CRYSTALLINE SILICA

AMBIENT AIR MONITORING AND EVALUATION OF COMMUNITY HEALTH IMPACTS NEAR AGGREGATE PRODUCTION OPERATIONS

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TOXICOLOGY, RISK ASSESSMENT, AND RESEARCH DIVISION
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ACRONYMS AND ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AMCV	air monitoring comparison value
APO	aggregate production operation
ATSDR	Agency for Toxic Substances and Disease Registry
BACT	Best Available Control Technologies
CAA	Clean Air Act
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
d	day(s)
DNR	Department of Natural Resources
DSD	Development support document
EPA	Environmental Protection Agency
ESL	effects screening level
ft	feet
h or hr	hour(s)
HAP	hazardous air pollutant
IDEM	Indiana Department of Environmental Management
IPCS	International Programme on Chemical Safety
LOD	limit of detection
LOQ	limit of quantification
m	meter(s)
MDE	Maryland Department of the Environment
min	minute(s)
MPCA	Minnesota Pollution Control Agency
$\mu g/m^3$	micrograms per cubic meter
µm	micron or micrometer
N/A	not applicable
NAAQS	National Ambient Air Quality Standards
NELAP	National Environmental Laboratory Accreditation Program
NIOSH	National Institute for Occupational Safety and Health
NSR	New Source Review
OSHA	Occupational Safety and Health Administration
PM	particulate matter
$PM_{2.5}$	Particulate matter with an aerodynamic diameter less than or equal to 2.5 µm. Also referred to as fine particles.
$PM_{2.5-15}$	Particulate matter with an aerodynamic diameter greater than 2.5 µm and less than 15 µm
PM_4	Particulate matter with an aerodynamic diameter less than or equal to 4 µm. Refers to respirable particles that are inhaled past the upper airways and reach into the human lung.
PM_{10}	Particulate matter with an aerodynamic diameter less than or equal to 10 µm. Refers to particles that penetrate past the larynx into the thoracic region.
ReV	Reference Value
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TDM	total dichotomous mass
TDSHS	Texas Department of State Health Services
UCL-95	95% upper confidence limit of the arithmetic mean
URF	unit risk factor

SUMMARY

Aggregate production operations (APOs) are defined in 30 Texas Administrative Code, Chapter 342, as sites where aggregates are removed or extracted from the earth, including entire areas of extraction, stripped areas, haulage ramps, and the land on which the plant processing the raw materials is located, exclusive of any land owned or leased by the responsible party not being currently used in the production of aggregates. Aggregates are defined as any commonly recognized construction material originating from an APO from which an operator extracts dimension stone, crushed and broken limestone, crushed and broken granite, crushed and broken stone not elsewhere classified, construction sand and gravel, industrial sand, dirt, soil, or caliche (i.e., mineral deposits containing calcium carbonate). Aggregates do not include clay or shale mined for use in the manufacturing of structural clay products.

Aggregates may contain silica, which occurs in two forms: amorphous and crystalline. Silica—present in soil, sand, and rock formations—is the most abundant mineral in the earth's crust (ATSDR 2019). Crystalline silica is significantly more hazardous than amorphous silica and is recognized as an occupational inhalation hazard. In the United States, approximately 2.3 million workers in 676,000 workplaces are exposed to crystalline silica; this includes approximately 2 million workers in the construction industry (OSHA 2016). Workers exposed daily for several years up to a lifetime to high workplace levels of fine particles of crystalline silica may develop silicosis: an irreversible, progressive, and fatal rare lung disease.

The effects of inhaled crystalline silica are strictly associated with occupational exposure to particles of respirable size—that is, small enough to be inhaled and reach into the lungs (i.e., PM_4, particulate matter with an aerodynamic diameter less than or equal to 4 micrometers (μm), which can be seen using a light microscope). The size of the particles that cause silicosis is at least 100 times smaller than ordinary sand found on beaches and playgrounds. Exposure in the workplace is regulated by the Occupational Safety and Health Administration (OSHA).

Despite the vast number of laborers working with silica-containing materials, targeted efforts in workplaces have largely been successful in minimizing potential exposure of workers to respirable crystalline silica and preventing silicosis. The most recent prevalence data for silicosis in Texas is from 2016; in that year, the annual age-adjusted hospitalization rate for silicosis was 4 per one million residents. And, from 1999 to 2018, the total number of silicosis-associated deaths in Texas was 157, with an age-adjusted death rate of 0.4 per one million residents (Bell and Mazurek 2020).

It is important to note that the risk from community exposure to crystalline silica differs from the risk associated with occupational exposure. Airborne silica, both in amorphous and crystalline forms, is a ubiquitous mineral that is not unique to areas near APOs, construction sites, and other silica-generating activities, and is not unique to Texas. Moreover, not all airborne ambient crystalline silica is small enough to be inhaled and reach deep into the lungs. Silica in ambient air is not specifically regulated by the United States Environmental Protection Agency (EPA). Federal standards, known as the National Ambient Air Quality Standards (NAAQS), for particulate matter (PM), a constituent that may include silica, are promulgated for fine particles with an aerodynamic diameter less than or equal to 2.5 μm ($PM_{2.5}$) and for respirable particles with an aerodynamic diameter less than or equal to 10 μm (PM_{10}). APOs require an air permit prior to start of operation and must meet federal standards for $PM_{2.5}$ and PM_{10}.

The Texas Commission on Environmental Quality (TCEQ) has developed health-based air monitoring comparison values (AMCVs) for crystalline silica. These AMCVs are not standards; they are guidelines that are protective of human health and welfare. Health-based AMCVs are safe levels at which exposure is unlikely to result in adverse health effects.

In October 2019, TCEQ began ambient air $PM_{2.5}$ monitoring at sites that are located within one mile of APOs in central Texas. There are currently five monitoring sites located predominantly downwind of APOs. The available data show that the concentrations of $PM_{2.5}$ at the monitoring sites near APOs currently follow the general regional trend for $PM_{2.5}$. The data also indicate that APOs do not appear to have an impact on measured $PM_{2.5}$ concentrations.

Although crystalline silica monitoring is not required under U.S. regulations, monitoring has been periodically conducted in urban areas, including Dallas and El Paso, and near APOs. In ambient air of 22 U.S. cities, annual average $PM_{2.5}$ crystalline silica concentrations ranged from 0 to 1.9 $\mu g/m^3$ (Davis et al. 1984), while the estimated annual average PM_{10} crystalline silica concentrations of 17 U.S. cities ranged from 0.3 to 5.0 $\mu g/m^3$ (USEPA 1996). The range of respirable crystalline silica (PM_4) concentrations measured near APOs ranged from 0 (many samples were below the limit of detection) to 2.8 $\mu g/m^3$ (Richards et al. 2009, MPCA May 2015, MPCA Dec. 2015, MPCA 2018, Richards and Brozell 2015, Peters et al. 2017).

The results of these monitoring studies indicate that the overall contribution of APOs to ambient air concentrations of particulate matter and crystalline silica is minimal or negligible. When compared to TCEQ's AMCVs for crystalline silica, the concentrations of crystalline silica near APOs are generally not likely to cause chronic adverse health effects and are not associated with silicosis (ATSDR 2019).

BACKGROUND

Citizens are concerned about the impact of aggregate production operations (APOs) in their communities. This includes the potential for increased emissions of particulate matter, which may contain crystalline silica, near these facilities. This document provides the definition of an APO, according to the Texas Administrative Code, and briefly describes what is involved in the granting of air permits for these facilities. APOs must meet the federal requirement for $PM_{2.5}$ and PM_{10}, which are regulated under the National Ambient Air Quality Standards (NAAQS) (40 Code of Federal Regulations, Part 50 [40 CFR 50]). Silica, in both amorphous and crystalline forms, is the most abundant mineral in the earth's crust (ATSDR 2019). APOs are a potential source of crystalline silica.

