source. The types and costs for these controls need to be evaluated on a facility-by-facility basis.

- Studies generally do not indicate the existence of any wide-spread significant concern about airborne crystalline silica exposures to individuals not living near an identified source of crystalline silica emissions. In circumstances where people live near a source of crystalline silica, data from other air pollution control agencies shows that silica ambient air concentrations could be above a level of concern. However, the data also suggests that other non-industrial sources contribute to the ambient levels.
- Of the states surveyed, six (Texas, California, Vermont, New York, New Jersey and Michigan) address emissions of crystalline silica. However, these states have not shown impacts from these sources on health. Some states use what may be considered a technology-based approach, focusing on control measures or specific management practices, while others establish an acceptable ambient air concentration of crystalline silica.
- Wisconsin Department of Natural Resources (WDNR) has extensive experience applying PM controls to many types of air pollution sources. For example, many permits for industrial sources require dust management plans and other controls to reduce PM emissions, which also help minimize crystalline silica emissions.
- Currently, WDNR has no crystalline silica monitoring data. Additional financial and staff resources would be needed to conduct crystalline silica monitoring. Monitoring to specifically analyze for crystalline silica is difficult, there are no federal standards and there is no standard reference method for monitoring crystalline silica in ambient air.
- The draft report was released to the public on January 4, 2011 and the WDNR received comments. Comments received requested additional WDNR actions including listing crystalline silica as a HAP, establishing acceptable ambient air concentrations and controls on sources and monitoring for crystalline silica. Other comments state that the WDNR does not have the authority to regulate silica, that only occupational exposures have been associated with silicosis and cancer risk and no public health risk exists from the lower level of exposure in ambient air.
- The comments received do not change the fundamental conclusions of the report. They were factored into the consideration of possible alternative strategies.

A recurring theme from the literature review and survey is that very little conclusive information exists regarding sources, controls or levels of silica present in ambient air. This lack of data means it is not currently possible to determine conclusively whether or to what extent the quantity, duration or types of silica emissions in the state may be a public health concern. It would take significant additional efforts to fill in these data gaps. That said, Wisconsin has regulated PM for 40 years. The controls for PM are the same controls for crystalline silica. This means that for those crystalline silica sources where PM is controlled, crystalline silica emissions are also reduced.

Introduction

The Wisconsin Department of Natural Resources (WDNR) conducted this special study of crystalline and amorphous forms of silica in accordance with the Wisconsin Air Toxics rule (Ch. NR 445, Wis. Adm. Code). This report describes what is currently known about sources, health effects, exposures, controls and the regulatory status of silica in Wisconsin as well as in other states and countries.

Silica was included along with hundreds of other chemicals as a candidate for listing as a hazardous air pollutant (HAP) in the process of a major revision of the Wisconsin Air Toxics rule in 2000-2004. The listings for various forms of silica were proposed because these various forms met the definition of a HAP in the rule. In particular, both the International Agency for Research on Cancer (IARC) and the National Toxicology Program (NTP) have determined that crystalline silica is a carcinogen. In addition, various amorphous forms of silica were listed as non-carcinogens by the American Conference of Governmental Industrial Hygienists (ACGIH) as a concern in the workplace at a level below 10 milligrams per cubic meter (mg/m3).

Silica is found in quartz containing soils, sands and rock formations. Due to its ubiquitous nature, concerns regarding health effects, and uncertainty regarding the sources, controls and monitoring methods, silica was not listed during the 2004 air toxics rule revision. Instead, the revised rule called for a special study of silica to be completed at a later date, as had previously been done for formaldehyde and chloroform. The language in the Wisconsin Air Toxics rule is as follows:

> "NR 445.14(2). The department staff shall, in consultation with affected industry, public health officials and other interested parties, undertake 2 separate studies of the emissions of amorphous and crystalline silica and wood dust. The studies shall evaluate the sources and amounts of emissions and alternative strategies for minimizing public health risks. The department staff shall report progress on the studies to the natural resources board by July 1, 2006. "

Due to resource constraints and competing Air Program priorities, the report to the NRB was not underway by the July 1, 2006 date specified in the Wisconsin Air Toxics Rule; however, work on the study was initiated in late 2009. A status report was provided to the Natural Resources Board in December 2010 and a draft report was subsequently released to the public, along with a request for any further information that may not have been identified or included in the draft report. Substantial comments and information were received, appropriate follow-ups were made, and the report was amended accordingly. A summary of the comments received is attached in Appendix C.

This report distinguishes between public exposures versus workplace exposures, and outdoor (ambient) air versus indoor air. WDNR has authority to manage ambient air exposures to people not occupationally exposed to air pollutants. WDNR has no regulatory authority to address indoor air quality. The Occupational Safety and Health Administration (OSHA) and the Mine Safety and Health Administration (MSHA) regulate exposures in the workplace (both indoor and outdoor air exposures). In addition, the Wisconsin Department of Health consults with individuals about indoor air quality issues not covered by OSHA requirements, including issues related to silica exposures.

What is Silica?

Silica is a compound made up of silicon and oxygen atoms. The chemical formula is SiO_2. It can be a naturally occurring substance, like quartz, or it can result from human activities. Silicon, the element, is the second most abundant element in the earth's crust. Silicon (the element) and other silicon-containing materials such as silicates and silicone are not air pollutants that are under consideration in this report.

Silica occurs in many forms. The two forms associated with air pollution are amorphous silica and crystalline silica. Amorphous silica is found in nature (e.g., diatomaceous earth and plants), as well as in synthetic materials. In amorphous silica, the silicon and oxygen atoms are not arranged in any particular pattern, but in crystalline silica, atoms of silicon and oxygen are arranged in a repeating, three-dimensional pattern or crystal lattice (US Bureau of Mines 1992). There are approximately twelve forms of crystalline silica. The three most common forms are:

- **Quartz** - by far the most common form of crystalline silica found in nature. About 12% of the earth's crust is made up of quartz. All soils contain at least trace amounts of crystalline silica in the form of quartz (US Bureau of Mines 1992).
- **Cristobalite** - found when diatomaceous earth is heat treated. This category includes calcined (heated to a high temperature) and metamorphosed sandstones and some volcanic siliceous rocks.
- **Tridymite** - found in volcanic siliceous rocks.

The distinction between crystalline and amorphous forms of silica is not always clear cut. The form of silica can change in a process depending on how the silica is treated. Chemical treatment, as well as high-temperature processes or treatment of amorphous silica, can create crystalline silica. For example, when diatomaceous earth, an amorphous form of silica, is calcined (heated to a high temperature), crystalline silica can be formed. Additionally, crystalline silica can be formed if plants containing amorphous silica are burned at high enough temperatures. Conversely, treatment of crystalline silica can convert it into amorphous silica; this occurs in glass manufacture and in silica gel production.

Sources of Silica Emissions

Crystalline Silica

In a review of the toxicology of crystalline silica, the World Health Organization (WHO 2000) stated that "Environmental exposure to ambient quartz dust can occur during natural, industrial, and agricultural activities".

Occupational exposures to silica have been studied more than environmental exposures. This report does not focus on workplace exposures, but it is important to note that industries where occupational exposures to crystalline silica have been high are also potential sources of crystalline silica emissions to the ambient air. A National Institute of Occupational Safety and Health (NIOSH) review of silica hazards identified five categories of industrial sources where estimated silica exposures to workers were at least ten times the NIOSH recommended exposure levels (NIOSH 2002). These include the following:

NIOSH Category

- 174 – Masonry and plastering;
- 162 – Heavy construction;
- 172 – Painting and paper hanging;
- 332 – Iron and steel foundries; and
- 347 – Metal services

Note: The NIOSH work-related lung disease reporting system (NIOSH 2011) places Wisconsin fifth in the US for the number of silicosis deaths (75 people) over the period 1996-2005. This workplace exposure related information is not directly applicable to ambient air exposures. These industries may be potential sources of silica to the ambient air.

Sources of crystalline silica include mining and rock crushing operations, as well as construction, foundries, glass manufacturing, abrasive blasting or any industrial uses of sand and quartz. Activities that move earth (e.g., mining, farming and construction), disturb silica-containing products (e.g., masonry and concrete removal) and use sand or silica-containing products (e.g., foundry processes, paints and coatings) are all sources of silica emissions. Paved and non-paved roads can represent a significant source of emissions into the ambient air (NIOSH 2002; US EPA 1996; California OEHHA 2005; Ruble and Goldsmith 1997). Windblown soils and long range transport during dust storms have also been documented as sources (Monteil 2008; Monteil and Antione 2009; De Berardis et al. 2007; Norboo et al.

1991; Saiyed et al. 1991). Agricultural exposures are also known to occur as a result of working the soil and from harvesting certain types of crops, such as rice (California OEHHA 2005; Ruble and Goldsmith 1997). In addition, the use of a variety of commercial products containing silica such as cleansers, cosmetics, art clays and glazes, pet litter, talcum powder, caulk, putty, paint, and mortar can release silica into the air (WHO 2000; US Bureau of Mines 1992). A general listing of potential sources of silica emissions into ambient air is presented in Table 1.

Mining and rock crushing are among the largest and most well-known sources of crystalline silica. A review of the WDNR air emission inventory reveals a large number of potential sources across the state – see Figure 1. While larger stationary sources are required to report their PM emissions to the WDNR air emissions inventory, silica is not reported separately. Only total particulate matter (PM) is reported. In addition, some sources of silica emissions in Wisconsin, such as masonry and plastering, heavy construction, and painting and paper hanging, are not included in the WDNR inventory.

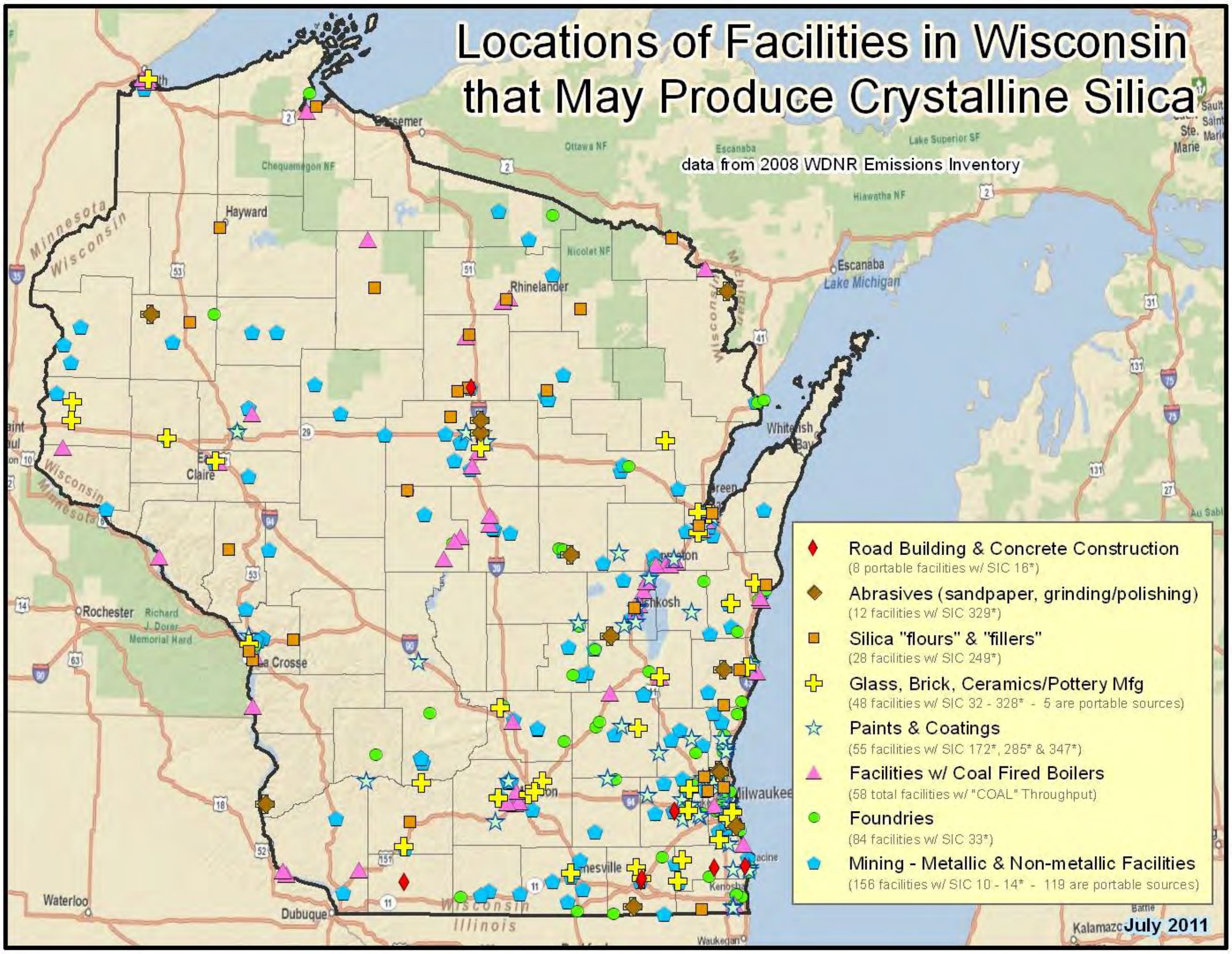
Table 1: Potential Crystalline Silica Sources

Source/Industry	**Description/Examples**
Mining – Metallic & Non-metallic	Rock quarries, sand & gravel mining, rock crushing
Road building, asphalt paving, concrete manufacture, construction, roofing materials manufacture	Masonry, stonework, tile setting, concrete work (e.g., grinding, sawing, jack hammering, mixing, drilling), plastering , roofing, sandblasting
Coal Fired Boilers	Utility & industrial boilers (silica is present in coal & in ash)
Foundries	Used in sand casting systems -molds & cores
Glass, Brick & Ceramics/Pottery Manufacturing	Mixing, pouring & otherwise using fine powdered sand or quartz, including clays & glazes that contain silica
Silica “flours” & “fillers”	Paper, plastics, paints, wood products & rubber
Filtration agents	Sand filter beds, decolorizing/filtering oils & petroleum products
Incinerators & high heat or high pressure processes for any amorphous silica or silica containing materials	Plant materials & biomass (e.g., burning of biomass, rice hulls, treatment in boilers, thermal oxidizers), diatomaceous earth calcining, computer chip & other silica manufacturing facilities that could subject amorphous silica to heat & pressure
Paints & Coatings	Sand finishes, inert fillers,
Stone working & abrasives	Stone cutting, jewelry work,
Abrasives	Sandpaper, grinding, polishing, abrasive blasting, sandblasting,
Miscellaneous	Dental materials; automobile repair
Clay products	Cleaning products/soaps, cosmetics, agricultural chemicals such as pesticides, fertilizers, cat litter, oil sorbents
Windblown soil	Agricultural sources, sandy soils, beaches, road dust from paved & unpaved roads

Sand and gravel pits and small mining operations are also sources of silica emissions into the ambient air. Information from the Department’s non-metallic mining and water permit programs indicates that there are approximately 2,300 non-metallic mines in Wisconsin. In response to increased demand for industrial sand for use in oil and natural gas extraction, mine related activity increased dramatically in recent years, especially in the west central portion of the state. Areas where industrial sand mining activities are occurring or proposed are: Barron, Buffalo, Chippewa, Dunn, Green Lake, Jackson, Monroe, Pepin, Pierce, St. Croix and Trempealeau counties. Many sand and gravel pits and mining operations are small and are not required to report their emissions to the air emissions inventory or obtain air pollution permits.

Figure 1: Map of Potential Crystalline Silica Sources that Report to Wisconsin's Air Emissions Inventory

Source: Wisconsin DNR Air Emissions Inventory – 2008 reporting year. No specific information exists as to actual silica emissions – this map denotes where facilities of a given type are located. Smaller sources are not included in the WDNR's emissions inventory and are not identified on the map.



Amorphous Silica

In nature, amorphous forms of silica exist in the skeletons of diatoms and radiolarians (microscopic organisms that live in water), diatomaceous earth (rocks/minerals formed from the shells of diatoms) (US Bureau of Mines 1992), and in plant materials. For example, rice, red mulberry and scouring rushes are known to have high silica content.

In addition to the amorphous silica found in nature, synthetic products contain amorphous silica in several forms. Amorphous silica in the form of diatomaceous earth is used in abrasives, filtering agents, as fillers in wood products, paints and plastics, insecticides and in the manufacture of firebrick and certain types of ceramics. Other forms of amorphous silica are used in a number of consumer and other products including eyeglass lenses, plastics, greases, paints, coatings, adhesives, lacquers, rubber, resins, pesticides, agrichemicals, insulation, toothpaste, pharmaceuticals, powders, foods and cosmetics. Amorphous silica is also produced as a byproduct in the manufacture and use of silicon and silicon containing alloys (TCEQ 2011a; Environment Canada 2011).