Although there is no federal requirement for the Texas Commission on Environmental Quality (TCEQ) to measure ambient levels of crystalline silica, TCEQ has reviewed the available information, including peer-reviewed published literature, on the adverse health effects of airborne crystalline silica, and developed health-protective air monitoring comparison values (AMCVs) and effects screening levels (ESLs). AMCV is a collective term for all chemical-specific short- and long-term air concentrations that are used to evaluate air monitoring data. ESLs are used in the evaluation of air permit applications as well as proposed rules and regulations (e.g., Permits by Rule). AMCVs and ESLs are not standards, but rather they are guidelines and are safe levels at which exposure is unlikely to result in adverse health effects.

Crystalline silica is a known occupational health hazard in workers exposed for several years, up to a lifetime, to high workplace concentrations of respirable crystalline silica particles (OSHA 2016). Respirable particles are approximately 100 times smaller than ordinary sand found in playgrounds and on beaches. Respirable crystalline silica is significantly more hazardous than amorphous silica (ATSDR 2019, OSHA 2016). Occupational exposure to respirable crystalline silica may result in silicosis, a rare and incurable, but preventable, lung disease (ATSDR 2019, Leung et al. 2012).

TCEQ has reviewed the existing guidelines and regulations for ambient crystalline silica in other states and has summarized the available air monitoring data of crystalline silica in urban areas and in vicinities near APOs throughout the United States. Currently, there are no air monitoring data for crystalline silica near APOs in Texas. However, based on data collected throughout the United States, the contribution of crystalline silica from these facilities to ambient air levels of particulate matter and respirable crystalline silica is negligible or minimal. Moreover, the levels generally are below the health-based AMCVs for crystalline silica developed by TCEQ. In summary, ambient air concentrations of crystalline silica near APOs are generally not likely to cause chronic adverse health effects and are not sufficiently high to cause silicosis (ATSDR 2019).

AGGREGATE PRODUCTION OPERATIONS

APOs are defined in 30 Texas Administrative Code, Chapter 342 (30 TAC 342), as sites from which aggregates are being or have been removed or extracted from the earth, including entire areas of extraction, stripped areas, haulage ramps, and the land on which the plant processing the raw materials is located, exclusive of any land owned or leased by the responsible party not being currently used in the production of aggregates. Aggregates are defined as any commonly recognized construction material originating from an APO from which an operator extracts dimension stone, crushed and broken limestone, crushed and broken granite, crushed and broken stone not elsewhere classified, construction sand and gravel, industrial sand, dirt, soil, or caliche (i.e., mineral deposits containing calcium carbonate) (30 TAC 342.1). Aggregates do not include clay or shale mined for use in the manufacturing of structural clay products.

Crystalline silica, one of the most abundant minerals in the earth's crust, is ubiquitous in the environment (ATSDR 2019, Leung et al. 2012). APOs, which can be found in most states, are necessary for the construction of homes, buildings, and infrastructure. Texas has approximately 1,000 registered APOs. Facilities such as rock crushers may be located at APOs. A rock crusher breaks larger rocks down into cobblestones, gravel, or other smaller pieces. Those smaller pieces are sorted by size so that they can be used for pavement, construction, etc. Aggregates from these operations may contain crystalline silica.

There are two ways rock crushers may be authorized to operate in Texas: via a standard permit or via a New Source Review (NSR) permit. Rock crushing plants, concrete batch plants, and hot-mix asphalt plants that are authorized under standard permits have limitations in production, hours of operation on site, and established setback distances (Table 1). These limitations are listed as requirements in the applicable standard permits (Texas Health and Safety Code, Section 382.05195, Standard Permit [THSC 382.05195]).

Facilities at APOs that do not meet the requirements of a standard permit are authorized under a case-by-case NSR permit. Equipment authorized under an NSR permit is limited to certain estimated emissions that are determined based on throughput and United States Environmental Protection Agency (EPA) estimated emission factors. Authorized equipment must also meet current Best Available Control Technologies (BACT) and best management practices,

Table 1. Operation Differences Between Permanent and Temporary Standard Permits for Rock and Concrete Crushers

Operations	Permanent Standard Permit	Temporary Standard Permit: Tier I	Temporary Standard Permit: Tier II
Operation Limits	≤ 2,640 hr in any 12-month period	45 days or 360 operating hr	180 days or 1,080 operating hr
Throughput Limits	≤ 200 tons/hr	≤ 125 tons/hr	≤ 250 tons/hr
Footprint of Plant: distance to property line	≥ 200 ft	≥ 200 ft	≥ 300 ft
Crusher Location: distance from any residence, school, or place of worship	≥ 440 yards	≥ 440 yards (concrete crushers)	≥ 440 yards (concrete crushers)
Facility Location	≥ 550 ft from any other rock crusher, concrete crusher, concrete batch plant, or hot-mix asphalt plant	Crushing facilities are not located or operated on the same site as any concrete batch plant or asphalt plant	≥ 550 ft from any concrete batch plant or hot-mix asphalt plant; may not locate or operate on the same site as any other crusher

Note: For general information, please refer to www.tceq.texas.gov/permitting/air/guidance/newsourcereview/rocks/nsr_fac_rock.html or www.tceq.texas.gov/assistance/industry/aggregate-production.

For permanent standard permits, refer to www.tceq.texas.gov/permitting/air/newsourcereview/mechanical/permcrush.html.

For temporary standard permits, Tier I and Tier II, refer to www.tceq.texas.gov/permitting/air/newsourcereview/mechanical/tempcrush.html.

in accordance with TCEQ requirements (www.tceq.texas.gov/permitting/air/guidance/newsourcereview/rocks/nsr_fac_rock.html). A BACT review provides the basis for the minimum set of controls an applicant is required to employ, and staff must confirm that the emissions from the facility will comply with the rules of TCEQ, which may include a toxicological evaluation of the potential for off-property health impacts of emissions from the proposed activity.

The technical requirements established in the rock and concrete crushing standard permit ensure that facilities operating under the standard permit achieve the emission standards determined to be protective of human health and the environment (THSC 382.05195). During the protectiveness review conducted during the development of the standard permit, TCEQ examined the potential for emissions of particulate matter from rock crushing facilities and determined that facilities operating under the standard permit conditions would meet the NAAQS for PM_{10} and $PM_{2.5}$.

Regarding cumulative emissions and the operation of rock crushers in a certain area, the standard permit establishes a separation distance of 550 feet, based on the impacts analysis, between any crushing facility authorized under the standard permit and either an additional operating crushing facility, concrete batch plant, or hot-mix asphalt plant to help ensure that cumulative emissions do not result in adverse off-property impacts. If this distance is not met, the new crushing facility authorized under the standard permit cannot operate at the same time as the additional crushing facility, concrete batch plant, or hot-mix asphalt plant. Therefore, if the plants are operated in accordance with the standard permit, there should be no adverse impact on air quality as a result of multiple plants' operations.

The Texas Clean Air Act (THSC 382.065) requires that all concrete crushing facilities in Texas be located at least 440 yards from residences, places of worship, or schools. All air permit authorizations must show that they are protective of human health and the environment at the property line. Both rock and concrete crushers authorized by the Temporary Rock and Concrete Crushers Standard Permit or the Permanent Rock and Concrete Crushers Standard Permit must meet additional distance requirements to the property line (at a minimum, 200 ft). Rock and concrete crushers authorized by an individual NSR permit must undergo a site-specific protectiveness review, which includes air-dispersion modeling of proposed emissions, to determine the location of the crusher from the property line.

CRYSTALLINE SILICA

Silica (silicon dioxide, SiO_2) is the most abundant mineral in the environment, with over 95% of the earth's crust made of minerals containing silica (ATSDR 2019, Leung et al. 2012). Silica exists in two forms: crystalline and amorphous (ATSDR 2019). Airborne silica, both in amorphous and crystalline forms, is ubiquitous in the environment, and may be found in airborne particles from various sources such as paved and unpaved roads, wind-blown soil, and agricultural activities, as well as industrial sources such as construction, foundries, glass manufacturing, abrasive blasting or any industrial or commercial use of sand and quartz, and mining and rock crushing operations.

Crystalline silica occurs naturally in four polymorphs: (1) quartz, the most common, which is in granite, shale, and beach sand, and in trace amounts in soil, (2) cristobalite, (3) tridymite, and (4) tripoli (ATSDR 2019, Leung et al. 2012). Crystalline silica is significantly more hazardous than amorphous silica and is recognized as an important occupational inhalation hazard (ATSDR 2019, OSHA 2016). Workers exposed daily for several years up to a lifetime to high occupational levels of fine respirable particles of crystalline silica may develop silicosis, an irreversible, progressive and fatal, but preventable, lung disease (ATSDR 2019).

The effects of inhaled crystalline silica are strictly associated with occupational exposure to particles that are of respirable size, which is particulate matter with an aerodynamic diameter of 4 µm or less (ACGIH 2019). Particles of this size are small enough to be inhaled past the upper airways and penetrate the human lung (Brown et al. 2013). Because of the natural hardness of silica, high energy is required to fracture this mineral into respirable size (OSHA 2016). Activities such as grinding, cutting, sawing, drilling, crushing, and abrasive blasting of stone, rock, concrete, mortar, or brick may generate respirable crystalline silica. The size of the particles that cause silicosis is at least 100 times smaller than ordinary sand found on beaches and playgrounds (OSHA 2016).

Occupations associated with exposures to respirable crystalline silica include construction, stone countertop fabrication, and hydraulic fracking. Virtually any process that involves movement of earth (e.g., mining, farming, and construction), mechanical disturbance of silica-containing products such as masonry and concrete, or use of sand or other silica-containing products may potentially expose a worker to crystalline silica (IPCS 2000).

Regulations and guidelines for exposures to crystalline silica in the workplace initially were established in 1946 by the American Conference of Governmental Industrial Hygienists (ACGIH), in 1971 by the Occupational Safety and Health Administration (OSHA), and in 1974 by the National Institute for Occupational Safety and Health (NIOSH) (ACGIH 2020, Mossman and Glenn 2013). In the United States, approximately 2.3 million workers in 676,000 workplaces are exposed to crystalline silica; this includes approximately 2 million workers in the construction industry (Centers for Disease Control and Prevention website, www.cdc.gov; OSHA 2016). Yet silicosis is a rare disease with generally a long latency period (National Institutes of Health's Genetic and Rare Diseases Information Center website, www.rarediseases.info.nih.gov; Leung et al. 2012). It is estimated that during 1987–1997, approximately 3,600–7,300 new silicosis cases were diagnosed yearly in the United States (ATSDR 2019). As reported by the NIOSH in 1994, 13,744 deaths with silicosis as a possible contributor (mentioned in the death certificate) occurred in the United States during 1968–1990 (ATSDR 2019).

Since then, silicosis mortality has declined due to improved industrial hygiene standards and more stringent regulatory standards and guidelines for occupational exposures (ATSDR 2019, Bang et al. 2005, Bell and Mazurek 2020). A recent resurgence in occurrences of silicosis in younger workers involved with new tasks and occupations (e.g., quartz countertop installation and hydraulic fracturing) emphasizes the need for appropriate industrial hygiene practices (Bang et al. 2015, Friedman et al. 2015, Mazurek et al. 2015, Mazurek et al. 2017, Bell and Mazurek 2020). The cumulative dose of respirable silica in exposed workers (respirable concentration multiplied by duration of exposure) is the most important factor in the development of silicosis (ATSDR 2019, Leung et al. 2012).

It is important to note that the risk of community exposure to crystalline silica differs from the risk of occupational exposure. Airborne silica, both in amorphous and crystalline forms, is a ubiquitous pollutant that is not unique to areas near APOs, sand mining, construction, and other silica-generating activities. Moreover, not all crystalline silica in ambient air is respirable (PM_4). Monitored respirable crystalline silica levels in ambient air are generally not likely to cause chronic adverse health effects and are not sufficiently high enough to cause silicosis. The health-based AMCVs for crystalline silica developed by TCEQ are protective of human health and welfare.

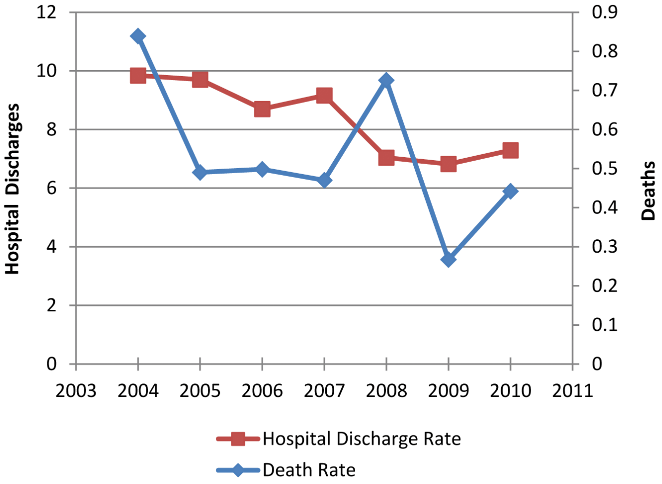
Silicosis in Texas

Silicosis is an occupational lung disease that is caused by long-term exposure to high workplace levels of respirable crystalline silica. Silicosis is a reportable disease in Texas, meaning that health-care providers, hospitals, laboratories, and other designated professionals report confirmed or suspected occupational cases of and deaths from silicosis (25 TAC 99.1) to the Texas Department of State Health Services (TDSHS), which then reports the data to the Centers for Disease Control and Prevention (CDC).

In 2014, the TDSHS received a report of the first case of silicosis reported in the United States associated with silica dust exposure during fabrication of engineered stone countertops (Friedman et al. 2015). In 2019, the TDSHS received reports of an apparent cluster of 12 silicosis cases among workers at an engineered stone countertop manufacturing and fabrication facility (also reported in Rose et al. 2019). Silicosis is defined as an occupational disease, meaning that workers who are exposed to high levels of silica occupationally are at risk of developing silicosis. The general public is not at risk of developing silicosis; however, some members of the general public could potentially be exposed to high levels of silica through hobbies, such as pottery making.

According to information (shown in Figure 1) available on the TDSHS website, www.dshs.texas.gov/epitox/Asbestosis-and-Silicosis-Surveillance/, the age-adjusted hospital discharge rates and age-adjusted death rates in Texas show that overall the burden of silicosis decreased from 2004 to 2010. In more recent statistics provided by the TDSHS, the age-adjusted hospital discharge rates from 2011 to 2016 continued to decrease; the average annual age-adjusted rate for inpatient hospitalizations for silicosis was 4.7 per million Texas residents (Table 2). This annual age-adjusted rate for inpatient hospitalizations is lower than the corresponding rate from 2004 to 2010.

Figure 1. Texas Annual Age-Adjusted Rates for Silicosis Hospital Discharges and Mortality by Year, 2004–2010, per 1 Million Population



Because the reporting rules of the CDC and TDSHS do not allow public reporting of deaths fewer than 10 and 5, respectively, for each year, the exact number of deaths in Texas from silicosis is not publicly available for each year, but they are generally below 10 from 2005 to 2016. The CDC website reports deaths in Texas from 2001 to 2010 (Table 3). The TDSHS provided data from 2011 to 2016 showing between 35 and 38 total deaths from silicosis in Texas, resulting in an approximate average annual age-adjusted silicosis death rate of 0.3 per one million Texas residents (Table 4). Bell and Mazurek (2020) recently summarized the number of silicosis-associated deaths and age-adjusted death rates among persons aged 15 years or older in 26 states, including Texas, from 1999 to 2018. In Texas, the total number of silicosis-associated deaths was 157 from 1999 to 2018, with an age-adjusted death rate of 0.4 per one million residents.

Table 2. TDSHS Occupational Health Indicator (OHI): Silicosis

	2011	2012	2013	2014	2015	2016
OHI 9.4.1: Annual Number of Inpatient Hospital Discharges	92	94	112	90	91	88
OHI 9.4.3: Annual Age-Adjusted Rate of Inpatient Hospitalizations for Silicosis (per million Texas residents)	5.1	5.0	5.6	4.4	4.2	4.0

Table 3. CDC Silicosis Mortality: Number of Deaths from Silicosis in Texas, 2001–2010

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Texas	<10[a]	14	15	12	<10	<10	<10	12	<10	<10

a. Statistics for fewer than 10 decedents are omitted from CDC tables and figures.