Stationary sources of amorphous silica include facilities where ferrosilicon production and the manufacturing of semiconductors and amorphous silica-containing materials (such as silica gels) occur. The number of these facilities in Wisconsin and their emissions are not known because the WDNR does not collect emissions data specifically for amorphous silica.

In summary, many potential sources of crystalline and amorphous silica exist. Currently quantitative data on silica emissions from Wisconsin sources does not exist. This is because stationary sources report total amount of particulate matter emissions (PM) and are not required to report the amount of crystalline or amorphous silica emitted. In addition, many non-metallic mines and sand and gravel pits are too small to require WDNR air permits and do not report their emissions. Smaller sources with lower emissions are presumed to pose less health risk and are not included in the WDNR's emissions inventory.

Health Effects

The cancer risk and non-cancer health effects from exposures to crystalline and amorphous silica are discussed below. This is not an exhaustive review, but highlights for the general audience the main health effects of concern from silica exposures. For a review of the carcinogenicity of crystalline silica, see the IARC (1997 and 2002) and NTP (2005) reports. For further information on non-cancer effects, see the NIOSH (2002) and WHO (2000) reports.

The main health effects concerns from silica focus on particles that are small enough to get into the deepest parts of the lung. The "respirable size fraction" is defined as particulate matter less than four microns (millionths of a meter), also referred to as particulate matter 4 or PM4. PM4-sized particles are what occupational health professionals measure to evaluate respiratory impacts of crystalline silica in the workplace. These respirable sized particles can penetrate into the deepest parts of the lung, where gas-exchange occurs. This is where the most critical toxic effects for crystalline silica – silicosis and cancer - are thought to occur. Note that the term "critical effect" here means the health effect of most concern at the lowest concentrations and this does not imply that this is the only health effect associated with silica exposure. Health scientists assume that if exposures are kept below a level where critical effects occur, there will not be any other health effects.

Once silica particles enter the pulmonary region, they are engulfed by cells in the lungs called alveolar macrophages. It is believed that the interaction of the particle and the macrophage causes the body to react the way it does. For example, the interaction of the particle with the macrophage causes a reactive form of oxygen to be released in the lung and this triggers inflammation and scarring in the lung. Since silica is toxic to the macrophages, and the silica particles are not soluble, they are not easily cleared from the lung. Particles build up in lung and lymphatic tissues.

In addition, the particles can get moved around to other organs in the body. Some particles are removed from the deepest part of the lung into the lymphatic system. From the lymphatic system the silica particles can move to the skin, kidney, liver, blood or other organs.

The chronic inflammation and scarring caused by the presence of these insoluble particles in the lung and lymphatic system can exacerbate existing respiratory disease. With enough exposure, silica can cause lung damage even in people without pre-existing conditions. Although rare, if the silica exposure is high enough, there can also be adverse health effects in other organs. Most health research regarding inhalation of silica has focused on crystalline silica which is thought to be less soluble and more toxic in the body.

Cancer Risk

The World Health Organization's International Agency for Research on Cancer (IARC) and the US National Toxicology Program (NTP) are recognized in Wisconsin's Air Toxics rule as the definitive sources of information when evaluating air pollutants for cancer risk. If both IARC and NTP determine that a pollutant is a carcinogen, then that pollutant meets the regulatory definition of a HAP in NR 445 and is evaluated as a carcinogen.

Crystalline Silica

The National Toxicology Program Eleventh Report on Carcinogens (2005) states that respirable crystalline silica is "known to be a human carcinogen, based on sufficient evidence of carcinogenicity from studies in humans, indicating a causal relationship between exposure to respirable crystalline silica and increased lung cancer rates in workers exposed to crystalline silica dust". In addition, IARC notes that: "Crystalline silica inhaled in the form of quartz or cristobalite from occupational sources [i.e., workplace exposures] is carcinogenic to humans," and is classified as a Group 1 carcinogen (IARC 1997). Group 1 carcinogens are "known human carcinogens". For more information about IARC cancer classifications, see http://monographs.iarc.fr/ENG/Classification/index.php.

The mechanism of how crystalline silica causes cancer is currently unknown. There are several theories, but this is still an active area of investigation. Another area of investigation is whether someone must have silicosis first before any cancer risk would be present.

Amorphous Silica

At this time, insufficient evidence exists to consider amorphous silica as a human carcinogen. The NTP does not have a listing for amorphous forms of silica. In addition, the IARC Monograph states that amorphous silica "*is not classifiable as to its carcinogenicity to humans (Group 3.)"*

Non-Cancer Health Effects

Non-cancer health effects include a wide variety of adverse health effects on lungs and other organs, as well as neurological and reproductive systems.

Crystalline Silica

Silicosis

Silicosis is a chronic, progressive inflammatory and fibrotic (i.e., causes lung scarring) disease of the lung (US EPA 1996). The disease is incurable and can progress even after exposure ceases, which means that people who are exposed occupationally need to have follow-up health evaluations even if they no longer work where the exposure occurred. It is generally believed that the particles of silica overload the capability of the pulmonary alveolar macrophages to remove foreign particles. The macrophages recruit other cell types to the site of the damage and the results of the byproducts of this chronic inflammation and cell-signaling cause the health effects observed in people (NIOSH 2002; US EPA 1996). The overwhelmed macrophages may not be able to clear the lung of invading pathogens and, as a result, lung infections of various types may occur (NIOSH 2002; US EPA 1996).

Other Effects

In addition to silicosis, other non-cancer health effects have been identified in studies of crystalline silica. While the lung is the principal target organ, inhaled silica can be engulfed by alveolar macrophages and moved to other organs in the body (NIOSH 2002). Some of those additional health effects include:

- **Silicotuberculosis** (US EPA 1996). This is tuberculosis infection associated with silicosis. Other opportunistic infections that result from a weakened immune system have been identified as well (US EPA 1996).
- **Other Pulmonary Diseases.** These include reduced lung function, Chronic Obstructive Pulmonary Disease (COPD), emphysema and bronchitis (US EPA 1996; California OEHHA 2005).
- **Enlargement of the heart** (US EPA 1996; California OEHHA 2005). This is an enlargement of the right ventricle as a result of increased resistance in the lungs. Another medical term for this is *cor pulmonale*.

- **Interference with the body's immune system.** These include scleroderma (US EPA 1996; California OEHHA 2005), a group of rare, progressive diseases that involve the hardening and tightening of the skin and connective tissues (Mayo Clinic 2008), rheumatoid arthritis, systemic lupus, Sjogren's syndrome, and glomerular renal disease (Steenland and Goldsmith1995; California OEHHA 2005; WHO 2000).
- **Kidney damage.** A correlation with kidney disease of various types, increased kidney weights and kidney failure (the latter of which has been linked to increased mortality), has been attributed or potentially attributed to silica exposure (US EPA 1996; California OEHHA 2005).

The issue of whether only occupational exposures to crystalline silica are high enough to cause diseases is important, as well as controversial. In spite of this controversy, the California Office of Environmental Health Hazard Assessment (California OEHHA 2005), Texas Commission on Environmental Quality (TCEQ 2009) and US EPA (1996) have determined that silicosis is the critical non-cancer health effect of concern for ambient air exposures to crystalline silica.

Amorphous Silica

More limited evidence exists for health effects to lung tissues from inhaling amorphous silica. However, at the time of the stakeholder process for the 2000-2004 WDNR Air Toxics rule revision, the ACGIH had listed amorphous silica with an occupational health limit sufficiently low enough to cause WDNR to add it to the list of proposed HAPs for the rule revision. As such, when the special study provision for silica was placed into the rule revision, it included amorphous silica.

ACGIH subsequently withdrew the Threshold Limit Values (TLVs) for amorphous silica in 2006, due to their determination that insufficient health data existed to support a TLV at that time. As a result, the amorphous forms of silica no longer meet the NR 445 definition of a HAP, as found in s. 445.13(2). If US EPA or ACGIH later develop health benchmarks, then the amorphous forms of silica could be reviewed further.

Studies suggest that amorphous silica is much less toxic (i.e., much higher levels of particulate loading need to occur in the lung) than crystalline forms. Since the amorphous particles are more easily removed from the lungs, their effects, although causing inflammation like crystalline silica, are not as long-lasting and are not progressive after exposure ceases (US EPA 1996; TCEQ 2009; TCEQ 2011a). In fact, unlike crystalline silica, some evidence exists that damage from exposure to amorphous silica is reversible once exposure ceases.

In summary, the main health effects concerns from silica focus on particles that are small enough to get into the deepest parts of the lung. The chronic inflammation and scarring caused by the presence of these insoluble particles in the lung and lymphatic system can exacerbate existing respiratory disease. With enough exposure, silica can cause lung damage even in people without pre-existing conditions. Although rare, if the silica exposure is high enough, there can also be adverse health effects in other organs. Based on a review of the health effects literature, most agencies believe that silicosis is the most sensitive endpoint for non-cancer health effects for potential ambient air exposures to crystalline silica. Crystalline silica has been identified as a human carcinogen but the mechanism of how it causes cancer and the causal effect of silicosis is unknown.

Health Benchmark Levels for Silica Exposures

Health benchmarks and reference exposure levels (RELs) are used interchangeably in this report and are threshold levels for crystalline and amorphous silica that have been established by a number of agencies to assess the health risks from exposure to silica in ambient air. One way to think of them is as "safe" levels of exposure. When concentrations in the air are below these health benchmarks or reference exposure levels, there is negligible risk to health for the general public. When concentrations in the ambient air are above the health benchmark or reference exposure levels, there is an increased potential for health effects. This is referred to as being above a "level of concern."

Crystalline Silica

California's Office of Environmental Health Hazard Assessment (OEHHA) established a non-cancer health benchmark – a REL- of 3 ug/m3 for crystalline silica of a PM4 size fraction. The averaging time for the health benchmark represents an annual exposure level. Below this REL, California estimates there is minimal risk for developing silicosis from exposure to crystalline silica in the ambient air. More information on this reference exposure level can be found at the OEHHA website: http://oehha.ca.gov/air/chronic_rels/pdf/SILICAcREL_FINAL.pdf.

Using a different approach that was based on an assumption that ambient exposures were similar to occupational exposures, US EPA (1996) established a health benchmark for the risk of silicosis from ambient air exposures of 3 ug/m3 (annual average of PM10 sized particles). EPA's approach involved using a mathematical extrapolation, based on occupational exposure data, to estimate an acceptable level of exposure to the public. EPA estimated that approximately 0.03% of the population (0.3 people out of 1,000) have a chance of contracting silicosis at the annual exposure level of 3 ug/m3. At a concentration of 8 ug/m3, the risk was estimated to be 2.3% (23 people out of 1,000). US EPA indicated that their benchmark estimates are probably conservative for the following reasons: 1) silica in the ambient environment is less toxic than in the workplace, primarily because of the larger particle sizes associated with ambient sources; 2) the reduced likelihood of exposure to the public from the more potent "freshly fractured" silica that is found in occupational settings (Fubini, et al. 2003; Castranova et al. 1997); and, 3) less frequent peak exposures than in the workplace (US EPA 1996). However, as pointed out in WHO (2000), the US EPA benchmark did not evaluate the "silicosis risk for persons with respiratory diseases." EPA has not set a National Ambient Air Quality Standard (NAAQS) for crystalline silica.

The Texas Commission on Environmental Quality (TCEQ) (2009) also established acute and chronic ambient air health benchmarks for crystalline silica to protect against non-cancer effects. TCEQ established a chronic health benchmark of 2 ug/m3 for PM4 sized particles based on exposures of up to one year. The TCEQ value of 2 ug/m3 is intended to prevent against silicosis and is fairly close to the California OEHHA derived chronic health benchmark of 3 ug/m3. TCEQ also established a short-term (acute) health benchmark level of 47 ug/m3 of PM10 sized particles, for evaluating one hour exposures. More information on the TCEQ health benchmarks can be found at: http://www.tceq.state.tx.us/assets/public/implementation/tox/dsd/final/october09/silica_crystalline_forms.pdf.

In addition to its non-cancer benchmarks, TCEQ is the only air agency in the US that has established a cancer-based health benchmark for ambient air exposures to crystalline silica. They established an annual ambient air concentration of 0.27 ug/m3 of PM4 size particles in the air as being the level of exposure corresponding to a lifetime cancer risk of one-in-one-hundred thousand. According to TCEQ, these benchmarks are guidelines and air permits for sources that would be expected to cause exposure impacts above 0.27 ug/m3 should be evaluated for inclusion of emissions control requirements to ensure that public health is protected (TCEQ 2009).

In addition to California and Texas, several other air pollution control agencies have adopted health benchmark levels for crystalline silica. Table 2 summarizes health benchmark levels for crystalline silica from these air agencies.

Table 2: Health Benchmark Levels for Crystalline Silica in Ambient Air

Agency	Health effect of interest	Reference Exposure Level/Health Benchmark*	Long-term (L) or short term (S)+	Reference
California Air Resources Board	Silicosis	3 ug/m^3 measured as PM4	L	California OEHHA 2005
Michigan Department of Environmental Quality	Silicosis; cancer	Revoked – see Appendix B	L	Michigan DEQ 2011
New Jersey Department of Environmental Protection	Silicosis	3 ug/m^3 measured as PM10	L	New Jersey DEP 2009
New York Department of Environmental Conservation	Silicosis	0.06 ug/m^3 measured as PM10	L	New York State DEC 2011a, 2011b
Oklahoma Department of Environmental Quality	Chronic disease; cancer	Revoked – see Appendix B	L	Oklahoma DEQ 2010
Texas Commission on Environmental Quality	Lung Inflammation	47.0 ug/m^3 measured as PM10	S (1hour)	TCEQ 2009, 2011b
	Silicosis	2.0 ug/m^3 measured as PM4	L	
	Cancer	0.27 ug/m^3 measured as PM4	L	
US Environmental Protection Agency	Silicosis	3 ug/m3 as PM10	L	US EPA 1996
Vermont Department of Environmental Conservation	Silicosis	0.12 ug/m^3 measured as PM10	L	Vermont DEC 2003a, 2003b

*Reference exposures levels and health benchmarks are used by air pollution agencies to establish an acceptable level of exposure to the public for an air pollutant. Some agencies use them to set an ambient air standard which is not to be exceeded, while other agencies use them as guidelines and evaluate permitted emissions to minimize exposures to the extent possible, but sources may still be permitted if their impact is estimated to exceed the reference exposure level or health benchmark.

+ Long-term reference values and health benchmarks are most often compared to annual average concentrations of air pollutants. Averaging periods for Short-term reference values and health benchmarks are indicated in the table.

Amorphous Silica

Fewer states (Michigan, Vermont and Texas) have established health benchmark levels for exposure to amorphous forms of silica. The Texas Commission on Environmental Quality conducted the most recent review of amorphous silica and revised its health benchmark levels in July 2011 (TCEQ 2011a).

Table 3 summarizes health benchmark levels for amorphous silica from these air agencies.

Table 3: Health Benchmark Levels for Amorphous Silica in Ambient Air

Agency	Health effect of interest	Reference Exposure Level/Health Benchmark*	Long-term (L) or short term (S)	Reference
Michigan Department of Environmental Quality	Lung inflammation	20 ug/m^3; 1 ug/m^3 for amorphous fused silica	S (8 hours)	Michigan DEQ 2011
Texas Commission on Environmental Quality	Lung inflammation	91.0 ug/m^3 measured as PM10	S (1 hour)	TCEQ 2011a
	Chronic lung Inflammation; decreased lung function	6.6 ug/m3 measured as PM10	L	
Vermont Department of Environmental Conservation	Chronic disease or toxicity	24 ug/m^3	L	Vermont DEC 2003a

*Reference exposures levels and health benchmarks are used by air pollution agencies to establish an acceptable level of exposure to the public for an air pollutant. Some agencies use them to set an ambient are standard which is not to be exceeded, while other agencies use them as guidelines and evaluate permitted emissions to minimize exposures to the extent possible, but sources may still be permitted if their impact is estimated to exceed the reference exposure level or health benchmark.
+ Long-term reference values and health benchmarks are most often compared to annual average concentrations of air pollutants. Averaging periods for Short-term reference values and health benchmarks are indicated in the table.

In summary, health benchmarks are threshold levels established by agencies to assess the health risks from exposure to silica in the ambient air. When concentrations are above the thresholds, there is an increased potential for health effects. This is referred to as being above a “level of concern”. Seven states and the EPA have adopted health benchmark levels for crystalline silica and three states have established levels for amorphous silica.

Silica Concentrations in the Air

Limited ambient air data is available in the United States for crystalline silica concentrations, and no monitoring data specifically for crystalline silica exists in Wisconsin. Based on the limited data available, silica concentrations are likely to be below levels of concern for those individuals not living near a source of crystalline silica emissions.

It is difficult to compare between various studies, because there have been relatively few studies specifically evaluating silica concentrations in the ambient air, different sampling and analysis methods have been used historically, and different particle sizes have been sampled,. In spite of these challenges, this section addresses some of the ambient air monitoring studies that were found to be most relevant for this silica study. A summary table reflecting the results of selected monitoring studies for crystalline silica can be found in Table 4.

Crystalline Silica

Two basic approaches exist for quantifying the concentrations of crystalline silica in the air. Particulate matter sampling typically consists of drawing air into a sampling device and then capturing particulate matter on a pre-weighed filter and calculating the amount of material on the filter to obtain the number of micrograms of particulate matter in a known volume of air. Since not all of the particulate matter on the filter is crystalline silica, one has to either use a method to directly test for crystalline silica (such as X-ray diffraction, spectroscopy, or microscopy) or one has to estimate the percent of the particulate matter that is silica by using other studies (e.g., using data from occupational testing) to extrapolate the percent of silica in particulate matter. The sections below discuss results from each of these methods – estimation and direct measurement.

Estimated crystalline silica concentrations

Since there is much more monitoring data for particulate matter that is not specifically analyzed for crystalline silica, most researchers have historically estimated crystalline silica concentrations based on an assumed percentage of crystalline silica in total particulate matter in PM10, PM2.5 or other size fractions.

This section summarizes the results of studies that extrapolated silica concentrations from particulate matter analysis along with their estimates of the percentage of crystalline silica in the particulate matter sampled. It is not known how much of the crystalline silica in these estimates is actually in the PM4 fraction (the respirable-sized particles).

Using data extrapolated from PM10 monitors, the US EPA calculated a national annual average crystalline silica estimate (across the US) of 3 ug/m3 with a maximum estimate across the US of about 8 ug/m3 (US EPA 1996). US EPA stated that a reasonable assumption was that about 10% of the total PM10 was crystalline silica. EPA acknowledged that some industrial processes, such as quarrying, might produce crystalline silica concentrations in the range of 6 to 12%. EPA also estimated that an upper-bound estimate of the percentage of PM10 that was crystalline silica near agricultural sites might be as high as 17% (US EPA 1996).

Using PM10 and PM2.5 monitoring data from 24 urban monitoring sites, Environment Canada (2011) estimated that about 5.22% of total PM10 and 2.52% of total PM2.5 was crystalline silica.

Discussions with Texas and California air agency staff suggest that for some sources, up to 25% of PM10 could be crystalline silica (e.g., California staff discussion of Shiraki and Holmen 2002).

Early 1990s sampling data from California suggested that monitoring near silica sources may also be important because exposures near sources could exceed the common assumption that crystalline silica comprised 10% of the total PM10 levels. Rather than focusing only on general exposures in cities, California agencies evaluated air quality near aggregate production facilities and diatomaceous earth mining operations. There may be exposures near facilities that could exceed the California health benchmark of 3 micrograms per cubic meter (ug/m3). For example, the US EPA (1996) reported the following:

> "Schipper et al. (1993) compared the quartz concentrations from three Central Valley and two coastal sand and gravel operations in California. In the Central Valley, the silica percentage of PM10 air emissions in the quarry pits ranged from 6.0% in Sacramento to 9.1% in Tracy, whereas the silica levels around the crusher ranged from 11.2% in Visalia to 25.5% in Tracy. In the coastal quarries in Monterey and Felton, the portions of quartz were from 14.1 to 16.6% in the PM10 samples (Schipper et al., 1993)."

The research and public information request conducted as part of this study did not yield information on ambient air crystalline silica concentrations in Wisconsin. Wisconsin has some data for elemental silicon from PM2.5 sampling associated with the National Air Toxics Trends Sites (NATTS). Monitoring is conducted at three sites, none of which is near a known silica source. The data from these sites reflect general ambient air concentrations at: 1) a rural background site (Mayville); 2) an urban site (Milwaukee); and 3) a suburban site (Waukesha). The elemental silicon concentration was converted to an equivalent concentration of silicon dioxide (SiO_2) with the assumption that 100% of the SiO_2 was quartz. This is a conservative estimate of crystalline silica from the monitoring data. The average estimated crystalline silica concentrations were: Milwaukee 0.14 ug/m3; Waukesha 0.32 ug/m3; and Mayville 0.10 ug/m3. Additional information regarding the monitoring data is included in Appendix A.

Direct measurement of crystalline silica concentrations

In direct measurement, particles are collected on a filter and special methods are used to identify the crystalline silica present in the sample. Direct measurement of crystalline silica is done using X-Ray diffraction which quantifies the amount of crystalline silica in a sample by examining the pattern of X-rays resulting from the arrangement of the atoms in the crystalline structure. Other methods for direct measurement of crystalline silica include infra-red spectroscopy and microscopy to determine which particles are quartz or other forms of crystalline silica.

There is currently no standard method for monitoring for crystalline silica in the ambient air. The lack of standardized methods (e.g., differences in particle sizes, sampling methods and analytical methods) makes direct comparisons between studies difficult. Researchers have directly analyzed crystalline silica in PM10, PM4 and PM2.5 samples.

Davis et al. (1984) measured crystalline silica in PM2.5 in California and found concentrations between 0 and 1.9 ug/m3. Crystalline silica was between 0 and 2.6% of the total PM2.5 weight. In another study in California, Ruble and Goldsmith (1997), found that crystalline silica ranged from 0.4% to 21% of total PM10, with a plausible upper bound estimate of 9% to 17.5%.

More recently Shiraki and Holmen (2002) monitored silica concentrations in PM10 near a sand and gravel facility in central California. One upwind monitor and four downwind monitors were deployed. Upwind silica concentrations in the PM10 particle size fraction were found to be 4.6 ug/m3, whereas downwind concentrations ranged from 9.4 to 62.4 ug/m3. The higher concentrations were found closest to the source. These concentrations are well above the California OEHHA (2005) health benchmark of 3 ug/m3. The percent of crystalline silica, by weight, as a percent of total particulate weight, decreased with increasing distance from the source. However, the impact from this source was still evident, even at the furthest downwind monitor - 745 meters away. PM2.5 measurements were also attempted, but all values were below the method detection level used. Therefore no data was reported for PM2.5 size fraction silica concentrations.

In a study of silica concentrations in urban environments around Rome, Italy (De Berardis et al. 2007), crystalline silica ranged from 1.6 to 10.4% of the total PM10 measured.

To date, the only data found for silica concentrations in PM4 sized particles is from the state of California. Monitoring for PM4 silica concentrations is of particular interest because this captures particles of the same size as is used to characterize industrial exposures. California has adopted a health benchmark value (called a reference exposure level) of 3 ug/m3 for PM4 sized particles.

In a recently reported study of PM4 crystalline silica concentrations at an aggregate production facility in California, Richards et al. (2009) found that measured ambient air concentrations of crystalline silica ranged from less than 0.3 ug/m3 (the level of detection) to 2.8 ug/m3. In addition, all measured values above 2.0 ug/m3 were at locations upwind from the source, indicating that sources other than the aggregate facility were contributing to this monitored value. The authors attributed the higher concentrations at the upwind monitor to “emissions from unpaved roads near the upwind monitoring sites”.

In another California study, monitoring for PM4 at several locations near quarrying operations, including a school in Duarte, California, did not show any crystalline silica concentrations above the California OEHHA Reference Exposure Level of 3 ug/m3 (South Coast Air Quality Management District 2008). The lower levels found in this study can possibly be explained by the dust control measures used, the size of the emission source and the distance of the monitors from sources of emissions (which were over 500 meters away). Exposures closer to the sources would be expected to be higher, because the plume of particulate matter is dispersed as it travels away from the emission source.

It should be noted that a standard federal reference method for monitoring PM4 size particles or for analyzing crystalline silica in the ambient air does not exist. In addition, the California Air Resources Board has not formally adopted the PM4 monitoring method. The California method uses a PM2.5 monitor that has been modified to collect PM4 sized particles. For more information, see NIOSH Method 7500 (NIOSH 2003) and the paper by Richards et al. (2009) cited in the reference section of this document.

Table 4: Crystalline Silica Concentrations in Particulate Matter, from Selected Monitoring Studies

Location of Study	**PM Size Evaluated**	**Percent of Silica in PM**	**Concentrations (ug/m3), Estimated (E) or Measured (M)**	**Reference**
United States	PM10	10%; 12-17% near silica sources	3-8 (E)	USEPA 1996
United States	PM2.5	0-2.6%	0-1.9 (M)	Davis et al. 1984
Canada	PM10	5.22%	0.01-8.77 (E); averages 3.73 urban, 0.41 remote	Environment Canada 2011
Canada	PM2.5	2.52% upper bound estimate	0.63-0.76 (E)	Environment Canada 2011
Central California, near sand and gravel facility	PM10	upwind 13.7%; downwind range 14.4% (at 745 meters)- 26.3% (at 22 m)	upwind 4.6; downwind range 9.4 (at 745 m)-62.4 (at 62 m) (M)	Shiraki and Holmen 2002
California, near five sand and gravel operations	PM10	6.0-25.5%	N/A	Schipper et al. 1993
California	PM10	17.5% upper bound; 0.1-30%	0.29-23.8 (E) (M)	Ruble and Goldsmith 1997
California, three locations near aggregate (sand & gravel) plants	PM4	6.5-21.9%	upwind 0.6-2.8; downwind 0-1.2 (M)	Richards et al. 2009
California, Duarte and Azusa	PM4	0	0-1.3; average 0.5 (M)	South Coast Air Quality Management District 2006, 2008
Wisconsin	PM2.5	2.4%; range 0.93-2.4%	0.10-0.32 (E)	WDNR Monitoring
Italy	PM10	1.6-10.4% Most (87%) were <PM2.5 size	0.25-2.87 (M)	DeBerardis et al. 2007

WDNR gathered data from other state air agencies but obtained a limited amount of information about additional monitoring studies. Some agencies had attempted to monitor for crystalline silica, usually at a discrete location and for a limited time period (for example, in California, New York, and Oregon). The Vermont Department of Environmental Conservation has conducted a longer term monitoring study of PM2.5 in ambient air which is expected to yield information about silica concentrations; however, the analysis had not been completed. The Quapaw Tribe in northeastern Oklahoma also conducted a long-term monitoring study of PM10, PM2.5, lead and silica in ambient air at the Tar Creek Superfund Site, an area where tailings piles from historic lead and zinc mining operations and are in close proximity to residential neighborhoods. However, the report from the Quapaw study focused only on other pollutants and did not present any data about silica.

Amorphous Silica
No information was found on the levels of amorphous silica in the ambient air.

In summary, little information exists nationally on ambient air concentrations of silica (especially in the PM4 size fraction) and no direct measurements of crystalline or amorphous silica are available for ambient air in Wisconsin. Obtaining monitoring data will be challenging because:

- No standard test method is available for silica monitoring in ambient air.
- WDNR has no experience with the California PM4 monitoring method (which is not a federal reference method).
- WDNR does not have equipment available that could readily be modified for monitoring of PM4 size particles.
- The Wisconsin Occupational Health Laboratory has experience with NIOSH Method 7500 (NIOSH 2003), however, neither the Occupational Health Laboratory nor the WDNR currently have the requisite funding to conduct monitoring.

Wisconsin has a monitoring network for fine particulate matter (PM2.5) but has no monitoring data specifically for crystalline silica. Nationally, ambient air data for crystalline silica concentrations is limited. Since much more monitoring data for particulate matter exists that is not specifically analyzed for crystalline silica, most researchers have historically estimated crystalline silica concentrations based on an assumed percentage of crystalline silica in total particulate matter in PM10, PM2.5 or other size fractions.

Are Silica Levels above Levels of Concern?

Researchers around the world have identified that some non-occupational exposures to crystalline silica can result in lung diseases in people and animals. Lung diseases have been identified from ambient exposures to crystalline silica in Israeli Bedouins (Bar-Ziv and Goldberg 1974), residents of the Himalayas (Saiyed et al. 1991, Norboo et al. 1991) and people in other desert environments (Mathur and Choudhary 1997). Animal studies have found evidence of silica related health effects in pigs, water buffalo (Roperto et al. 1994; Roperto et al.1995) and horses (Arens et al. 2011; Environment Canada 2011). In addition, Environment Canada (2011) summarized findings from studies in camels, badgers, ring neck pheasants and kiwi.

In North America, concerns about silica exposures to the general public were addressed in several reports. The California Office of Environmental Health Hazard Assessment (California OEHHA 2005), Texas Commission on Environmental Quality (TCEQ 2009), US EPA (1996) and Environment Canada (2011) have determined that silicosis is the critical non-cancer health effect of concern for ambient air exposures to crystalline silica.

The California monitoring data (California OEHHA 2005; Richards et al. 2009) and US EPA (1996) and Environment Canada (2011) reports generally do not indicate the existence of any wide-spread significant concern about airborne crystalline silica exposures to the general public. (Note: "general public", as the term is used here, means individuals not living near an identified source of crystalline silica emissions.) However, US EPA (1996) stated that "some potential exists for environmental silicosis to human populations". Exposures of potential concern may be more likely if populations are close to large sources of uncontrolled emissions. Data from other air pollution control agencies shows that some emissions from industrial facilities could result in air concentrations above a level of concern for people living near these sources. However, it is currently unknown whether emissions from large sources in Wisconsin are high enough and people are close enough to have significant exposures.

Non-occupational inhalation of quartz may also occur while using a variety of commercial products, such as cleansers, cosmetics, art clays and glazes, pet litter, talcum powder, caulk, putty, paint, and mortar (WHO 2000; US Bureau of Mines 1992). These emissions typically occur indoors, are small in magnitude and are more intermittent, making it unlikely that these emissions contribute significantly to ambient air concentrations of crystalline silica.

Environment Canada (2011) recently evaluated crystalline silica as an air pollutant as part of a national screening assessment challenge for hazardous air pollutants. Their data showed that the general public (those not living near a mine or other source of crystalline silica emissions) had an adequate margin of safety between conservative estimates of exposure and their comparison level. As a result, Environment Canada stated that “quartz and cristobalite are not entering the environment in a quantity or concentrations that constitute or may constitute a danger in Canada to human life or health.” [Note: The Environment Canada assessment uses a comparison value of 50 ug/m3 - which is not the same thing as a health benchmark or reference exposure level and is significantly higher than the California chronic non-cancer health benchmark of 3 ug/m3 and the Texas Commission for Environmental Quality reference exposure level of 2 ug/m3.]

In summary, more research is needed in Wisconsin in order to ascertain the range of ambient air exposures likely to occur, both near sources of silica emissions as well as from background levels of exposure. EPA’s (1996) evaluation of the state of knowledge nationally also holds true for Wisconsin: “Individual situations should be evaluated because process-stream activities and natural conditions may lead to locally higher concentrations”. The best way to determine what crystalline silica impacts are near a source is to conduct monitoring, which as stated earlier, is very difficult to conduct and the methodology for the test methods are not standard. While the state of knowledge specific to crystalline silica is limited, most significant industrial or commercial sources of emissions are regulated for particulate matter in a manner that could also reduce silica emissions.

Alternative Strategies for Minimizing Public Health Risks

The table below lists general categories of strategies that can be used to control particulate matter (PM) or silica emissions and resulting impacts. The table also lists considerations related to the strategies. The strategies can be used individually, or in combination with one another.

Strategy	Considerations
Establish air quality standards for silica (or the PM fraction of concern related to silica)	• Current statutes substantially constrain establishing ambient air standards in Wisconsin in the absence of federal standards. • There are currently no federally approved methods for quantifying PM4 (the PM fraction of concern related to silica). • Would likely have to be implemented by WDNR, not local governmental units.
Establish reference exposure levels for silica, use as a screening tool for the need for including silica controls in permits	• Current statutes substantially constrain establishing hazardous air pollutants (HAPs) in the absence of federal standards. • Silica or PM control requirements in permits are not directly tied to an air quality standard. • Would likely have to be implemented by WDNR, not local governmental units.

Strategy	Considerations
Utilize technology standards or best management practices (BMPs) to control silica emissions	• Other states currently utilize PM controls to indirectly control silica emissions. • Does not directly regulate silica or PM emissions to meet an air quality standard. • The Wisconsin Administrative Code (NR 415) currently contains requirements/provisions of this sort. • Does not require quantification of silica/PM4 (no approved test method currently available). • Would likely have to be implemented by WDNR, not local governmental units.
Require ambient monitoring for silica or PM	• There are currently no federal reference methods for quantifying silica or PM4 (the PM fraction of concern related to silica). However, various monitoring methods and types of equipment are currently available. • PM monitoring could be used as a surrogate for silica, although the silica fraction of PM is variable. • Could be used as “indicator” to trigger implementation of BMPs. • The Wisconsin Administrative Code (NR 415) currently contains authority to require ambient monitoring.
Zoning/Conditional Use permits/nuisance ordinances	• Zoning and conditional use permits issued by local governments could include requirements to pave and/or maintain roads, reduce vehicle track-out of dust, establish property setbacks, place restrictions on vehicle speeds and require transport of material to be in covered containers. • Nuisance ordinances can be used in response to excessive fugitive dust emissions. • Not all local governmental units may have zoning authority.
Voluntary measures/compliance assistance (such as fact sheets)	• WDNR is currently developing a fact sheet related to particulate matter emissions and requirements. • Does not directly regulate silica or PM emissions. • Could be used by WDNR or local governmental units to assist sources in controlling silica or PM emissions.