Table 4. TDSHS Silicosis Mortality: Number of Deaths from Silicosis in Texas, 2011–2016

	2011	2012	2013	2014	2015	2016
Texas	5	5	8	6	10	<5[a]

a. Data are suppressed for fewer than 5 decedents.

For more information regarding silicosis in Texas, please contact the TDSHS Asbestosis and Silicosis Surveillance Program of the Environmental and Injury Epidemiology and Toxicology Unit at 512-776-7222.

Regulations and Guidelines

Crystalline silica is not one of the six criteria air pollutants regulated under the Clean Air Act (CAA), which requires EPA to establish the NAAQS, and is not included on EPA's list of 187 hazardous air pollutants (www.epa.gov/haps/what-are-hazardous-air-pollutants). The six criteria pollutants regulated under the CAA are carbon monoxide, lead, nitrogen dioxide, ozone, sulfur dioxide, and particulate matter ($PM_{2.5}$ and PM_{10}) (40 CFR 50). Particulate matter, measured as $PM_{2.5}$ and PM_{10}, is a mixture of various substances, including some that may contain crystalline silica (e.g., crustal materials). Since crystalline silica is widely considered an occupational hazard and not an ambient air quality concern, EPA does not monitor for crystalline silica, nor does it have an approved method for monitoring for crystalline silica in ambient air. There is no federal regulation or EPA standard for ambient crystalline silica concentrations, and there is no EPA requirement for TCEQ to monitor for crystalline silica.

TCEQ has established AMCVs for crystalline silica, which are used as guidelines to evaluate ambient air concentrations of PM_4 crystalline silica and are protective of human health and welfare (Table 5). Health-based AMCVs are safe levels at which exposure is unlikely to result in adverse health effects. These values were developed using state-of-the-science guidance, which was subject to scientific peer review and public comment (TCEQ 2015). The TCEQ guidelines incorporate standard scientific methods commonly used by other agencies, including EPA.

Short-term AMCVs are based on data concerning acute health effects, odor potential, and acute vegetation effects, while long-term AMCVs are based on data concerning chronic health or vegetation effects. The health-based AMCVs for crystalline silica are shown in Table 5 (TCEQ 2009, 2020). In summary, AMCVs are designed to prevent adverse health effects of PM_4 crystalline silica, including respiratory disease such as silicosis and lung cancer, for all members of the general population, including potentially sensitive subpopulations (e.g., children, the elderly, and those with pre-existing health conditions).

TCEQ reviewed the website of each state's environmental protection agency to determine which other state agencies have regulations or guidelines for crystalline silica in ambient air. Of the 50 states, 14 (including Texas) appear to have guidelines in place and one state appears to have a draft rule regarding health-based ambient air concentrations of crystalline silica.

The California Environmental Protection Agency's Office of Environmental Health Hazard Assessment has set a chronic reference exposure level of 3 $\mu g/m^3$ for respirable crystalline silica (PM_4). Agencies in Indiana, Michigan, Minnesota, and New Jersey have adopted the chronic reference exposure level of 3 $\mu g/m^3$, and the Oregon Department of Environmental Quality has this exposure level listed in a draft rule. The New York Department of Environmental Conservation has adopted TCEQ's chronic threshold non-cancer reference value of 2 $\mu g/m^3$. Note that TCEQ's carcinogenic-based long-term reference value is 0.27 $\mu g/m^3$. States with guidelines for crystalline silica are shown in Table 6. This information is current as of March 2020.

Agencies in other states (Maryland, New Hampshire, North Dakota) clearly indicated that their guidelines for ambient air concentrations of crystalline silica were derived using the ACGIH threshold limit value–time weighted average (TLV-TWA) of 25 $\mu g/m^3$ respirable crystalline silica (PM_4) for an 8-hour workday. When not otherwise specified, it was assumed that PM_4 is indicated for the ambient air concentration levels in states that derived their guidelines or regulations from the ACGIH guidelines.

Table 5. Air Monitoring Comparison Values (AMCVs) for Crystalline Silica in Ambient Air

	AMCV ($\mu g/m^3$) (applies to PM_4)
Short-Term AMCV (1-hr)	47
Short-Term AMCV (24-hr)	24
Long-Term AMCV	0.27

AMBIENT AIR MONITORING

Crystalline Silica Monitoring Method

Ambient air concentrations of crystalline silica are generally not likely to pose a health threat. Crystalline silica in ambient air is not regulated by the EPA and the EPA does not require crystalline silica to be monitored. Even though ambient measurement of crystalline silica is not federally required, the TCEQ has developed health-based AMCVs for crystalline silica. Since the EPA does not typically monitor for crystalline silica in ambient air, there are no EPA-approved methods for monitoring or analytical analysis of crystalline silica in ambient air. However, NIOSH has developed methods for personal monitoring and analysis of crystalline silica for worker safety. Several monitoring studies that have been conducted across the United States have utilized the NIOSH methods, with modification, to successfully measure ambient levels of crystalline silica.

In 2015, an ambient PM_4 crystalline silica sampling method was described by Richards and Brozell that combined the high-volume sampling capability of $PM_{2.5}$

Table 6. Exposure Limits for Crystalline Silica in Air, by State

State	Agency	Level of Crystalline Silica ($\mu g/m^3$)	Duration	PM Measured
California	CalEPA	3	Chronic	PM_4
Idaho	Department of Environmental Quality	2.5 (cristobalite, tridymite) 5 (quartz, tripoli)	24-hr	Not specified
Indiana	IDEM	3.1 (indoor air residential screening level)	Chronic	PM_4
Maryland	MDE	0.25	Chronic	PM_4
Michigan	Department of Environment, Great Lakes, and Energy	3.0	Chronic	PM_4
Minnesota	Pollution Control Agency	3.0	Chronic	PM_4
New Hampshire	Department of Environmental Services	0.060	Chronic – carcinogen	PM_4
New Jersey	Department of Environmental Protection	3.0	Chronic	PM_4
New York	Department of Environmental Conservation	2.0	Chronic	PM_4
North Dakota	Department of Environmental Quality	0.5 (guideline concentration)	8-hr	PM_4
Oregon	Department of Environmental Quality	3 (draft)	Chronic	PM_4
Texas	TCEQ	0.27	Chronic – carcinogen	PM_4
Vermont	Department of Environmental Conservation	0.12	Chronic	Not specified
Virginia	Department of Environmental Quality	3	Chronic	Respirable
Washington	Department of Ecology	3	24-hr	Respirable

Abbreviations: CalEPA, California Environmental Protection Agency's Office of Environmental Health Hazard Assessment. IDEM, Indiana Department of Environmental Management. MDE, Maryland Department of the Environment. PM, particulate matter. TCEQ, Texas Commission on Environmental Quality.

reference method samplers meeting the requirements of 40 CFR 50, Appendix L with the sensitive crystalline silica analytical capabilities provided by the X-ray diffraction (XRD) analysis procedures in NIOSH Method 7500. Typically, PM is measured either with a 50% cut-off point of 2.5 or 10 µm. When particles pass through the size-selective inlet, there is a 50% efficiency cut-off at the aerodynamic diameter specified. For instance, the $PM_{2.5}$ size fraction ranges from 0 to 2.5 µm in aerodynamic diameter.

To get a 50% cut-off point of 4 µm for crystalline silica, a 2.5 µm inlet can be modified to gain the desired aerodynamic diameter cut-off point of 4 µm. A polyvinyl chloride filter, as outlined in NIOSH Method 7500, is used to monitor for crystalline silica. XRD analysis, also outlined in NIOSH Method 7500, quantifies the amount of crystalline silica in a sample using X-rays that show a specific diffraction pattern in the presence of crystalline silica (due to the uniform pattern of a crystal structure). This approach provides a direct measurement of crystalline silica in the respirable size range of interest (4 µm) (Richards and Brozell 2015).