Regulations and Controls

While Wisconsin does not directly regulate silica emissions, several regulations and permit conditions that apply to particulate matter would also control silica emissions as well. Other states have addressed silica controls more directly. The information gathered from a survey of air agencies is summarized in this section.

Wisconsin

WDNR has extensive experience applying particulate matter (PM) controls to many types of air pollution sources. These controls will reduce silica particles which are a component of the PM controlled. WDNR manages ambient air exposures to people, excluding occupational or indoor exposures to air pollutants.

Potentially applicable rules include the Control of Particulate Emissions rule (Ch. NR 415, Wis. Adm. Code) and particulate matter limitations found in the Standards of Performance for New Stationary Sources rule for various industries (Ch. NR 440, Wis. Adm. Code), such as those pertaining to nonmetallic mineral processing plants, or to calciners and dryers in mineral industries.

The Control of Particulate Emissions rule (Ch. NR 415, Wis. Adm. Code) contains specific provisions for fugitive dust and establishes particulate matter emissions limitations for ledge rock quarries and industrial sand mines. The particulate emissions rule applies to "all air contaminant sources which emit particulate matter and to their owners and operators". The application of NR 415 would minimize dust generation potential, including any silica that may be present.

Many air pollution permits issued in Wisconsin include provisions relating to particulate matter; although, none of these specifically address crystalline silica. Many smaller sources are not required to have permits because these generally have smaller emissions and fall below permit threshold levels. For many larger sources, their permits can require dust management plans and other controls to reduce PM emissions, which will also help minimize crystalline silica emissions. The permit rules may also establish limits for emissions that can be controlled by a particulate control device such as a baghouse, cyclone, or water spray. Fugitive dust control, although not specific to crystalline silica, is required in the form of dust control plans. While these are generally only required for larger permitted facilities, this is a general rule requirement for all sources of particulate emissions.

Other States

As part of this study, the WDNR surveyed a number of air agencies across the US, to collect information on regulation of silica as an air pollutant in other states. Interviews were conducted with agency staff contacts located through the National Association of Clean Air Agencies (NACAA) Monitoring Committee and recommended by various state agency staff.

The survey gathered general information about the regulation of silica emissions and monitoring for silica in ambient air or industrial process emissions and any other relevant data that was publicly available. The survey collected information on the following subjects:

- Regulation of silica emissions—history of regulation in state, how state's regulatory standard is described and implemented, forms of silica regulated in state, regulatory requirements
- Toxicity concerns—any particular aspects of toxicity targeted by state's regulations
- Permitting—permit conditions, control measures, and reporting required
- Sources of silica emissions—major industries in state that may have silica emissions or where states have evaluated such sources
- Monitoring—any monitoring conducted by state to measure silica concentrations in ambient air and/or industrial emissions; availability of data from any monitoring projects.

Regulatory activities vary substantially from state to state. Some states do not list crystalline and amorphous silica as air pollutants and do not regulate emissions at all (though they may regulate emissions of particulate matter in general). Other states do use the health benchmarks or reference exposures levels as regulatory standards or guidelines for silica emissions.

Certain similarities did emerge from the survey. Among the states we surveyed, the most common regulatory approach is to apply the state's guideline or standard when reviewing applications for new air permits. If emissions would be expected to exceed the state's guideline or standard, control measures might be required to reduce silica emissions or, in some cases, a permit application might be denied.

Control measures take various approaches but often depend on the specific industries or processes involved. Among the states we surveyed, construction and rock crushing industries were most often cited as sources of silica emissions. Several agencies indicated that silica emissions from these industries are addressed through general controls for particulate matter and dust. Controls in these industries include wetting, use of chemical dust suppressants and the use of particulate matter control devices such as fabric filters, baghouses or cyclones. In Texas, which has the most comprehensive silica regulations among the agencies surveyed, permit conditions may specify allowable particle size distributions for road construction materials to limit quantities of respirable crystalline silica in this industry.

The survey revealed other similarities for controlling silica emissions in additional industries. Two states reported that coating and painting operations could be required to use high volume, low pressure (HVLP) spray guns and filter overspray. In addition, these operations could have restrictions placed on the silica content of coatings they apply or raw materials they use. Two states reported that the semiconductor and computer chip industry typically employs fairly sophisticated methods for controlling air emissions (e.g., scrubbers and oxidizers), and these effectively control silica emissions. These sources tend to separate their waste streams for treatment and proper disposal.

Requirements for reporting silica emissions also vary from state to state. Some states simply do not require reporting for any hazardous air pollutant. In states that do require reporting of hazardous air pollutants, the most common response in our survey was that sources do not report their silica emissions. Instead they report their total particulate matter emissions. They are not required to analyze what portion of the PM is comprised of crystalline silica. The only state found in our survey that requires reporting of silica emissions is the state of Michigan. Their reporting requirement is only for amorphous forms of silica. Texas requires abrasive blasting facilities to speciate crystalline silica emissions, but sources keep that information on-site and do not need to report it to the state.

Among Wisconsin's neighboring states, only Michigan currently regulates silica emissions, and Michigan regulates both crystalline and amorphous forms of silica. Michigan uses specific screening levels for amorphous silica (see Table 3 and Appendix B for more information). Sources of amorphous silica that have emissions within 10% of the screening level need permit conditions that control emissions.

Michigan's regulation of crystalline silica is more complicated and has changed over the years. The state recently eliminated their health benchmark levels for crystalline silica. Michigan's current regulation exempts certain sources of silica emissions—for example, sand production and processing, mineral extraction and processing, glass manufacturing, and foundries. However, any source with crystalline silica emissions that are greater than 10% of the total PM emissions might be subject to requirements for control measures. Michigan does not require sources to monitor for crystalline or amorphous silica. No specific permit limits for crystalline silica were found.

Fewer states have established ambient air standards or guidelines for amorphous silica. Among the states the WDNR surveyed, only Michigan, Texas and Vermont currently regulate amorphous silica. The Vermont standards are based on the earlier ACGIH threshold values that have been withdrawn. The Michigan guidelines have been applied to two air pollution sources of amorphous silica for silicon chip/solar cell production.

Texas has a lengthy history of regulating amorphous silica (since 1993) and recently reviewed and updated its health benchmark levels in July 2011 (TCEQ 2011a).

Table 5 summarizes information gathered from states that were contacted as part of WDNR's survey. Additional details about the survey questionnaire and state and local air agencies' responses can be found in Appendix B.

In summary, Wisconsin does not have specific standards or guidelines for crystalline or amorphous silica. Five of the states the Department surveyed address crystalline silica emissions with health benchmarks or reference exposure levels (a sixth state, Michigan, regulates crystalline silica emissions but does not use a specific health benchmark). Three of the states surveyed have ambient air standards or guidelines for the amorphous form of silica. Most of the surveyed states which regulate silica require general particulate matter or dust management control strategies to address silica emissions. Among the states surveyed, Texas has the most comprehensive approach to controlling silica emissions. Depending on the type of industry involved, permit conditions may specify limits on emission rates, total annual emissions, hours of operation, particle size distribution of materials used, type of media used, shrouding requirements, and requirements for filtering air. Texas does not usually monitor ambient air specifically for crystalline silica. However, particulate matter monitoring may be conducted for silica sources, with the potential for further analysis (i.e., speciation) of the portion of particulate matter that is comprised of crystalline silica. Among Wisconsin's neighboring states, only Michigan regulates emissions of crystalline and amorphous forms of silica. Wisconsin has extensive experience limiting particulate matter with both regulations and permit conditions. These requirements will also help to control crystalline silica emissions.

Table 5: Summary of Selected States' Regulatory and Monitoring Activities Related to Silica

State	Regulatory Information	Toxicity Concerns	Industrial Sources Identified by Agency	Permitting & Control Measures	Monitoring Studies
CA	--California lists crystalline silica as a Toxic Air Contaminant. -- Crystalline silica is also listed as a carcinogen under CA's Proposition 65 program. --CA Air Resources Board uses the Reference Exposure Level (REL) established by CA Office of Environmental Health Hazard Assessment. --Regulations are implemented by individual air pollution control/air quality management districts throughout the state. --Bay Area Air Quality Management District added crystalline silica to its list of air toxics in January 2010.	▪ Adverse effects from chronic exposure ▪ carcinogenicity	▪ Aggregate plants ▪ cement plants ▪ mining ▪ specialty sand mining ▪ diatomaceous earth mining and processing ▪ semiconductor industry ▪ agriculture (burning of rice straw)	--In the Bay Area AQMD, the REL is used for review of permit applications. Monitoring can be required as a permit condition if silica emissions are suspected to be problematic. --Most other districts try to minimize silica emissions through general controls related to PM and fugitive dust. --Computer chip industry commonly uses scrubbers and other fairly sophisticated methods to effectively control silica emissions.	--South Coast Air Quality Management District has conducted two monitoring projects, one short-term (3 weeks) and the other more long-term (2 years) (South Coast AQMD 2006, 2008). --Santa Barbara Air Pollution Control District conducted a study in 1992-1993 of crystalline silica emissions from diatomaceous earth mining and sand/gravel/rock facilities and potential risks for chronic illness and cancer. --California Air Resources Board also reviewed the monitoring methods used by a coalition of industry representatives, but concluded that those methods would not provide a standardized sampling methodology that the state or air districts could use for future studies.
MA	▪ Massachusetts does not currently regulate silica emissions. ▪ Approximately 10 years ago, MA Department of Environmental Protection considered adding crystalline silica to state list of suspected carcinogens.	▪ Carcinogenicity ▪ occupational exposure	▪ Road/highway construction ▪ mining	▪ None	▪ "Big Dig" construction project in Boston monitored to measure occupational exposures to silica, but ambient air was not monitored. ▪ University of Massachusetts has conducted other studies at individual mining or construction operations, but they also focused on occupational exposures.
MI	--Michigan regulates both crystalline and amorphous silica as Toxic Air Contaminants. --MI Department of Environmental Quality uses specific screening levels for amorphous silica. --For crystalline silica, screening levels were revoked and have not been re-established. Impacts are evaluated on a case by case. Certain industries are exempted from regulation of crystalline silica emissions. See Appendix B for more information.	▪ Chronic illness ▪ carcinogenicity	▪ Mining and mineral processing ▪ road and highway construction ▪ sand production and processing ▪ blast cleaning operations ▪ concrete operations ▪ foundries ▪ glass manufacturing ▪ chemical manufacturing	▪ Screening levels are used for review of permit applications. Expected emissions within 10% of the screening level require control measures in the permit. ▪ Reporting may be required of some sources of amorphous silica emissions. ▪ Reporting is required for sources of crystalline silica emissions, but only total PM is reported.	

State	Regulatory Information	Toxicity Concerns	Industrial Sources Identified by Agency	Permitting & Control Measures	Monitoring Studies
MT	▪ Montana does not regulate silica emissions.	▪ Carcinogenicity ▪ occupational exposure	▪ Vermiculite mining	▪ None	▪ Department of Environmental Quality, Air Quality Monitoring Program analyzed filters from air monitoring samples taken at Libby (site of long-term contamination resulting from vermiculite mining). ▪ Analyses were unsuccessful because most crystalline silica in the sample was lost during filter preparation.
NJ	--New Jersey regulates crystalline silica as a toxic air pollutant. --NJ Department of Environmental Protection adopted the long-term reference concentration used by CA Air Resources Board.	▪ Chronic, non-carcinogenic illness	▪ Highway construction ▪ other construction ▪ dental labs ▪ monument builders ▪ glass manufacturing ▪ mining ▪ sandblasting	▪ Reference concentration is used for review of permit applications. Emissions above certain risk thresholds may result in denial of permit application. ▪ Reporting is not required.	
NY	--New York regulates crystalline silica as an air contaminant. --NY Department of Environmental Conservation added it to state list of air contaminants in 1995.	▪ Adverse effects from chronic exposure	▪ Rock crushing ▪ abrasives production ▪ glass manufacturing	--Annual Guideline Concentration is used for permit review. Emissions above guideline level might need to control silica emissions. --Reporting is required; after 1996, facilities report total PM emissions but not individual components.	--Ambient air monitoring at World Trade Center site included monitoring for crystalline silica (both NIOSH and the US EPA). --Respirable crystalline silica was not detected in the NIOSH samples. In the US EPA samples, concentrations of crystalline silica remained below the detection levels. --Some monitoring results are available online; see Appendix B.
OK	--Oklahoma does not currently regulate silica emissions. --Oklahoma did regulate both crystalline and amorphous forms of silica as air pollutants from 1988-2005.	▪ Health of residents living nearby ▪ environmental pollution ▪ carcinogenicity	▪ Lead and zinc mining and milling	▪ None	--Quapaw Tribe monitored for silica in ambient air at Tar Creek Superfund site, an area containing tailings piles from historic lead and zinc mining operations. --Most samples contained low concentrations of crystalline silica, but concentrations ranged up to 21 ug/m^3. --See Appendix B for additional information about the study.

State	Regulatory Information	Toxicity Concerns	Industrial Sources Identified by Agency	Permitting & Control Measures	Monitoring Studies
OR	Oregon does not currently regulate silica emissions.	▪ Health of residents living nearby	▪ Diatomaceous earth mining and processing	▪ None	--OR Department of Environmental Quality conducted limited, short-term monitoring at a former diatomaceous earth mine pursuant to a complaint from nearby residents. --Silica concentrations in the air samples were below the detection limits, though the ore sample did contain crystalline silica. --Some results and information are available online; see Appendix B.
TX	--Texas regulates emissions of both crystalline and amorphous silica. --TX has lengthy history of concern for silica emissions from certain industries in the state; regulatory activities began in 1971. -- TX Commission on Environmental Quality Toxicology Division reviews information and publishes Effects Screening Levels (ESLs) for short-term and long-term exposure. --TCEQ reviewed its ESLs for crystalline silica and revised the guidelines in October 2009. --TCEQ reviewed its ESLs for amorphous silica and revised the guidelines in July 2011.	▪ Chronic illness	▪ Ship and barge repair/refinishing ▪ oil/gas field pipe and outdoor tanks repair/refinishing ▪ abrasive blasting ▪ coating operations ▪ concrete batch plants ▪ cement plants ▪ quarries ▪ rock crushing ▪ asphalt ▪ foundries ▪ fractured sand (for oil industry) ▪ semiconductor industry	--Using ESLs, TCEQ conducts health effects review of air permit applications. --Crystalline silica emissions would typically be reviewed as part of total PM emissions. Agency will direct additional effort toward silica emissions in the face of public concern. --For many industries, permit conditions are directed toward controlling PM in general. --Some industries—including abrasive blasting, coating operations, and road construction—may have specific permit conditions that limit silica emissions. --Reporting is required; usually total PM is reported, but abrasive blasting operations may be required to speciate PM emissions. --See Appendix B for more information about permit conditions and control measures.	TCEQ air program may occasionally speciate PM samples collected during routine monitoring; silica shows up in speciated samples.

State	Regulatory Information	Toxicity Concerns	Industrial Sources Identified by Agency	Permitting & Control Measures	Monitoring Studies
VT	--Vermont has identified silica as a Hazardous Air Contaminant since the late 1980s. --VT Air Pollution Control Division regulates crystalline, amorphous, and fused forms of silica.	▪ Chronic illness	▪ Road construction ▪ rock crushing ▪ coating operations, including wood furniture painting	--Sources emitting more than 5 tons per year do not require permits but do report emissions of total PM (not required to quantify the silica fraction). --Sources emitting 10 tons or more per year require permits. --Permit conditions usually require controlling PM emissions in general through best management practices and emission limits. Coating operations have process-specific requirements.	--VT Air Pollution Control Division conducted a multi-year PM2.5 monitoring project some years ago. --Samples are being analyzed now, and data are expected to include some information about silica concentrations.

References

Arens, A.M.; Barr, B.; Puchalski, S.M.; Poppenga, R.; Kulin R.M.; Anderson, J.; Stover, S.M. 2011. Osteoporosis Associated With Pulmonary Silicosis in an Equine Bone Fragility Syndrome. Vet Pathol. 48:3 593-615.

Bar-Ziv, J.; Goldberg, G.M. (1974) Simple Siliceous Pneumoconiosis in Negev Bedouins, Arch. Environ. Health, vol. 29: 124.

California Office of Environmental Health Hazard Assessment (California OEHHA). 2005. Chronic Reference Exposure Level (REL) for Silica (Crystalline, Respirable. (California Office of Health Hazard Evaluation - www.COEHHA.ca.gov/air/chronic_rels/silica_final.html).

Castranova, V.; Vallyathan, Vl; Ramsey, D.M.; McLaurin, J.L.; Pack, D.; Leonard, S.; Barger, M.W.; Ma, J.Y.C.; Dalal, N.S.; Teass, A. (1997) Augmentation of pulmonary reactions to quartz inhalation by trace amounts of iron-containing particles. Environ. Health Perspect. 105(5): 1319-1324.