Several studies that used these modified methods also used approved sampling equipment, procedures, and quality-assurance parameters from the EPA sampling methods specified in 40 CFR 50, Appendix L, to keep as close to the speciated particulate matter EPA sampling methods as possible. Quality-assurance procedures required for federal reference methods, such as those used for $PM_{2.5}$ sample collection, are also applicable to the adjusted methods for PM_4 sample collection (Richards and Brozell 2015).

Use of these modified sample collection and analysis procedures can provide reliable quantitative measurements of crystalline silica in ambient air that may be compared to safe levels, such as the TCEQ AMCVs.

Crystalline Silica and PM Monitoring Studies

Although crystalline silica air monitoring is not required under U.S. regulations, monitoring has been periodically conducted in urban areas and near APOs, industrial sand mines, and sand processing plants. Ambient air monitoring of crystalline silica in urban areas has been performed in 22 locations in various states, including Texas (Davis et al. 1984, USEPA 1996). In addition, ambient air monitoring for particulate matter and/or crystalline silica near APOs has been conducted in several states, including Texas. Texas has placed five stationary $PM_{2.5}$ ambient air monitoring sites within one mile of APOs in central Texas. Available data from these sites indicate that APOs do not appear to have an impact on the measured ambient air concentrations of $PM_{2.5}$.

Upwind and downwind ambient air monitoring at facilities in California, Colorado, Minnesota, North Carolina, Virginia, and Wisconsin revealed that the overall contribution of APOs to ambient air concentrations of PM and crystalline silica is minimal or negligible. The results are consistent with plant operations such as hauling, loading, and screening that do not involve the large amount of energy necessary to break mineral material down to respirable size. Monitored crystalline silica levels in ambient air are generally not likely to cause acute or chronic adverse health effects.

In many of the studies, total $PM_{2.5}$ and/or total PM_{10} concentrations were measured. As mentioned previously, $PM_{2.5}$ and PM_{10} sampling and measurements should be performed in accordance with EPA requirements (40 CFR 50), which specify a 24-hour sample collection. Primary ambient air quality standards define levels of air quality, with an adequate margin of safety, that protect public health (40 CFR 50). Secondary ambient air quality standards define levels of air quality that protect public welfare from any known or anticipated adverse effects of a pollutant (40 CFR 50).

The current standards for $PM_{2.5}$ include primary and secondary annual arithmetic means averaged over 3 years (12 and 15 µg/m^3, respectively), and primary and secondary 24-hour, 98th percentile values averaged over 3 years (35 µg/m^3 for both primary and secondary standards [40 CFR 50]). The current primary and secondary standard for PM_{10} is a 24-hour value of 150 µg/m^3 not to be exceeded more than once per year on average over a 3-year period (40 CFR 50). Because crystalline silica may be a component of particulate matter, including $PM_{2.5}$ and PM_{10}, several studies included measurements of total $PM_{2.5}$ and/or PM_{10} to determine the potential contribution of crystalline silica to total PM.

Ambient Air Monitoring in Urban Areas

The following sections provide a summary of the ambient monitoring of crystalline silica and particulate matter that has been conducted in urban areas. See Table 7 for a tabular summary of these studies.

Davis et al. 1984

An investigation of ambient air quartz concentrations was performed using aerosol samples collected in 1980 at EPA's Inhalable Particulate Network sites. Samplers operated for 24 hours once every sixth day for a duration of 1 year. A total of 228 filter samples collected from 22 cities was used for measurement of quartz concentrations. Total $PM_{2.5}$ and total $PM_{2.5–15}$ samples (104 for each) were collected on Teflon filters using a dichotomous sampler, which has a virtual impactor design and separates particles into two sizes: (1) less than 2.5 µm ($PM_{2.5}$) and (2) greater than 2.5 µm, with a sampling inlet designed to eliminate particles greater than an approximate 15 µm aerodynamic diameter ($PM_{2.5–15}$). Samples were analyzed for quartz using X-ray diffraction. In individual cities, including Dallas and El Paso, ambient average $PM_{2.5}$ quartz levels ranged from 0 to 1.9 µg/m^3, and ambient average $PM2_{2.5–15}$ quartz concentrations ranged from 0.9 to 8.0 µg/m^3.

United States Environmental Protection Agency 1996

From 1987 to 1993, EPA estimated annual PM_{10} average quartz concentrations in 17 urban areas, including Dallas and El Paso. These estimates were based on the percent quartz composition in the total dichotomous mass (TDM) (% quartz in TDM = % quartz in $PM_{2.5}$ + % quartz in $PM_{2.5–15}$) reported in each of the 17 individual cities from Davis et al. 1984. For each city, taking into account the percent quartz in the TDM and the average PM_{10} concentrations from 1987 to 1993 (i.e., a 7-year average), EPA calculated a 7-year average PM_{10} concentration for each city (PM_{10} quartz = % quartz in TDM x 7-year average PM_{10} concentration). The estimated annual average PM_{10} quartz concentrations ranged from 0.3 to 5.0 µg/m^3. Across the 17 cities, the overall average PM_{10} quartz level was 1.9 µg/m^3.

Pennsylvania Department of Environmental Protection 2016

Ambient background levels of PM_4 crystalline silica and of total $PM_{2.5}$ and PM_{10} were measured in Tunkhannock, Pennsylvania, in response to citizen concerns regarding a silica sand facility that was planned to be built in the township. If built, the facility would have been next to a day-care center and two adjacent little-league baseball fields. Residents were concerned about exposure to crystalline silica, as well as diesel emissions from an increase in truck traffic. One monitor each was sited upwind, downwind, and lateral to the location of the planned facility. For 30 days, a total of 113 24-hour samples were collected for measurement of PM_4 crystalline silica, prior to planned construction of the facility. During this same time frame, a total of 105 samples were collected for measurement of total $PM_{2.5}$ and PM_{10}.

Samples were collected in accordance with EPA procedures and were analyzed by a laboratory certified by the National Environmental Laboratory Accreditation Program (NELAP). Analysis of PM_4 crystalline silica was performed using NIOSH method 7500 X-ray diffraction with a reporting limit of 1 µg/m^3. Total $PM_{2.5}$ and PM_{10} analyses were conducted as specified in 40 CFR 50, Appendices J and L, respectively.

The short-term $PM_{2.5}$ and PM_{10} results in the Tunkhannock area were comparable to other PM samplers operating in the region; there were no concentrations higher than the numerical values of the NAAQS for $PM_{2.5}$ and PM_{10}. For each day, measured concentrations of total $PM_{2.5}$ and PM_{10} were similar at all three sites throughout the sampling period. The analysis for crystalline silica (measured as PM_4) indicated non-detects for the majority of samples; for the three PM_4 crystalline silica samples that had concentrations above the detection limits, the concentrations were 0.69 or 0.75 µg/m^3 quartz. These trace amounts were insufficient to raise concern about potential short-term adverse health impacts. The report compares results to Minnesota's 3 µg/m^3 health-based chronic value for crystalline silica and TCEQ's 2 µg/m^3 chronic threshold non-carcinogen reference value for crystalline silica. The plant cancelled construction of the silica transloading facility; therefore, ambient air monitoring for crystalline silica was discontinued.

Ambient Air Monitoring $PM_{2.5}$ Data Near APOs in Central Texas

TCEQ has an extensive ambient air monitoring network that includes sampling for PM. PM samples are collected and analyzed in accordance with EPA requirements. In October 2019, TCEQ began to install five new ambient air $PM_{2.5}$ monitoring sites near APOs in central Texas. Each of these new monitoring sites is located within one mile of an APO in a predominantly downwind configuration. Between October 2019 and May 2020, four new $PM_{2.5}$ ambient monitors came online near APOs in the San Antonio area, and in July 2020, one new $PM_{2.5}$ ambient monitor came online near an APO in the Austin area (Figure 2).

Available total $PM_{2.5}$ data collected from these monitors, beginning as early as October 2019, were compared to the value of the 24-hour $PM_{2.5}$ NAAQS (35 µg/m^3). With the exception of one day, total $PM_{2.5}$ concentrations were lower than 35 µg/m^3. There was a documented Saharan dust event that spanned from June 26 to July 9, 2020. On June 27, 2020, all monitors collecting $PM_{2.5}$ data in central Texas had measured 24-hour total $PM_{2.5}$ concentrations higher than 35 µg/m^3 (the range was 59.1 to 68.9 µg/m^3), resulting in a regional average of 62.3 µg/m^3. Throughout the period evaluated (Oct. 1, 2019 through Sept. 15, 2020), the concentrations of total $PM_{2.5}$ near APOs followed the general regional $PM_{2.5}$ trend. Ambient air concentrations of total $PM_{2.5}$ at the new monitors were similar to background levels, indicating that APOs do not appear to have an impact on measured total $PM_{2.5}$ concentrations. ($PM_{2.5}$ data may be accessed via the agency's $PM_{2.5}$ Data webpage, www.tceq.texas.gov/agency/data/lookup-data/pm25.html.)

Ambient Air Monitoring Studies Near APOs

Air monitoring data have been collected near silica sand mining and processing facilities in several states, with emphasis either on $PM_{2.5}$ concentrations or crystalline silica concentrations in ambient air. The following sections and Table 7 provide summaries of these studies.

Particulate Matter 2.5

The following sections provide a summary of studies that have been conducted near APOs to determine the contribution APOs may make to $PM_{2.5}$ concentrations in ambient air.

Colorado, North Carolina, and Virginia

Richards et al. 1999

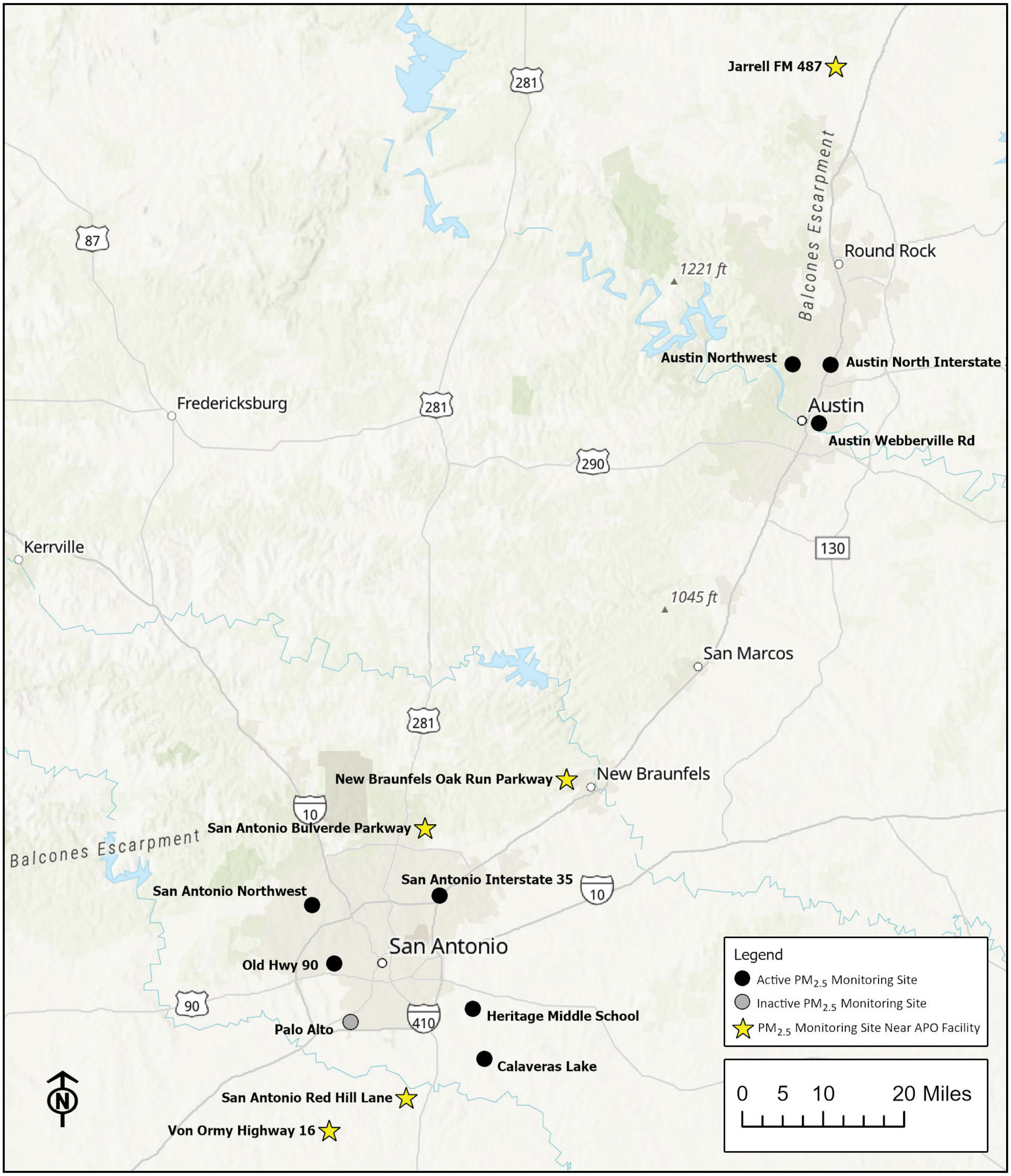
The National Stone Association sponsored a series of three ambient monitoring projects to evaluate the impact of stone crushing plants on ambient levels of $PM_{2.5}$. Ambient air monitoring for $PM_{2.5}$ was performed near stone crushing plants in Benson, North Carolina; Leesburg, Virginia; and Denver, Colorado. All three plants were large permanent facilities with typical processing equipment and quarries. At each plant, one monitor was located upwind and two monitors were located downwind within plant boundary lines. Ambient concentrations were measured in accordance with the EPA method as defined in 40 CFR 50 (USEPA 1997) and monitoring was performed 24 hours per day for 30 consecutive days during normal to high production rates.

At the Benson plant, ambient $PM_{2.5}$ levels were low and the concentration difference between the upwind and downwind sites was only 0.7 µg/m^3. Analysis of the $PM_{2.5}$ composition revealed that most of the particulate matter was composed of ammonium sulfate and organics, neither of which are products or byproducts of the plant or plant activities. In addition, negligible quantities of mineral particulate matter were found in the $PM_{2.5}$ samples collected downwind.

At the Leesburg plant, the upwind and downwind concentration data tracked very closely, with a mean downwind to upwind difference of 1.6 µg/m^3, showing that the plant had little impact on $PM_{2.5}$ concentrations. Chemical analysis of the $PM_{2.5}$ filters indicated that the particulate matter consisted of sulfates, ammonium compounds, and organics; mineral PM, which is the type of dust emitted by stone crushing plants, was not detected.

At the Denver plant, mineral PM levels were very low, and most of the $PM_{2.5}$ consisted of sulfates, nitrates, ammonium compounds, and organic and elemental carbonaceous compounds. Overall, the results indicate that stone crushing operations have negligible impact on ambient $PM_{2.5}$ concentrations.

Figure 2. $PM_{2.5}$ Ambient Air Monitoring Site Locations in Central Texas: TCEQ Region 11–Austin and Region 13–San Antonio



Note: This map was generated by the Toxicology Division (TD). No claims are made to the accuracy or completeness of the data, or to the suitability of the map for a particular use. This area may contain facilities other than those identified. For more information regarding this map, please contact the TD at 512-239-3900.

Date Created: 11/23/2020

Minnesota and Wisconsin

Walters et al. 2015

The aim of this pilot study was to measure total $PM_{2.5}$ concentrations around fracking-sand plants in Wisconsin and Minnesota. Limited sampling was conducted, and no measurements of crystalline silica were performed. Six nominal 24-hour ambient air samples were collected with an SKC deployable particulate sampler using the $PM_{2.5}$ sampling head. Five of the six samples were collected for approximately 24 hours (~22 to 24 hr), and one sample was collected for 347 minutes. Two of the samples were collected near inactive mines. Sampling conditions included calm and high wind, and rain and snow conditions, at 30 to 1,300 meters from operations. The results were compared to the nearest monitored $PM_{2.5}$ levels in the ambient air network of the Wisconsin Department of Natural Resources (DNR) and/or Minnesota Pollution Control Agency (MPCA), matched hour for hour to sampling times.