De Berardis, B.; Incocciati, E.; Massera, S.; Gargaro, G.; Paoletti L. (2007) Airborne silica levels in an urban area; Sci. Total Environ. 382:251–258.

Davis, B. L.; Johnson, L. R.; Stevens, R. K.; Courtney, W. J.; Safriet, D. W. (1984) The quartz content and elemental composition of aerosols from selected sites of the EPA inhalable particulate network. Atmos. Environ. 18: 771-782.

Environment Canada. 2011. Quartz and Cristobalite: Draft screening assessment for the challenge. Environment Canada and Health Canada. http://www.ec.gc.ca/ese-ees/1EB4F4EF-88EE-4679-9A6C-008F0CBC191C/batch12_14464-46-1%20%26%2014808-60-7_en.pdf

Fubini, B.; Hubbard, A. 2003 Reactive oxygen species (ROS) and reactive nitrogen species (RNS) generation by silica in inflammation and fibrosis. Free Radic. Biol. Med. 34(12): 1507-1516.

International Agency for Research on Cancer (IARC) (1997). Silica, some silicates, coal dust and para-aramid fibrils. Lyon, France, International Agency for Research on Cancer, pp. 1–242, IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol. 68. http://monographs.iarc.fr/ENG/Monographs/vol68/volume68.pdf

International Agency for Research on Cancer (IARC) (2002) MAN-MADE VITREOUS FIBRES. Lyon, France, International Agency for Research on Cancer, IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol. 81). http://monographs.iarc.fr/ENG/Monographs/vol81/volume81.pdf

Mathur, M. L.; Choudhary, R. C. (1997) Desert Lung Syndrome, in rural dwellers of the Thar Desert, India. J. Arid Environs, 35(3)559-562.

Mayo Clinic Foundation for Medical Education and Research (2008) – Mayo Clinic On-line Scleroderma Definitions webpage. Last updated 10/17/2008. http://www.mayoclinic.com/health/scleroderma/ds0036.

Michigan Department of Environmental Quality. 2011. Michigan Department of Natural Resources and Environment - Air Quality Division List of Screening Levels. Accessed at http://www.michigan.gov/documents/deq/deq-aqd-toxics-ITSLALPH_244167_7.pdf

Monteil, M.A. (2008) Saharan dust clouds and human health in the English-speaking Carribean: what we know and what we don't know. Environ. Geochem. Health. 30:339-343. Epub 2008 Mar 12.

Monteil, M.A.; Antoine, R. (2009) African dust and asthma in the Caribbean: medical and statistical perspectives. Int. J Biometeorol. Correspondence. Epub 26 Aug 2009.

Mukhopadhyay, K; Ramalingam, A.; Ramani, R.; Dasu, V.; Sadasivam, A.; Kumar, P.; Prasad, S.N.; Sambandam, S.; Balakrishnan, K. (2010). Exposure to Respirable Particulates and Silica in and Around the Stone Crushing Units in Central India. Industrial Health. Advance Publication Date December 16, 2010.

National Institute for Occupational Safety and Health (NIOSH). 2002. Health Effects of Occupational Exposure to Respirable Crystalline Silica: NIOSH Hazard Review; Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

National Institute for Occupational Safety and Health (NIOSH). 2003. Silica, Crystalline, by XRD (filter redeposition): Method 7500, Issue 4. March 15, 2003. http://www.cdc.gov/niosh/docs/2003-154/pdfs/7500.pdf

National Institute for Occupational Safety and Health (NIOSH). 2011. Work-Related Lund Disease (WoRLD) Surveillance System. Volume 1: Silicosis: Mortality. Table 3.5. Silicosis: Number of deaths, death rates (per million population), and years of potential life lost (YPLL) by state, U.S. Residents age 15 and over, 1996-2005. Online version – viewed August 2, 2011. http://www2.cdc.gov/drds/worldreportdata/FigureTableDetails.asp?FigureTableID=539&GroupRefNumber=T03-05

National Toxicology Program (2005) 11th Report on Carcinogens. Online version for silica listing - http://ntp.niehs.nih.gov/?objectid=72016262-BDB7-CEBA-FA60E922B18C2540.

New Jersey Department of Environmental Protection. 2009. Air Quality Permitting Program, Risk Screening Tools. Accessed at http://www.state.nj.us/dep/aqpp/risk.html.

New York State Department of Environmental Conservation. 2011a. Policy DAR-1: Guidelines for the Control of Toxic Ambient Air Contaminants. Accessed at http://www.dec.ny.gov/chemical/30681.html.

New York State Department of Environmental Conservation. 2011b. DAR-1 AGC/SGC Tables and Software Support Files. Accessed at http://www.dec.ny.gov/chemical/30560.html.

Norboo, T.; Angchuk , P. T.; Yahya M.; Kamat, S. R.; Pooley, F .D.; Corrin, B.; Kerr, I. H.; Bruce ,N.; Ball, K. P. (1991) Silicosis in a Himalayan village population: role of environmental dust. Thorax 46(5): 341–343.

Oklahoma Department of Environmental Quality (2010) Air Quality Division, Air Toxics Partial Listing. Accessed at http://www.deq.state.ok.us/aqdnew/toxics/SC41.html.

Richards, J.R.; Brozell, T.T.; Rea, C.; Boraston, G.; Hayden, J. (2009). PM4 Crystalline Silica Emission Factors and Ambient Concentrations at Aggregate-Producing Sources in California. J. Air & Waste Manage. Assoc. 59: pp 1287-1295.

Roperto, F.; Damiano, S.; De Vico, G.; Galati, D. (1994) Silicate pneumoconiosis in pigs: optical and scanning electron microscopical investigations with X-ray microanalysis. J Comp Pathol. 110(3):227-36.

Roperto, F.; Troncone, A.; Tranquillo, A.; Galati, P. (1995). Extrapulmonary silicosis in two water buffaloes. J Comp Pathol. 1995 Jan; 112(1):97-103.

Ruble, R; Goldsmith, D.F. (1997) Ambient PM10 Emissions: Contributions and Impact on Silica Emissions. J. Expos. Anal. Environ. Epidemiol. 7(3): 327-344.

Saiyed, H N; Sharma, Y. K.; Sadhu, H. G.; Norboo.; Patel, P. D.; Patel, T. S.; Venkaiah, K.; Kashyap, S. K. (1991) Non-occupational pneumoconiosis at high altitude villages in central Ladakh. Br. J. Ind. Med. 48:825-829

Schipper, L. B., III; Chow, J. C.; Frazier, C. A. (1993) Particulate air toxic emission estimation of the PM10 fraction in natural aggregate processing facilities. Presented at: 86th annual meeting and exhibition of the Air & Waste Management Association; June; Denver, CO. Pittsburgh, PA: Air & Waste Management Association; paper no. 93-MP-6.03.

Shiraki, R.; Holmen, B. (2002) Airborne respirable silica near a sand and gravel facility in Central California: XRD and Elemental Analysis to Distinguish Source and Background Quartz. Environ. Sci. Technol., 36 (23) pp 4956-4961.

South Coast Air Quality Management District (2006). Sampling and Analysis of Samples Collected in the Cities of Duarte and Azusa. December 2006. Report MA #2006-01

South Coast Air Quality Management District (2008). Sampling and Analysis of Samples Collected in the Cities of Duarte and Azusa Follow-up #4 November 2008 Report MA #2008-03

Steenland, K.; Goldsmith, D. F. (1995) Silica exposure and autoimmune diseases. Am. J. Ind. Med. 28: 603-608.

Texas Commission on Environmental Quality (TCEQ) (2009) Silica, Crystalline Forms. Development Support Document, Final. October 8, 2009. http://www.tceq.com/assets/public/implementation/tox/dsd/final/october09/silica_crystalline_forms.pdf.

Texas Commission on Environmental Quality (TCEQ) 2011a. Silica, Amorphous and Other Non-Crystalline Forms Development Support Document. http://www.tceq.state.tx.us/assets/public/implementation/tox/dsd/final/july11/amorphous_silica.pdf.

Texas Commission on Environmental Quality. 2011b. Effects Screening Levels (ESL) Lists Used in the Review of Air Permitting Data. Accessed at http://www.tceq.state.tx.us/implementation/tox/esl/list_main.html.

US Bureau of Mines (1992) Special publication: Crystalline silica primer. Washington, DC, US Department of the Interior, Bureau of Mines.

US EPA (1996) Ambient Levels and Non-cancer Health Effects of Inhaled Crystalline and Amorphous Silica: Health Issue Assessment. EPA/600/R-95/115. November 1996.

Vermont Department of Environmental Conservation. 2003a. Air Pollution Control Division Rules and Regulations. Accessed at http://www.anr.state.vt.us/air/htm/AirRegulations.htm.

Vermont Department of Environmental Conservation. 2003b. 1998 Air Toxics Report. Accessed at http://www.anr.state.vt.us/air/airtoxics/htm/AirToxReport1998.htm (reference Methodology for Deriving Hazardous Ambient Air Standards for Category II Compounds).

World Health Organization (2000). Crystalline silica, quartz. Concise International Chemical Assessment Document 24.

Xu, X.Z.; Cai X.G.; Men X.S.; Yang, P.Y.; Yang, J.F.; Jing, S.L.; He, J.H.; Si, W.Y. (1993). A study of siliceous pneumoconiosis in a desert area of Sunan County, Gansu Province, China. Biomed Environ Sci. 1993 Sep; 6(3):217-22

Appendix A: Ambient Air Concentrations of Silica

In lieu of actual data on PM4[2] concentrations of crystalline silica, some researchers have attempted to extrapolate data from TSP - Total Suspended Particulate matter, PM10 - Particulate Matter less than 10 microns particle diameter and PM2.5 – Particulate matter less than 2.5 microns particle diameter. These varying measurements and analytical methods, which have changed over time, make comparisons between different monitoring studies difficult.

Because there was no national information on silica emissions and concentrations, US EPA chose to use PM10 as a surrogate and examined the major source of PM10 emissions in the US.

In looking more broadly at PM10 emissions (not just the crystalline silica portion) across the United States, US EPA found that the vast majority (84 - 90%) of PM10 emissions into the ambient air are from fugitive sources. Of the fugitive sources of PM10, the most significant sources were paved and unpaved roads, construction, agricultural tilling and wind erosion. Mining activities represented approximately one percent of total PM10 emissions (US EPA 1996- Tables 3-1 and 3-2). This data suggested that natural and fugitive sources are larger sources than industrial sources. However, this did not eliminate potential concerns near larger industrial sources of silica emissions.

US EPA (1996) also looked at data from the Inhalable Particulate Network IPN (Davis et al., 1984). This study found that crystalline silica in 22 cities was less than 3% of the "fine" (PM2.5) sized fraction and less than 10% of the "coarse" sized fraction (PM2.5 to PM15). This study looked at several Midwestern cities, but none of them were in Wisconsin. Based on this data, EPA made an estimate that crystalline silica compromises approximately 10% of the total PM10 concentrations.

The US EPA report (1996) cited additional ambient air monitoring studies in California and Arizona as well. Based on the available data, US EPA stated that a reasonable assumption would be that about 10% of PM10 could potentially be crystalline silica, while acknowledging that some "Industrial processes, such as quarrying, produce crystalline silica concentrations in the 6 to 12% range or higher and a possible upper-bound estimate of crystalline silica near agricultural sites might be approximately 17%" (US EPA 1996). EPA estimated that an average US ambient air concentration for crystalline silica in PM10 would be 3 micrograms per cubic meter (ug/m3) and a high concentration in the US (in US metropolitan areas) would be 8 ug/m3 (US EPA 1996). The report stated that there may be locations where these generalizations about expected silica concentrations would not represent local conditions, such as near silica sources.

Rather than focusing only on general exposures in cities, early 1990s sampling data from California suggested that monitoring near silica sources may also be important because exposures near sources could exceed 10% of the total PM10 levels. Thus, there may be exposures near facilities that could exceed the California health benchmark of 3 micrograms per cubic meter (ug/m3). For example, the US EPA (1996) reported the following:

> "Schipper et al. (1993) compared the quartz concentrations from three Central Valley and two coastal sand and gravel operations in California. In the Central Valley, the silica percentage of PM10 air emissions in the quarry pits ranged from 6.0% in Sacramento to 9.1% in Tracy, whereas

[2] As previously noted, the industrial hygienist community measures PM4 sized particles (i.e., particulate matter less than 4 microns).

the silica levels around the crusher ranged from 11.2% in Visalia to 25.5% in Tracy. In the coastal quarries in Monterey and Felton, the portions of quartz were from 14.1 to 16.6% in the PM10 samples (Schipper et al., 1993)."

De Berardis et al. (2007) evaluated silica concentrations in urban environments around Rome in order to understand general population exposures. The crystalline silica concentrations in PM10 were found to be between 0.25 and 2.87 µg/m3, with a mean value of 1.31 µg/m3. Crystalline silica ranged from 1.6 to 10.4% of the total PM10 particulate measured in this study. About 87% of the crystalline silica particles were less than 2.5 microns (millionths of a meter in size). A potential source of the silica particles was from southern winds emanating from the Saharan desert region. This study illustrates the fact that background levels of silica can be affected by distant sources of silica. Silica particles in the PM10 size range and smaller can travel thousands of kilometers. For example, researchers in Barbados and Trinidad have evaluated the impact of particulate matter containing crystalline silica from dust storms that originate in Saharan deserts in Africa (Monteil 2008; Monteil and Antoine 2009). In addition, African dust has been tracked to northern Scandinavia and Asian dust from the Gobi desert in China can be transported to British Columbia and California (Environment Canada 2011). The mean particle sizes for this dust were in the respirable size range (median diameter was 2 to 3 microns). The dust storms are periodic in nature and typically are very short term events. The concentrations are not extremely high many miles away due the long distances involved and the long time available for dispersion, but their effect on background concentrations are noticeable. Therefore, low levels of silica can exist in ambient air, even in remote locations.

Levels of silica in ambient air are sometimes higher due to human activity however. For example Environment Canada (2011) reported that levels of silica in PM10 were 0.01-6.68 ug/m3 with a median 0.41 ug/m3 in four remote rural sites, 0.73-8.77 ug/m3 in 24 urban sites (median 3.73) and 0.4 to 27 ug/m3 (median 7.0) in agricultural areas.

Subsequent data from California also suggests that there is potential for higher silica concentrations near industrial sources of crystalline silica. Shiraki and Holmen (2002), monitored silica concentrations in PM10 near a sand and gravel facility in Central California. One upwind monitor and four downwind monitors were deployed. Upwind silica concentrations in PM10 particle size fraction were found to be 4.6 micrograms per cubic meter (ug/m3), whereas downwind concentrations ranged from 9.4 ug/m3 to 62.4 ug/m3, with the higher concentrations found closest to the source. These concentrations are well above the California OEHHA (2005) health benchmark of 3 ug/m3. The percent of crystalline silica, by mass, as a percent of total particulate mass decreased with increasing distance from the source. However, the impact from this source was still evident, even at the furthest downwind monitor - 745 meters away. PM2.5 measurements were also attempted but all data was below the method detection level used and therefore no data was reported for PM2.5 size fraction silica concentrations. Another study in California, Ruble and Goldsmith (1997), found that crystalline silica ranged from 0.4% to 21% of total PM10, with a plausible upper bound estimate of 9% to 17.5%. Mukhopadhyay et al. (2010) evaluated crystalline silica near stone quarrying and crushing operations in Central India and found that about 10-12% of respirable PM was crystalline silica. Thus, while US EPA (1996) and other researchers have used an estimate of crystalline silica to be 10% of total PM10, that assumption may under estimate some exposure scenarios near a silica emission source, depending on the distance to the source, the chemical makeup of the materials being processed and the unique nature of the process and equipment used.

Monitoring was conducted in 1989 to determine silica levels in an urban site, a rural site, and a remote background site in California. Table A-1 reflects the results of this monitoring (California OEHHA 2005).

Table A-1: California Urban, Rural and Background Monitoring Data (1989) - Silica Concentrations in PM10

Site Type	Location	Number of Samples	Silica Concentration (ug/m3) - PM10 particle size range (minimum and maximum values found)
Urban	Santa Maria	12	2.3 (1.17 - 3.46)
Rural	Santa Ynez	16	0.6 (0 - 1.44)
Remote Background	Buellton	18	0.2 (0 - 1.15)

In addition, data from South Coast Air Quality Management District (2006; 2008) for Duarte California (Los Angeles County) found the maximum crystalline PM4 value from a 24 hour sample was 1.1 micrograms per cubic meter (ug/m3) in the 2006 report and 1.3 ug/m3 in the 2008 report. The annual average concentration of crystalline silica (PM4) was 0.5 ug/m3. This is below the California OEHHA reference exposure level of 3 ug/m3.

Wisconsin had three PM2.5 speciation monitors with data on elemental constituents found in PM2.5 samples. Silicon (the element) is measured in these samples. This data is less than ideal for use in evaluation of crystalline silica for the purposes of this report because the analysis is only for the element silicon and cannot be used to identify the form of silicon in the sample. In addition, the size fraction is smaller than the PM4 particles used by occupational health agencies and the state of California to evaluate the most significant particles.

The three PM2.5 speciation monitors had data that spans over numerous years. For example, the Mayville data spans from September 2001 to November 2009 and there were 958 samples taken during this period. In order to calculate the silica concentration from the silicon concentration, the ratio of the molecular weights of Silica (SiO_2) to Silicon (Si) was taken – this is a ratio of 2.14. The silicon concentrations were converted to an equivalent SiO_2 concentration by using the 2.14 factor and then an average of all of the data points were taken to make the following table – Table A-2. The average percent of silica as a percent of PM2.5 was between 1 and 2.4%.

Table A-2 Wisconsin– PM2.5 Speciation Data from EPA National Monitoring System

Site Name	Monitor ID	Number of Samples	Average Silicon Concentration (ug/m3)	Average Quartz (SiO2) Concentration (ug/m3)	PM2.5 Concentration (ug/m3)	% SiO2 in PM
Milwaukee	550790026	1045	0.065	0.14	12.6	1.1
Mayville	550270007	958	0.048	0.10	11.0	0.93
Waukesha	551330027	472	0.15	0.32	13.2	2.4

In addition to conventional gravimetric methods, where particles are collected on a pre-weighed filter and the mass loading on a filter determined as a weight per volume of air sampled, there are some real-time instruments now being used to examine particle counts. These devices use laser technology to estimate the number of particles. As particle numbers increase, they increasingly scatter the laser beam. These instruments are considered to be survey level instruments – they are not calibrated to a standard reference material for PM4 crystalline silica and are not as accurate as needed for regulatory purposes. However, they are inexpensive, portable, present real-time data and can be used to fix potential problems at a facility.

The Concerned Chippewa Citizens (http://wisair.wordpress.com/)) have undertaken monitoring studies, using particle counters, in several locations near sand mines in the Western part of the state (Chippewa

Falls and Menomonie). The samples collect real-time data for particulates using laser based technology (Dylos© monitors) to evaluate total particulate matter near industrial sand mines. The laser technology uses light scattering of particles to calculate particle numbers in the air. Instead of measuring the mass of particles, the monitor estimates the number of particles in two size categories (between 0.5-2.4 micron and >2.5 micron). As mentioned above, this type of monitor does not speciate crystalline silica from total particulate matter nor does it calculate particle number for PM4 sized particles. While it can be useful in detecting changes in particles in the air, it is unclear how the data from this type of monitor could be compared against measurement of the mass of particles of a certain size in the air (e.g., comparing with the OEHAA health benchmark of 3 ug/m3 of PM4 sized particles). The reader is referred to the Concerned Chippewa Citizens (http://wisair.wordpress.com/) and the Dylos© website (www.dylosproducts.com/index.html) for additional information.

Appendix B: WDNR Silica Survey of State and Local Air Pollution Agencies in the US

The WDNR collected information from air agencies regarding regulation and monitoring of silica emissions in other areas of the country. This appendix describes the survey used and summarizes the information obtained from state and local air pollution agencies.

The goal of the survey was to gather information about regulatory activities related to silica emissions, learn about monitoring studies that have been conducted, and identify sources of any data that are available.

Survey Procedure

The WDNR employed two methods for gathering information from other air agencies: (1) soliciting responses to an inquiry sent through email, and (2) conducting interviews on the telephone. The agency initially disseminated a request for information to the Monitoring Committee of the National Association of Clean Air Agencies (NACAA). Most of the responses were brief, but some responders did suggest names of specific agency staff who could potentially contribute information. We subsequently conducted interviews on the telephone with air agency staff from other states. These staff were either identified through the Monitoring Committee inquiry or located by telephoning air agencies in states which our contacts or published information indicated had undertaken some regulatory or monitoring activities. We also contacted the air agencies in other states within US EPA Region 5 (Great Lakes region)—Illinois, Indiana, Michigan, Minnesota and Ohio—along with Iowa. The survey did not exhaustively query every state, or every local/regional air agency within any state.

The WDNR developed a survey questionnaire to guide our telephone interviews with other state agencies. The survey questions primarily addressed five subject areas:

- regulation of silica emissions
- permitting (including control measures and reporting requirements)
- industrial sources of silica emissions
- toxicity concerns
- monitoring studies

Figure B-1 shows the list of questions discussed during telephone interviews conducted for this survey, and Table B-1 lists the agency staff who provided information to the WDNR about regulation and monitoring of silica emissions in their states.

Figure B-1: Questionnaire used by WDNR to survey other air agencies for information about regulation and monitoring of silica emissions

WDNR Silica Survey

Organization	
Contact name	
Phone	
Email	
Date of contact	

Background info/opening remarks:

WDNR is considering possible future regulation of silica (crystalline and amorphous forms) and, prior to making a determination as to whether silica should be addressed as a hazardous air pollutant, WDNR is interested in learning about other U.S. air agency rules and assessments of silica as a Hazardous Air Pollutant.

We have already conducted some research into the health effects and sources of silica, but want to talk to you about your agency history of evaluating and regulating these various forms of silica. In addition, we would like to obtain contact information regarding permitting, monitoring and compliance issues that pertain to silica sources.

Overview of crystalline silica regulation and/or assessment by your agency:

- Did your agency ever conduct studies or analyses of sources and emissions of silica?
- What are the important sources of silica emissions in your state?
- Has your agency ever monitored for silica in the ambient air? Previously/currently? If so, can we obtain any data or results?
- Does your agency regulate emissions of silica in any way?
- If yes, what does the regulation require (permits, control measures, reporting)?
- If yes, ask about rule and its history...Where to find the rule(s)? Did the rule generate any controversy? If so, what comments were received? What changes were made as a result of public comments?

- Applicability of rule(s) — What types/sizes of silica sources are covered? What silica sources are exempt? Does the rule distinguish between new/modified sources versus existing sources (i.e., is anybody “grandfathered”)?
- Permitting — What permits have been issued to silica sources? Are copies available? What type of control equipment is required? For what types of sources?

Figure B-1 (continued)

- Emissions — What emissions factors do you have? Do you have a silica inventory?
- Fugitive emissions — How does the agency approach fugitive emissions of silica? Are they exempt? What types of controls are required?

Additional information about silica, or sources of information, within your agency or state:

- Who else do you know that has expertise in the area of silica (e.g., sources, permitting, compliance, emissions inventories, monitoring, health effects)? Do you have contact information?

Where can I find out more about:

- Compliance — any compliance issues at silica sources?
- Health Effects?
- Monitoring — what methods are used; what are actual results of monitoring?
- Any other rules that apply to silica emissions?

Questions about amorphous silica:

- Amorphous silica sources — are they covered by any rules, permits, etc.?
- Does your agency/has your agency done any monitoring for amorphous silica?
- What is known about amorphous silica sources being converted into crystalline silica through processes like heat and pressure? Has this issue been investigated in your agency?

Table B-1: Staff representatives of state and regional air agencies who provided information to WDNR about regulation and monitoring of silica emissions

State	Agency Information	Contact Name	Email	Phone
CA	CA Air Resources Board (ARB), Planning & Technical Support	Chris Halm	chalm@arb.ca.gov	916-323-4865
CA	CA ARB, Monitoring & Laboratory Division	Ahmed Mehadi	amehadi@arb.ca.gov	916-327-4730
CA	CA ARB, Stationary Source Division, Technical Assessment Section Mgr	Todd Wong	twong@arb.ca.gov	916-324-8031
CA	Bay Area Air Quality Management District (AQMD), Air Quality Engineering Mgr	Scott Lutz	slutz@baaqmd.gov	415-749-4676
CA	Butte County AQMD, Enforcement & Permitting Mgr	Bob McLaughlin		530-891-2882 x111
CA	Butte County AQMD, Major Stationary Source Permits, General Toxics Control Program	David Lusk	dlusk@bcaqmd.org	530-891-2882 x113
CA	Mojave Desert AQMD, Air Quality Engineer	Richard Wales	rwales@mdaqmd.ca.gov	760-245-1661 x1803
CA	Santa Barbara County Air Pollution Control District (APCD), Air Quality Engineer, Supervisor	Kaitlin McNally	mcnallyk@sbcapcd.org	805-961-8855
CA	Shasta County AQMD, Air Pollution Inspector	Donal Jonio		530-225-5236
CA	South Coast AQMD, Program Supervisor	Cheryl Marshall	cmarshall@aqmd.gov	909-396-2576
CA	South Coast AQMD, Senior Enforcement Mgr/Lab Mgr	Rudy Eden	reden@aqmd.gov	909-396-2391
IA	IA Dept of Natural Resources, Environmental Protection Division, Air Quality Bureau Compliance & Monitoring, Environmental Specialist	Diane Brockshus	diane.brockshus@dnr.iowa.gov	515-281-4801
IL	IL Environmental Protection Agency, Bureau of Air, Division of Air Pollution Control, Air Quality Planning	Dixon Nwaji	Dixon.Nwaji@illinois.gov	217-785-1731
IL	IL EPA, Bureau of Air, Division of Air Pollution Control, Air Quality Planning	Jeff Sprague	Jeff.Sprague@illinois.gov	217-524-4692
IN	IN Dept of Environmental Management, Office of Air Quality/Programs Branch, Section Chief	Brian Wolff	bwolff@idem.in.gov	317-234-3499
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Survey Results

This section provides a summary of the information collected from air agencies in each state interviewed during WDNR's survey. In general, the questions about regulatory activities generated straightforward responses. Much less information was available about monitoring studies, and it could be more difficult to find; often, reports were not published and not well known even within the air agency.

Some states have monitored silica, or tried to, even though they do not currently regulate emissions. This section also contains information about those monitoring efforts. WDNR's inquiry about monitoring for silica also resulted in responses from several states indicating that silica had not been addressed in their agency at all, or they only had limited data. Several responses to WDNR's inquiry were simple statements that an agency had not conducted any monitoring for silica (for instance, Florida Department of Environmental Protection, Pennsylvania Department of Environmental Protection, and city of Albuquerque, New Mexico, Air Quality Division). Pennsylvania added that it does not have the capability to analyze samples for silica concentrations. Albuquerque stated that there is some interest in silica emissions within the agency, but was unable to provide further data to WDNR.

The information collected during WDNR's survey is organized and presented by state:

California

The state of California regulates crystalline silica as a Toxic Air Contaminant. However, the state rule is implemented at the level of individual air pollution control (or air quality management) districts. WDNR found only one district that recently added crystalline silica to its list of air toxics. Monitoring in this state, particularly in southern California, has been more extensive than most other states we surveyed. WDNR obtained this information from numerous telephone interviews. We surveyed staff of the state air agency plus several local air districts; the agencies were:

- CA Air Resources Board
- Bay Area Air Quality Management District (AQMD)
- Butte County AQMD
- Mojave Desert AQMD
- Santa Barbara County Air Pollution Control District (APCD)
- Shasta County AQMD
- South Coast AQMD

Regulatory information:

- California regulates crystalline silica as a Toxic Air Contaminant.
- CA Air Resources Board uses the Reference Exposure Level (REL) established by the CA Office of Environmental Health Hazard Assessment. California's REL is 3 $\mu g/m^3$, measured as PM4.
- The REL is used for review of permit applications.
- Crystalline silica is also listed as a carcinogen under California's Proposition 65 program.
- Specific regulatory activities are determined at a local level, by the individual air pollution control or air quality management districts throughout the state.
- Bay Area Air Quality Management District added crystalline silica to its list of air toxics in January 2010. The district had only reviewed one or two permit applications for silica at the time of WDNR's survey and had not yet developed any permit conditions specifically aimed at reducing silica emissions. WDNR is not aware of any other districts in the state that have incorporated silica emissions into their rules and regulations.
- While the state standard requires testing and evaluation of crystalline silica at the PM4 level, many air districts are not able to implement the standard because their current testing methods do not specifically analyze for that particle size fraction.

Permitting requirements:

- Bay Area AQMD can require monitoring as a condition of air permits if silica emissions are suspected to be problematic. In such a case, the facility would be required to conduct upwind/downwind sampling of silica concentrations in ambient air.
- Bay Area AQMD had only reviewed a small number of permit applications for silica emissions at the time of our interview and had not yet required any specific controls in permit conditions.
- Most other districts would require controlling for general particulate matter and fugitive dust emissions; any controls for silica emissions would be incorporated within that framework (e.g., baghouses for rock crushing facilities).
- Bay Area AQMD in particular has computer chip manufacturing facilities located in the district also, but the industry commonly employs scrubbers and other fairly sophisticated methods to control emissions very effectively.

Industrial sources of silica emissions:

- Aggregate plants
- Cement plants
- Mining
- Specialty sand mining
- Diatomaceous earth mining (cooking and calcining part of the process)
- Semiconductor industry
- Agriculture (rice straw burning)

Toxicity concerns:

- Adverse health effects from chronic, long-term exposure
- Carcinogenicity

Monitoring studies:

- South Coast AQMD has conducted two monitoring studies:
  - The first study involved short-term monitoring at a hillside development/construction project at the site of a very old diatomaceous earth mine. Monitoring lasted approximately three weeks and was conducted during earth moving activities. Silica levels never approached the state standard. Data were not published.
  - Longer term monitoring has been conducted at a rock aggregate/gravel mine and plant that is located near residential areas and a school. The study involved sampling ambient air near the school, and monitoring lasted almost two years. Silica levels did not approach the state standard. The district constructed its own sampler, modified from a PM2.5 sampling device, to collect PM4.0 samples. Additional monitoring is planned at this site (upwind/downwind), because the mine wants to expand and move its operations across the canyon, and the project has been very contentious in the nearby local community (South Coast AQMD 2006, 2008).
- Santa Barbara County APCD also conducted a study, in 1992-1993, to measure crystalline silica emissions from diatomaceous earth mining and sand/gravel/rock facilities and assess potential risks for chronic illness and cancer. Concentrations of silica largely remained below the state standard.
- In addition, a coalition of industry representatives conducted a very short-term study of monitoring methods at a single site within the Mojave Desert Air Quality Management District (Richards et al. 2009). The CA Air Resources Board reviewed the methodology and results, and concluded that methods used in the study would not provide a standardized sampling methodology that the state or air districts could use for future monitoring.
- Bay Area AQMD required one cement plant in the district to analyze the components of its raw materials. The facility's analysis used AP42 emission factors for PM10, combined with modeling, to estimate emissions. Concerns focused more on compounds like mercury and chromium than on silica.

Illinois

The state of Illinois does not specifically regulate silica emissions, and there is no particular concern about this pollutant in the state at this time. WDNR obtained this information from a telephone interview with staff of the Illinois Environmental Protection Agency, Bureau of Air, Division of Air Pollution Control, Air Quality Planning section.

Indiana

The state of Indiana does not specifically regulate silica emissions, though silica might be managed to some extent under controls for particulate matter emissions. Air permit holders are required to report particulate matter emissions but report total PM only. The state also does not conduct any monitoring for silica in ambient air. WDNR obtained this information from two telephone interviews with staff of the Indiana Department of Environmental Management, Office of Air Quality, the Programs (permitting) and Air Monitoring Branches.

Iowa

The state of Iowa does not currently regulate silica emissions, nor has it conducted any monitoring studies to measure silica in ambient air. Air permit holders are required to report particulate matter emissions but report total PM only. WDNR obtained this information from a telephone interview with staff of the Iowa Department of Natural Resources, Environmental Protection Division, Air Quality Bureau, Compliance and Monitoring section.

Massachusetts

The Massachusetts Department of Environmental Protection has considered both regulatory and monitoring activities related to silica emissions. The state did not take any regulatory actions at the time, and current monitoring activities are limited to occupational exposures to silica in air. WDNR obtained this information from an email response to the NACAA Monitoring Committee inquiry. The information came from (a) a DEP staff member who investigated information about health effects of silica exposure and possible methods for monitoring and analysis; and (b) a university professor who conducts monitoring of occupational exposures to crystalline silica.

Regulatory information:

- Approximately ten years ago, Massachusetts Department of Environmental Protection investigated adding crystalline silica to the state list of suspected carcinogens. Apparently no action was taken.

Industrial sources of silica emissions:

- Road and highway construction
- Mining

Toxicity concerns:

- Occupational exposure
- Carcinogenicity

Monitoring studies:

- Massachusetts DEP considered monitoring for crystalline silica pursuant to complaints about two quarries in the eastern part of the state. MA DEP investigated monitoring and analysis methods but ultimately did not conduct any studies.
- Monitoring for occupational exposures to silica has been conducted in the state. The University of Massachusetts-Lowell has a faculty member in the Department of Work Environment who has measured exposures of construction workers at road construction sites and near quarries. Her work included monitoring for silica exposure at the “Big Dig” highway construction site in Boston.