The authors stated that the measured fine particulate levels were likely due to a combination of regional pollution, car and diesel truck exhaust, local industrial pollution, and fracking-sand particulate emissions. In this pilot study, the range of concentrations of total $PM_{2.5}$ was 5.82–50.8 µg/m³ $PM_{2.5}$. Generally, lower concentrations of $PM_{2.5}$ were seen with higher wind conditions, heavy snowfall, and heavy rain conditions. Also, lower concentrations of $PM_{2.5}$ were seen near inactive mines. The samples with $PM_{2.5}$ concentrations above the numerical value of the NAAQS also were higher than $PM_{2.5}$ levels measured at the nearest agency (DNR or MPCA) network sites, which were in the range of 0–13.5 µg/m³. Overall, the results of the study are limited due to the small sample size and, therefore, conclusions cannot be made about the impact of APOs on total $PM_{2.5}$.

Crystalline Silica

The following sections provide a summary of studies that have been conducted near APOs to determine the contribution that APOs may make to crystalline silica concentrations in ambient air. See Table 7 for a tabular summary of these studies.

Monitored crystalline silica levels in ambient air are generally not likely to cause acute or chronic adverse health effects. The air monitoring studies listed below show that emissions from crystalline silica sources beyond the workplace are minimal. There is a general consensus among air quality professionals that ambient levels of crystalline silica pose little risk of silicosis. Overall, the results near facilities at various locations indicated similar low ambient levels of respirable crystalline silica.

California

Shiraki and Holmén 2002

The goal of this study was to provide preliminary data on ambient crystalline silica concentrations near a sand and gravel facility in California and to develop analytical techniques to distinguish source and background crystalline silica contributions so that exposure was not overestimated. Particulate matter measurements were made at four locations downwind and one location upwind of the facility in Tracy, California. Samples were collected on eight separate test periods, and PM_{10} samples of three sampling periods were analyzed for quartz concentrations using X-ray diffraction. Sampling durations were 2.7 to 11.5 hours; the authors did not state the duration of sampling for the samples subjected to analysis of PM_{10} quartz.

The highest concentrations of quartz PM_{10} observed were closest to the source at the facility. At three locations downwind, which encompassed the main plant where conveyor, separating, and crushing equipment and product piles were located, quartz PM_{10} concentrations were 26.2 to 97.2 µg/m³. The downwind location outside of the gate of the plant and the upwind location had quartz PM_{10} concentrations of 5.4–16.3 µg/m³ and 4.1 – <5.4 µg/m³, respectively. Of note, the current NAAQS value for PM_{10}, which reflects all particulate matter with an aerodynamic diameter ≤ 10 µm, is 150 µg/m³ (24-hour sample).

Based on the study, the operations at the facility did contribute to ambient concentrations of crystalline silica. However, the authors note that the airborne quartz concentrations were of the same order of magnitude as those measured in respirable dust during agricultural operations in California. In addition, sampling was done during the dry season, and quartz concentrations during the wet season are expected to be lower due to reduced facility activity and reduced emissions when facility product piles have higher moisture content. It is important to note that concentrations of PM_{10} crystalline silica will be greater than PM_4 crystalline silica, as PM_{10} includes more particles. However, unlike with PM_4, not all the particles in PM_{10} are respirable, meaning that they will not deposit deep into the lungs where they can cause damage. Another limitation of this study was the small number of samples analyzed for levels of quartz PM_{10}.

Richards et al. 2009

This investigation was sponsored by the California Construction and Industrial Minerals Association and the National Stone, Sand, and Gravel Association. The goal was to measure ambient respirable (PM_4) crystalline silica at two sand and gravel plants located in Carroll Canyon and Vernalis, California. The authors adapted the EPA reference method for $PM_{2.5}$ filter-based samplers to provide respirable particulate (PM_4) filter samples (USEPA 1997). The sampler was modified to have a 50% cut point of 4 µm instead of 2.5 µm by reducing the airflow used for monitoring $PM_{2.5}$. The adequacy of the cut size was confirmed using National Institute of Standards and Technology traceable microspheres. Crystalline silica content of PM_4 was measured using the NIOSH method 7500 X-ray diffraction (NIOSH 2003). The minimal detectable limit was 0.3 µg/m^3. At each facility, two samplers were located downwind from the quarry and processing equipment, and one sampler was located upwind of the entire facility. Samples were collected during three consecutive 24-hour periods. Concentrations of ambient crystalline silica ranged from 0 (below the detectable limit) to 2.8 µg/m^3. Differences between the upwind and downwind concentrations were small. Slightly higher upwind values observed were due to the emissions from unpaved roads near the upwind monitoring sites. In summary, the sand and gravel plants had a slight impact, if any, on ambient concentrations of PM_4 crystalline silica.

Minnesota

Minnesota Pollution Control Agency 2015 (May)

In response to community requests regarding the impact of diesel truck traffic and activities related to silica sand mining, MPCA placed air monitors at the Family Young Men's Christian Association in downtown Winona, and at a reference location in Stanton, Minnesota. The Stanton location did not have sand-related facilities or transportation in the area but did have other sources of airborne silica from unpaved roads and farm fields. The monitors collected 24-hour measurements of respirable crystalline silica (PM_4) every 6 days for 1 year. At each site, a total of 61 samples were collected for measurement of crystalline silica.

The Winona monitor had two samples with detectable crystalline silica concentrations, and the Stanton monitor had ten detected samples. The samples with detectable concentrations at the Winona site were just above the limit of detection of 0.3 µg/m^3; therefore, the average crystalline silica concentration in Winona was estimated to be <0.3 µg/m^3. At the Stanton site, all the samples with detectable concentrations were <1 µg/m^3; the 95% upper confidence limit of the arithmetic mean (UCL-95) was 0.4 µg/m^3. Total $PM_{2.5}$ also was measured at the Winona site. There was one measured value that was higher than the numerical value of the NAAQS for $PM_{2.5}$ over the one-year monitoring period. This measured $PM_{2.5}$ value (daily concentration ~ 39 µg/m^3) occurred on a day when the crystalline silica measurement was not detected and was due to a regional weather pattern with a strong temperature inversion, light winds, and heavy fog. In summary, the ambient concentrations of crystalline silica in Winona, located near silica sand mining, were mostly non-detectable and were within the UCL-95 of the reference location in Stanton, which was not near a silica sand mining plant.

Minnesota Pollution Control Agency 2015 (October)

This study evaluated crystalline silica concentrations in PM_{10} for 17 months at a single location northeast of and outside Shakopee Sand (formerly Great Plains Sands) in Jordan, Minnesota, which is approximately 25 miles southwest of Minneapolis. Samples were collected for 24 hours once every 12 days. Seven samples were collected pre-permit and 37 samples were collected post-permit. Activities conducted after issuance of the permit were construction, mining, blasting, and stockpiling. The limit of detection was 1 µg/m^3. All PM_{10} crystalline silica samples were below the limit of detection, except for one sample collected pre-permit with a concentration $<2\ \mu g/m^3$ ($\sim 1.9\ \mu g/m^3$) and one sample collected post-permit with a concentration $<1.5\ \mu g/m^3$ ($\sim 1.4\ \mu g/m^3$). In addition, total PM_{10} was measured for three years at one fenceline location northeast of and one fenceline location south of the facility. Throughout the 3-year period, there were no measured concentrations higher than the numerical value of the NAAQS for PM_{10} (i.e., no daily total PM_{10} concentrations were greater than 150 $\mu g/m^3$). This study demonstrates that the plant activities at this silica sand facility had negligible contributions to ambient PM_{10} crystalline silica.