Michigan

The state of Michigan has identified silica as a Toxic Air Contaminant and regulates emissions of both crystalline and amorphous forms of silica. The Michigan Department of Environmental Quality has identified health benchmark levels for amorphous silica; the agency had previously adopted health benchmark levels for crystalline silica, but those have been revoked. Currently, Michigan does not have health benchmark levels for crystalline silica. Michigan evaluates emissions sources of crystalline silica on a case-by-case basis. The state has not conducted any monitoring studies for silica in ambient air. WDNR obtained this information from telephone interviews with staff of the Michigan DEQ, Air Quality Division, the Chemical Process Unit and the Toxics Unit.

Regulatory information:

- Michigan regulates crystalline and amorphous forms of silica as Toxic Air Contaminants.
- The Michigan DEQ evaluates the health effects of exposure to air pollutants when reviewing applications for new air permits. The agency’s health effects evaluation compares the expected exposure concentration to a health benchmark value, called a screening level. If the exposure concentration is below the health benchmark, then silicosis—and, by extension—cancer would not be expected to occur.
- Michigan DEQ has adopted screening levels for amorphous silica:
  - amorphous fused silica (CAS 60676-86-0), 1 ug/m^3 averaged over 8 hrs
  - silica amorphous fume (CAS 69012-64-2), 20 ug/m^3 averaged over 8 hrs
  - silica amorphous (CAS 112945-52-5), 20 ug/m^3 averaged over 8 hrs

  Sources that have emissions within 10% of the emissions screening levels need permit conditions that require controlling emissions of amorphous silica.
- Michigan DEQ has not established a screening level for crystalline silica. The Air Quality Division has recently used California’s Reference Exposure Level of 3 ug/m^3 as the health benchmark for its permit review process.
- Michigan’s definition of Toxic Air Contaminants exempts specific sources of crystalline silica emissions from regulation. The exemptions include:
  - metallic and non-metallic mineral extraction and processing;
  - sand production, processing and drying;
  - asphalt production;
  - concrete production;
  - glass and fiberglass manufacturing;
  - foundries and foundry residual recovery activities; and
  - any process with crystalline silica emissions less than 10% of the total PM10 emissions.

  Processes that are not specifically exempted, or with crystalline silica emissions greater than 10% of the total PM10 emissions, are subject to the health based screening requirements.

Permitting requirements:

- Reporting is required for sources of crystalline silica emissions, but sources only report their total PM emissions.

- Emissions of crystalline silica are usually managed through general PM control measures.
- Some sources of amorphous silica emissions above threshold levels may be required to report their emissions.
- One recent instance of public concern over crystalline silica emissions involved a permit application from a portable concrete crushing operation located near a residential neighborhood, elementary school, and day care center. Modeled concentrations of silica were below the 3 ug/m^3 benchmark level but were in the range of 1-2 ug/m^3. Silica emissions were addressed in the permit through PM controls, which included requirements for spraying water, wetting storage piles, wheel washing on transport trucks, and other measures.

Industrial sources of silica emissions:
- Asphalt production
- Blast cleaning operations
- Chemical manufacturing
- Concrete operations
- Foundries
- Glass and fiberglass manufacturing
- Mining and mineral processing
- Road and highway construction
- Sand production and processing

Toxicity concerns:
- Chronic illness (e.g., silicosis)
- Carcinogenicity

Minnesota

The state of Minnesota does not specifically regulate silica emissions, though silica might be managed to some extent under controls for fine particulate matter emissions. Air permit holders are required to report particulate matter emissions but report total PM only. Minnesota Pollution Control Agency staff recently evaluated permit applications for two taconite mining operations and a steel mill. Modeled concentrations of crystalline silica were compared to the California REL of 3 ug/m^3. Minnesota PCA staff determined that the off-site impacts would not pose a significant risk and did not exceed a predicted concentration of 3 ug/m^3). This analysis was for information only as part of a risk assessment done for the environmental analysis of these projects. MPCA is also responding to permit requests for silica sand mines such as the one proposed in Red Wing, MN (Goodhue County). There is citizen concern about this and other sand mine proposals. The state does not conduct any monitoring for silica in ambient air. WDNR obtained this information from two telephone interviews with staff of the Minnesota Pollution Control Agency, Environmental Analysis and Outcomes Division, Air Assessment and Environmental Data Management Section.

Montana

The Montana Department of Environmental Quality, Air Monitoring Program attempted to analyze crystalline silica concentrations from particulate matter samples collected as part of the state's long-term air quality monitoring activities. WDNR obtained this information from an email response to the NACAA Monitoring Committee inquiry. The responder is a staff member at the MT DEQ Air Monitoring Program who is knowledgeable about the analytical experiments conducted by the agency.

Industrial sources of silica emissions:

- Vermiculite mining

Toxicity concerns:
- Asbestos exposure
- Occupational exposure
- Carcinogenicity

Monitoring studies:
- Montana DEQ attempted to analyze crystalline silica concentrations in particulate matter samples collected at Libby, the site of long-term environmental contamination resulting from vermiculite mining.
- The ultimate focus of the effort revolved around developing methods for analyzing asbestos fibers in PM2.5 samples. The MT DEQ Air Monitoring Program attempted to analyze samples for crystalline silica particles as a first step toward developing a similar methodology for asbestos fiber analysis.
- MT DEQ could not successfully quantify crystalline silica amounts using the methods it tried. Although MT DEQ's samples were collected on Teflon filters, up to 90% of the crystalline silica in the sample was lost during the process of filter preparation. The effort stalled at that point.

New Jersey

The state of New Jersey regulates crystalline silica as a toxic air pollutant, though it is not clear whether any existing air permits have conditions or control requirements specific to silica. Monitoring in the state has been limited to occupational settings and exposures. WDNR obtained this information from an email response to the NACAA Monitoring Committee inquiry, which was followed by three telephone interviews. We spoke with staff of both the Department of Environmental Protection, Air Quality Evaluation Section, who work on air permits; and a staff member at the Department of Health and Senior Services, who conducts occupational monitoring and outreach and works on silicosis.

Regulatory information:
- New Jersey regulates crystalline silica as a toxic air pollutant.
- NJ Department of Environmental Protection conducts a risk screening process when reviewing applications for new air permits. Emissions are compared to reference concentrations to evaluate potential health effects, and emissions above reference levels may lead to further risk assessment or denial of a permit.
- For crystalline silica, NJ DEP uses a long-term reference concentration of 3 $\mu g/m^3$, which is based on the standard used by the California Air Resources Board.

Permitting requirements:
- Reporting is not required.
- There may not be any existing air permits in the state with permit conditions or control measures specifically directed at emissions of crystalline silica.

Industrial sources of silica emissions:
- Highway construction
- Other construction
- Dental laboratories
- Monument builders
- Glass manufacturing
- Mining
- Sandblasting

Toxicity concerns:
- Chronic illness (e.g., silicosis)

Monitoring studies:
- NJ Department of Health and Senior Services developed a water suppression system for controlling occupational exposures to silica emissions. The agency conducted video exposure monitoring combined with real-time measurements of silica emissions to test its control method.

New York

The state of New York regulates crystalline silica as an air contaminant. Emissions are often controlled with general particular matter and dust suppression methods. Monitoring in the state has been limited mainly to the World Trade Center site. WDNR obtained this information from an email response to the NACAA Monitoring Committee inquiry, which was followed by telephone interviews with staff of the Department of Environmental Conservation, Bureau of Air Quality Surveillance and Bureau of Air Quality Analysis and Research.

Regulatory information:
- Crystalline silica is regulated as an air contaminant in New York.
- Crystalline silica has been listed as an air contaminant in the state since approximately 1995.
- For crystalline silica, NY Department of Environmental Conservation uses an Annual Guideline Concentration (a "long-term" concentration) for review of permit applications. The AGC for crystalline silica is 0.06 $\mu g/m^3$. This guideline applies to both stack emissions and outdoor operations. If silica emissions are above the guideline, permit holders might need to control them.

Permitting requirements:
- Controls—In rock crushing industry, silica emissions are usually regulated using particulate matter standards; control measures for dust and general particular matter are usually employed (e.g., wetting or filtering through baghouses). In glass manufacturing industry, specific requirements for controlling silica usually do not come up as an issue, perhaps because facilities adequately reduce emissions with their existing control measures.
- Reporting—requirements have changed over time. Before 1996, air permit holders were required to report individual, speciated hazardous air pollutants. Since 1996, permit holders are only required to report total particulate matter emissions (not individual PM components).

Industrial sources of silica emissions:
- Rock crushing
- Abrasives production
- Glass manufacturing

Toxicity concerns:
- Adverse health effects from chronic exposure

Monitoring studies:
- After the World Trade Center disaster, both NIOSH and US EPA collected air samples in areas adjacent to the debris pile and where rescue/cleanup personnel were working.
- This ambient air monitoring at the World Trade Center site included collecting data on crystalline silica emissions.
- Air samples were analyzed using NIOSH method 7500.

- Respirable crystalline silica was not detected in the NIOSH samples, collected between September 18 and October 4, 2001 (NIOSH 2002, Summary Report to the New York City Department of Health: NIOSH Air Sample Results for the World Trade Center Disaster Response accessed at http://www.cdc.gov/niosh/wtcsampres.html).
- The US EPA collected air samples weekly, for a period of almost six months, in areas near the World Trade Center site. Concentrations of the forms of crystalline silica analyzed—cristobalite, tridymite, and quartz—all remained below the detection level during the sampling period.
- Data from a demolition project at 130 Liberty St (World Trade Center) showed respirable silica concentrations remained below 1 $\mu g/m^3$ in most cases.
- Other monitoring which would include particle identification is performed only during investigations of complaints.

Ohio

The state of Ohio does not specifically regulate silica emissions, and there is no particular concern about this pollutant in the state at this time. Within the state, possible industrial sources of silica emissions might include cement operations, foundries, road construction, rock/gravel crushing operations, and sand blasting operations. Some silica emissions might be controlled through particulate matter controls, which can include filtering air through baghouses, misting with water, and wheel washing on transport vehicles. Air permit holders are required to report particulate matter emissions but report total PM only. WDNR obtained this information from a telephone interview with staff of the Ohio Environmental Protection Agency, Division of Air Pollution Control; we spoke with the supervisor of the Air Toxics Unit.

Oklahoma

The state of Oklahoma does not currently regulate silica emissions. However, Oklahoma regulated silica as an air pollutant in the past, beginning in about 1988. In 2005, the Oklahoma Department of Environmental Quality changed its approach to air toxics, and silica was dropped from the list of regulated pollutants at that time. Oklahoma is the site of one long-term monitoring study which measured crystalline silica in ambient air, conducted by the Quapaw Tribe in northeastern Oklahoma. However, silica was not addressed in the report of this monitoring study, which focused on results for other pollutants. WDNR obtained this information from an email response to the NACAA Monitoring Committee inquiry, followed by several telephone interviews with staff of the Oklahoma Department of Environmental Quality, Air Quality Division, Technical Resources & Projects Section; the Quapaw Tribe Environmental Office; and a former contractor who worked for the tribal air monitoring support center and was involved in the monitoring study (the latter person is now employed in a different state).

Regulatory information:

- From 1988 until 2005, Oklahoma regulated both crystalline and amorphous forms of silica as air pollutants.
- Both crystalline and amorphous forms of silica were in the state's Toxics Category A, which contained "substances of high toxicity" and suspected/confirmed carcinogens.
- Regulation of silica was a bit controversial at the time due to the compound also being present in 'background' ambient air.
- The state's approach to air pollutant regulation changed in 2005, and silica is no longer on the state's list of regulated air pollutants.

Industrial sources of silica emissions:

- Lead and zinc mining and milling, including tailings piles left from previous operations (i.e., the Tar Creek Superfund Site).

Toxicity concerns:

- Assessing risk of exposure and potential health effects for residents living adjacent to old mining area
- Environmental pollution

Monitoring studies:

- The Quapaw Tribe conducted a monitoring study of crystalline silica in ambient air at the Tar Creek Superfund Site (some background on the project can be found on the tribe's web site, at http://www.quapawtribe.com/site/view/TarCreekProject.pml; EPA's web page for the Superfund activities at this site is at http://www.epa.gov/region6/6sf/oklahoma/tar_creek/index.htm).
- Tar Creek is the site of historic lead and zinc mining operations where tailings piles remain over a 40 square mile area.
- Monitoring was conducted at four sites within the area during two 18-month periods over a span of four years.
- Approximately 575 ambient air samples were collected and analyzed using a modified NIOSH 7500 method. The analysis reported concentrations of three forms of crystalline silica—cristobalite, tridymite, and quartz—along with total dust in the samples.
- Most of the samples contained low concentrations of crystalline silica. Concentrations of quartz averaged 1.8 ug/m^3, although the maximum was 21 ug/m^3. Approximately 75% of the data points showed concentrations below 3.2 ug/m^3 (Luedecke, personal communication). Concentrations of cristobalite and tridymite were commonly below the detection limit.
- The data from this monitoring project are unpublished; the report from the study focused on other air pollutants (e.g., lead) and did not present any data or information about silica.

Oregon

The Oregon Department of Environmental Quality conducted some limited monitoring for crystalline silica emissions at the site of a former diatomaceous earth mine and processing operation. WDNR obtained this information from an email response to the NACAA Monitoring Committee inquiry, followed by telephone interviews with the DEQ staff member for Air Quality who conducted the monitoring project and the staff member at Oregon Health Authority who prepared the health consultation report.

Industrial sources of silica emissions:

- Diatomaceous earth mining and processing into cristobalite, a form of crystalline silica

Toxicity concerns:

- Risk of exposure and potential health effects for residents living nearby; the county planning commission had received an application to re-zone the mine site from industrial to residential use

Monitoring studies:

- Oregon DEQ conducted limited, short term air monitoring at a former diatomaceous earth mine.
- The monitoring was conducted as a result of complaints from neighbors who have built houses near the mine site.
- A small number of air samples was collected over one week, and they were processed by a commercial laboratory using NIOSH method 7500.
- A single grab sample of ore was also analyzed for silica content.
- Silica content of the air samples was below the detection limit for all samples collected. The ore sample did contain silica (0.3% quartz and 0.2% cristobalite; Messina, personal communication).
- Data collected during the monitoring were used by the Oregon Health Authority for its Environmental Health Assessment of an application to re-zone the mine property for residential use (web site at

http://public.health.oregon.gov/HealthyEnvironments/EnvironmentalExposures/HazardousSites/EnvironmentalHealthAssessment/Pages/lbmsite.aspx).

- The OHA recommended that the developer be required to conduct additional monitoring as a condition of re-zoning the site to residential use.
- To date, the developer has not pursued any residential development of the property and has not conducted any monitoring.

Texas

The state of Texas regulates emissions of the crystalline and amorphous forms of silica. Texas Commission on Environmental Quality (TCEQ) has more extensive experience with regulation of silica emissions than any other air agency we surveyed. Monitoring, however, has been much more limited. WDNR obtained this information from numerous telephone interviews. We spoke with TCEQ staff in the Toxicology Division, the Technical Analysis Division, and several divisions of the Office of Permitting and Registration.

Regulatory information:

- Texas has a long history of concern about silica emissions from certain industries in the state. The issue comes up regularly during permitting processes, and TCEQ began regulatory activities in 1971.
- Texas uses a peer-reviewed, toxicology-based methodology for developing its health benchmark levels and emissions regulations. The TCEQ Toxicology Division conducts a review of existing information and publishes Reference Exposures Values (ReVs), which are equivalent to health benchmark levels; and Effects Screening Levels (ESLs), for permitting purposes. Their health benchmark levels represent short-term and long-term estimates for a safe level of exposure to air pollutants. ESLs are ambient air concentration guidelines used to gauge the potential of constituents associated with modification of an existing facility or construction of a new facility to cause adverse health effects. They are screening tools used for review of permit applications; exceedence of the ESLs triggers a more in-depth health effects review. "Short-term" ESLs generally have a one-hour averaging period, and "long-term" ESLs have annual averaging periods (bdlaw.com/news-503.html). The rationale and supporting data behind ReVs and ESLs are published in Development Support Documents.
- The threshold concentrations in the state's regulations undergo periodic review, and the most recent review/revision of the ReVs and ESLs for crystalline silica occurred in October 2009. The guidelines for amorphous silica were revised in July 2011 (TCEQ 2011a). (Updated or revised ESLs affect new permit applications but are not retroactive.)
- *Crystalline Silica*
  - The current health benchmark levels - ReVs (guidelines) for crystalline silica in Texas are:
    - short-term (30 min), 47.0 µg/m^3 measured as PM10
    - long-term (annual), 2.0 µg/m^3 measured as PM4
  - The current ESL guidelines for crystalline silica in Texas are:
    - short-term (30 min), 14.0 µg/m^3 measured as PM10
    - long-term (annual), 0.27 µg/m^3 measured as PM4 – note: 0.27 ug/m3 represents a lifetime additional excess cancer risk of one-in-one hundred thousand.

- *Amorphous Silica*
  - The current health benchmark levels - ReVs (guidelines) for amorphous silica in Texas are:
    - short-term (30 min), 91.0 µg/m^3 measured as PM10
    - for non-cancer health effects - long-term (annual), 6.6 µg/m^3 measured as PM10

  - The current ESL guidelines for amorphous silica in Texas are:

- short-term (30 min), 27.0 µg/m^3 measured as PM10
- long-term (annual), 2.0 µg/m^3 measured as PM4

- Using the state ESLs, the TCEQ Office of Permitting and Registration conducts a health effects review of air permit applications. Crystalline silica could typically be reviewed as part of total particulate matter emissions, and the portion of PM that might be crystalline silica is usually estimated. However, the agency will direct additional effort toward controlling silica emissions in the face of public concern. In cases with emissions above the guidelines, the agency will perform modeling to estimate silica concentrations relative to health benchmarks.
- In cases where emissions would be expected to exceed the ESLs, permits may contain requirements for measures to control or limit the amount of silica emitted. The specific control requirements vary depending on the type of industry or process involved and can include, for example, limits on emission rate or annual total emissions, restrictions on particle sizes or silica content of materials used, requirements for enclosing or shrouding operations, and controls to limit particulate matter emissions.

Permitting requirements:

- Controls— Control measures required in air permits can vary depending on the type of industry or process involved, and some examples are given here. Silica emissions will be often addressed through controls for particulate matter.
  - Such control measures can include wetting stock piles and conveyor belts, or applying chemical dust surfactants or suppressants (e.g., for road construction operations), and filtering through baghouses.
  - In shipping and tanks refinishing operations, controls can include shrouding, filtering of air, and maintaining negative air pressure within the enclosure.
  - Abrasive blasting operations may be required to meet limits on emissions, either rate of emissions per hour or total annual emissions, and controls can also include requirements for using alternate media (e.g., substituting steel shot or other materials with silica concentrations less than 1% for silica sand).
  - Road construction operations may also be required to use materials that meet specified particle size distributions, to control the percentage of particles that could contain respirable silica.
  - For coatings operations, the silica content of coatings may be limited, or operations can have hour restrictions on their painting activities.
  - Fractured sand particles are much larger than the respirable size, but the operations typically dispose of fine particles by washing them out with water.
  - Emissions from glass manufacturing operations are typically controlled adequately by methods used for reducing other emissions at the facilities or by controlling the silica content of their raw materials.
  - Semiconductor manufacturing operations are usually well controlled through scrubber and oxidizer systems, and the facilities separate their waste streams and treat each separately.
- Reporting—Reporting of emissions is required. After 1996, facilities are required to report total PM emissions but do not have to speciate PM into the component compounds. Abrasive blasting operations may be required to speciate their PM emissions; reporting is not required, but facilities must keep those records on site.

Industrial sources of silica emissions:

- Ship and barge repair and refinishing
- Oil/gas field pipe and outdoor tank repair and refinishing
- Abrasive blasting
- Coating operations
- Concrete batch plants
- Cement plants
- Quarries
- Rock crushing operations
- Asphalt operations

- Foundries
- Specialty sand production (i.e., fractured sand for oil industry)
- Glass manufacturing
- Semiconductor industry

Toxicity concerns:

- Chronic illness

Monitoring studies:

- TCEQ conducts routine monitoring for particulate matter and may occasionally speciate some PM samples taken during those studies. Silica is detected in the speciated analyses.
- During permitting, the agency has occasionally examined speciated chemical analyses of emissions; however, other pollutants like lead or VOCs are often the primary focus of attention.

Vermont

The Vermont Department of Environmental Conservation has identified silica as a Hazardous Air Contaminant, and the state regulates three forms of silica (crystalline, amorphous, and fused). VT DEC has hazardous ambient air standards for these forms of silica in its regulations. Emissions are often controlled with general particular matter and dust suppression methods. The state has conducted long-term monitoring for PM2.5, but the samples had not yet been analyzed at the time of this survey. WDNR obtained this information from an email response to the NACAA Monitoring Committee inquiry, which was followed by two telephone interviews. We spoke with staff of the Air Pollution Control Division, both the Planning Section and the Permitting Section.

Regulatory information:

- Three forms of silica—crystalline, amorphous, and fused—are regulated as Hazardous Air Contaminants in Vermont.
- Silica has been regulated in the state since the late 1980s. (The state list actually pre-dates the federal HAPs list.)
- Vermont's air pollution control regulations specify both short-term and long-term standards for silica. The thresholds in the state's regulations are shown in the following table:

Vermont Air Pollution Control Standards for Silica		
Compound	Hazardous Ambient Air Standard (annual) (µg/m^3)	Action Level (short-term) (lbs/8 hr)
amorphous silica (CAS 61790-53-2)	24.0	2.0
crystalline silica (CAS 14808-60-7)	0.12	0.01
fused silica (CAS 60676-86-0)	0.02	0.0017

- Emissions above the Action Level make a facility subject to the rule, and those facilities are required to meet the Hazardous Most Stringent Emission Rule controls. (However, in some areas, background concentrations in ambient air are above the Action Level.)
- Controlling silica emissions is often part of the justification for requiring general dust suppression.

Permitting requirements:

- The regulation does not target specific particle sizes, but permit conditions may target certain particle sizes.

- General requirements—Requirements apply to stacks only, not road construction (and public roadways are exempt). Certain very small facilities may be exempt from the requirements.
- Sources emitting more than 5 tons per year need to report emissions. (However, they might report total particular matter emissions without speciating the silica fraction.)
- Sources emitting 10 tons or more per year are required to have permits.
- Controls—In some industries, permit conditions usually require controlling general PM emissions. For rock crushing activities, permits may require dust suppression, which can include wetting at portable facilities or filtering through baghouses at stationary facilities. For coating operations, requirements may include High Volume Low Pressure (HVLP) spray equipment, filtering of overspray, and limits on silica content of coatings used. For fugitive emissions and road construction activities, the agency has some flexibility for control requirements; in road construction, for instance, wet suppression of dust can be required.
- Reporting—As above; facilities might report total PM emissions rather than separating the silica fraction.

Industrial sources of silica emissions:
- Rock crushing
- Road construction
- Coating operations (wood furniture painting is a prominent industry source in the state)

Toxicity concerns:
- Chronic systemic toxicity due to long-term exposure

Monitoring studies:
- Some years ago, VT DEC Air Pollution Control Division conducted a multi-year monitoring project to collect PM2.5 samples. The samples from that study are just being analyzed now, and the resulting data are expected to include information about silica concentrations. Data are not available yet, however.

Appendix C: Summary of Comments Received on Silica Report: Draft for Public Comment

The Draft public comment version of the Silica Report for was issued on January 4, 2011 along with a request for information. The text from the WDNR webpage from the press release is included below. Public comments were due by February 18, 2011.

At total of 47 total comments were received by the end of comment period (February 18, 2011). The number of comments by commenter category were: citizens (29), health care professionals (3), Industry/trade associations (6), Environmental Groups (2), and Government (4). Of the comments received, 31 were by email, 9 by on-line survey, and 7 by letter.

The vast majority of comments related to recommendations for future policy directions. Since the subject of this report is meant to address what is known about silica emissions, sources, monitoring, exposures and health effects and not a policy recommendations document, there are no responses to these policy questions in this document. In general, citizen, public health and environmental groups, as well as the city of Chippewa Falls asked the Department to take action to list silica as a hazardous air pollutant, to establish interim and final acceptable ambient air concentration for crystalline silica, monitor and enforce standards for sources of silica emissions. In general, businesses and trade associations suggested, for various reasons that no further Department action should be taken to address crystalline silica. More specific details are given below.

Where commenters corrected errors and supplied additional technical data for the report that was applicable to the issues at hand (e.g. if comments addressed the sources and amounts of emissions and alternative strategies for minimizing public health risks), those comments were included in the report.

The following is a bullet point summary of comments received by category of commenter:

Citizens (29 Commenters) – Common Issues Identified

Health

- How silica exposure might affect people with pre-existing diseases, respiratory (e.g., asthma, bronchitis, emphysema, COPD, cancer)
- These sources can be very close to homes, schools, day cares, nurseries, hospitals and healthcare facilities as well as nursing homes
- Mines may expand increasing exposures to residents
- Is there a safe distance or “set back” that can be established?
- Make sure health is protected and prudent precautionary levels are established to protect health
- Evaluate risks from “freshly fractured” silica
- People should be informed about the health effects of crystalline silica
- Concern about exposures resulting from transport of silica sand on roads and via rail

Air quality

- More mines and mining related projects are being proposed and being operated
- Please ensure that air quality is not compromised

Environment

- Concern about effect on animals and ecosystems

Regulation

- Silica needs to be regulated
- Standards need to be set and enforced quickly
- At least one commenter suggested also including amorphous forms of silica (in part because Texas had recently proposed a health benchmark for amorphous silica)
- Concern about not enough regulation of non-metallic mines – “Non-metallic mining should be strictly regulated.”
- Oversight is needed
- Concern about regulation of storage piles, use of street sweepers and control of emissions from sand storage, loading, hauling and transport via roadways, rails, etc. For example, will they be required to have dust suppression on storage piles even during the winter and will coverings be required on trucks and rail cars?
- Example Comment (several others of similar anecdotal information): Citizens of Maiden Rock find dust all over their village on freshly washed cars, decks, home etc.
- Are controls that might be proposed and conditions in permits adequate?
- More mines are coming. Please act now

Monitoring

- Monitoring is needed – multiple monitors needed in upwind and downwind directions– at the mine, along travel routes (and for Chippewa Falls, at the processing plant)

Timeliness

- Please do not wait to respond to our concerns
- Take action now (e.g., “The WDNR must complete the studies and demonstrate a high level of concern regarding the dangers to humans and wildlife.”)

Industry and Trade Associations (5 Commenters)

Regulation

- Wisconsin Manufacturers and Commerce (WMC) - Statement that WDNR does not have regulatory authority to regulate Silica as a Hazardous Air Pollutant
- American Chemistry Council – There is no basis for determining that the public is at risk of developing disease from ambient silica exposures – “there is no evidence indicating that concentrations of crystalline silica in the ambient air (in Wisconsin or elsewhere) have caused silicosis or any other silica-related disease in the general population”
- EOG resources (Canadian Sands and Proppants) – Chippewa Falls/Hdqtrs. Dallas/Fort Worth Texas
    - Any regulatory action will need to address source attribution and background concentrations
    - Ambient air exposures, in contrast to occupational exposures, have not been linked to adverse health impacts
    - Use of risk assessment to extrapolate dose and response is problematic for ambient air risk determinations
    - EPA risk assessment methodologies are overly conservative
    - Whether there is an assumed threshold for risks represents a large uncertainty in any estimation of setting an acceptable air concentration for crystalline silica
    - WNDR needs to conduct a regulatory impact assessment using acceptable methodologies such as found in OMB and EPA guidance to demonstrate cost-effectiveness as part of evaluating alternative strategies to minimize risks

- Badger Mining – “there is no evidence of non-occupational exposures resulting in an adverse health effect”.

Controls and Ambient Concentrations

- Equipment Manufacturers Association – provided a power point slide show from NIOSH indicating there is work being done to minimize risks to workers in construction trades to make equipment produce less silica dust

Environmental Groups (2 commenters)

- Clean Wisconsin – Silica meets requirements for regulation as a carcinogen and should be listed and regulated as a hazardous air pollutant. In addition, a statewide silica monitoring system needs to be established
- Midwest Environmental Advocates – Silica study should be completed promptly and should consider instituting silica monitoring and regulatory standards for crystalline silica

Health Professionals (2 Commenters)

- Physicians and Health Care Providers of the Chippewa Valley (80 + individuals as signatories to the letter) – Department is requested to: 1.) List crystalline silica as Hazardous Air Pollutant; 2.) Establish and adhere to an enforceable standard for respirable crystalline silica identical to the level established by Collins in the California (California OEHHA) study, and; 3.) Monitor the air at multiple sites around processing plants, mines, and transport routes in order to include fugitive dust.
- Crispin Pierce, PhD.- recommendations for action include: 1.) listing crystalline silica as a hazardous air pollutant under NR 445, and; 2.) establishing an exposure standard (e.g., New York value of 0.06 micrograms per cubic meter, Texas value of 0.27 micrograms per cubic meter, or California value of 3 micrograms per cubic meter).

Government Agencies (4 Commenters)

- City of Chippewa Falls – Department should take action to move toward future regulation of crystalline silica and also consider addressing further study of amorphous silica. More specifically: 1. List crystalline silica as a known carcinogen in NR 445; 2. Develop an interim and final standard; 3. require monitoring at multiple locations surrounding current and future industrial sources that may emit crystalline silica
- Toxicology Division, Texas Commission for Environmental Quality – Silica health values are guidance values and not standards
- US EPA Region 5 – expressed support for the study, stating they would like to follow our progress
- WDNR staff person – stated that road grinding/pavement grooving machines emit large clouds of particles – suggested including that in source categories

Comments regarding the content of the report and responses to those comments:

- Badger mining – OSHA and MSHA govern occupational exposures that can be either indoor or outdoor. The report incorrectly states that OSHA only evaluates indoor exposures.
- Response: The report has clarified this point to state that WDNR only regulates non-occupational exposures to ambient air.
- Texas Commission on Environmental Quality – The report incorrectly states that TCEQ has established standards for crystalline silica, but these are actually guideline values, not regulatory values.
- Response: The report has been changed to reflect that the TCEQ health benchmarks are guidelines and are not standards.
- We Energies - Include PM2.5 speciation monitoring results for silicon.
- Response: The commenter is referring to data from 3 monitors in Wisconsin that analyze fine particulates where further chemical analysis is done to identify the compounds that make up the particulate matter. The data is for the element silicon (the silicon could come from any form of silicon containing material) and there is no crystalline silica measurement possible using this method. The particles are also smaller than the 4 micron particles (PM4), so the data misses some of the particles of concern for health. In spite of these limitations, the data from these 3 monitors has been added to the report. The data suggest that even if all of the silicon was in the form of crystalline silica, the exposures would be well below a value of 1 ug/m3.
- Citizen comment: Every emission source from every process at sand mines should be identified in the report and evaluation of how far the silica travels from the source should be included in the report.
- Response: Not enough is known about each source's emissions and the particle sizes to include this much detail in this report and sand mining is just one source category. That level of detail is not possible to achieve in a report such as this. In addition, since particle sizes are not known and emission estimates are uncertain it is not possible to quantify how far silica travels from a source.
- Health professional comment: Several additional studies should be evaluated for inclusion in the report that detail the amount of crystalline silica in particulate matter and in ambient air.
- Response: Those studies were included, as appropriate. No change in the finding of the study resulted from the consideration of data from these additional studies.
- Health professional and citizen comment: Increased PM emissions from silica sources can increase stress on the respiratory and cardiovascular system, much like has been documented with fine particulate health effects in general. The resultant increase in PM concentrations will cause increased illness (e.g., decreased lung function, aggravate asthma, increase heart attack rates and cause irregular heartbeats).
- Response: In general, the literature supports the concept that increased particulate in the air will increase symptoms such as those mentioned by the commenter, but the exact role of crystalline silica relative to other particulate matter that comes from other sources (e.g., vehicle emissions and other combustion related particles) is unknown.

Press Release January 4, 2011
– web copy –

Comments sought on draft study of health effects of silica in outdoor air

Weekly News Article Published: January 4, 2011 by the Central Office

MADISON -- The public has an opportunity to review and comment on a draft study by state air quality officials on the possible health effects of exposure to silica in the outdoor air.

Silica is a compound made up of silicon and oxygen atoms and can be both naturally occurring and synthetic. It is present in the environment in both crystalline and amorphous forms; only the crystalline form is of concern as an air pollutant. Ambient sources of silica include mining and rock crushing, construction, foundries, glass manufacturing, abrasive blasting, or other uses of sand and quartz.

“While health officials generally do not consider ambient exposures to silica, a known carcinogen, to pose a health risk to the general public, data from some states shows emissions from some industrial facilities could result in levels of concern for people living near the sources,” said Jeff Meyers, an environmental toxicologist with the Department of Natural Resources Bureau of Air Management.

The study focuses on exposure to silica in the outdoor air. DNR has the responsibility and authority only to manage outdoor, or ambient, air quality and not indoor air quality.

The draft silica study [pdf; 2.3 MB] is available for review on the air management pages of the DNR website.

After reviewing the study, individuals can go to an online questionnaire to submit comments on the draft. Supporting data, studies or other relevant information can be submitted via e-mail or post to: Jeff Myers, Wisconsin DNR – AM/7, PO Box 7921, Madison, WI 53707-7921 or send them by e-mail to [jeff.myers@wisconsin.gov].

Submissions will be accepted until 5 p.m. on Friday, Feb. 18.

FOR MORE INFORMATION CONTACT: John Melby, 608-264-8884

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