Minnesota Pollution Control Agency 2015 (December)

In this study, ambient air monitoring of PM_4 crystalline silica was performed at one fenceline location north of and one fenceline location south of the Titan Lansing Transload (previously Tiller) Corporation's sand processing facility in North Branch, Minnesota. The facility is located approximately 35 miles north of the Twin Cities (Saint Paul and Minneapolis). Sampling occurred for 24 hours, once every 6 days, for approximately 68 weeks over the course of 2 years. The total sampling duration was not the entire 2 years (i.e., 104 weeks), as some samples were invalidated due to flow rate problems and maintenance issues with the monitors. Regardless, valid data were collected during a period of approximately 68 weeks.

Most of the samples were below the detection limit. Some samples were above the detection limit (not specified); those samples above the detection limit ranged from $<2\ \mu g/m^3$ to $\sim 6\ \mu g/m^3$ PM_4 crystalline silica. Wind and pollution roses were developed and reviewed for days when the samples were above the detection limit. The contribution of the sand processing facility to PM_4 crystalline silica was concluded to be minimal because about half the samples with detectable levels occurred on days when the monitor was either upwind or offwind of the facility. The UCL-95 PM_4 crystalline silica values for the monitors were 1.8 and 1.7 $\mu g/m^3$. In addition, total $PM_{2.5}$ and PM_{10} levels were measured at both monitoring locations for 2.75 years and there were no measured concentrations higher than the numerical values of the NAAQS for either $PM_{2.5}$ or PM_{10}. Overall, the sand processing facility contribution to ambient crystalline silica was minimal.

Minnesota Pollution Control Agency 2018

The aim of this study was to conduct ambient air monitoring for PM_4 crystalline silica outside of the Jordan Sands LLC sand mining and processing facility in Mankato, Minnesota. The facility includes a wet plant for washing and screening; a dry plant for drying, screening, and sorting; stockpile areas for raw sandstone, wet sand, and sorted material; a rail loadout facility; an office; a maintenance building; and staging areas. Two monitors were located at opposite sides (north, south) of the facility. One monitor was located near the dry plant and large outdoor storage sand pile and the other monitor was located near the mine site. Total PM_{10} and $PM_{2.5}$ were measured in accordance with EPA regulations, once every 6 days, for 3 years.

At both monitors, there were no measured concentrations higher than the numerical values of the NAAQS for PM_{10} and $PM_{2.5}$ over the 3-year period. In addition, PM_4 crystalline silica was measured every 6 days for most of the 3-year period (no data were collected for a few weeks in 2014 through November 2016, and from mid-December 2016 through March 2017). The majority of the crystalline silica results were below the detection limit, which appears to be 0.3 $\mu g/m^3$, as shown on the graphs. For those samples above the limit of detection, the PM_4 crystalline silica values were $\leq 1\ \mu g/m^3$. Overall, the sand mining and processing facility contribution to ambient crystalline concentrations was determined to be negligible or minimal.

Wisconsin

Richards and Brozell 2015

The purpose of this study was to conduct long-term fenceline monitoring for respirable (PM_4) crystalline silica near four Wisconsin facilities (three fracking-sand mines and one fracking-sand processing plant in Chippewa and Barron counties). Prior to this study, the Wisconsin DNR and MPCA expressed concerns regarding the lack of ambient respirable crystalline silica data in communities near fracking-sand producing facilities. The authors adapted the EPA reference method for $PM_{2.5}$ filter-based samplers to provide respirable particulate

(PM_4) filter samples (USEPA 1997). Crystalline silica content of PM_4 was measured by an accredited laboratory using the NIOSH method 7500 X-ray diffraction (NIOSH 2003). The limit of quantification (LOQ) for crystalline silica was 0.31 µg/m^3. Three samplers were placed near the fenceline at each facility: two downwind from the facility, and one upwind.

All sampling locations met sampling site criteria specified by EPA (USEPA 2013). At each facility, the sampling locations were 10 to 150 meters from the closest fugitive dust source and 500 to 1,000 meters from the most distant fugitive dust source. Samplers operated on a once-every-third-day schedule and the sampling days matched the once-every-third-day calendar schedule used by EPA and state agency monitoring networks. Therefore, the data generated could be compared with data generated simultaneously with state agency $PM_{2.5}$ samplers. Sampling time was between 23 and 25 hours in duration, and samples were collected for 2 years. A total of 2,128 24-hour-average samples were collected from the eight different sample locations at four facilities.

Variations in the total PM_4 data were very similar to variations in total $PM_{2.5}$ data, suggesting that most of the total PM_4 particulate matter was background total $PM_{2.5}$ particulate matter. As expected, the total PM_4 concentrations were slightly higher than the total $PM_{2.5}$ concentrations, because the total PM_4 size range extends into the coarse mode of ambient particulate matter. For respirable crystalline silica, 88% of the 2,128 samples were below the LOQ of 0.31 µg/m^3. Across the four facilities, the annual averages calculated based on LOQ/√2 values substituted for the below-LOQ samples ranged from 0.22 to 0.33 µg/m^3**.** In addition, 24-hour sample upwind to downwind differences were zero on 78% of the days and were very small on the remaining days. Overall, the results indicate that the sand mining and processing facilities contribute very little, if any, to the ambient respirable crystalline silica concentrations.

Peters et al. 2017

The aim of this study was to evaluate the impact of proppant sand mining and processing activities on particulate matter concentrations, including respirable (PM_4) crystalline silica, in a Wisconsin community. PM_4 crystalline silica concentrations were measured in Trempealeau County, Wisconsin, outside of 17 residential homes within 800 meters of the property line of facilities with active sand mining, processing, and/or transport. Sampling using PM_4 samplers occurred for a minimum of 48 hours, and samples were analyzed for crystalline silica using NIOSH method 7500 X-ray diffraction (NIOSH 1994). The minimum reporting limit for crystalline silica (defined as five times the minimum detectable level) was 0.4 µg/m^3.

Crystalline silica was detected above the limit of detection in seven of 17 samples. Of those samples, quartz represented 2% to 4% of the mass. All PM_4 crystalline silica concentrations were below the minimal reporting level of 0.4 µg/m^3. Additionally, long-term air monitoring at homes near the sand mining and processing operations revealed that total PM concentrations were well below the numerical values of the NAAQS for $PM_{2.5}$ and PM_{10}. The authors noted higher local concentrations when the averaging time was shortened from 24 hours to 1 hour or 5 minutes. Elevated short-term (5 min) total $PM_{2.5}$ and PM_{10} concentrations were more likely to occur when the wind was blowing from the sand facility; these elevated concentrations occurred less than 3% of the sampling time.

These infrequent peak concentrations may explain observed dust deposits that raised concerns from the community. Spikes in concentrations may also result from a variety of industrial, community, agricultural, and natural sources. Overall, the 24-hour total $PM_{2.5}$ and PM_{10} concentrations were within the numerical values of the NAAQS for $PM_{2.5}$ and PM_{10}. Respirable crystalline silica concentrations measured near residences were below the minimal reporting level of 0.4 µg/m^3, indicating that the proppant sand mining and processing facilities made minor contributions, if any, to the ambient respirable crystalline silica concentrations.

Summary of Crystalline Silica Air Monitoring Studies

The following table (Table 7) provides a summary of the crystalline silica measurements from studies that measured crystalline silica in urban areas and in areas near APOs.

Table 7. Crystalline Silica Air Monitoring: Baseline and At or Near Sand Mining, Fracking-Sand, and Sand and Gravel Facilities in the United States

Study	Location of Study	Facility	Distance	Crystalline Silica ($\mu g/m^3$)	Duration	PM measured
Davis et al. 1984	22 U.S. Cities[a]	N/A	Baseline	0–1.9 0.9–8.0	24 h every 6 d for 1 year	$PM_{2.5}$ $PM_{2.5-15}$
USEPA 1996	17 U.S. Cities[a]	N/A	Baseline	0.3–5.0	24 h every 6 d for 7 years	PM_{10}
PA DEP 2016	Pennsylvania (Tunkhannock)	N/A	Baseline	Most < LOD; 3 samples: 0.69 – 0.75	24 h every d for 30 d	PM_4
Shiraki and Holmén 2002	California (Tracy)	Sand and gravel facility	1 fenceline location downwind	4.1 – <5.4	2.7 – 11.5 h, 8 samples collected	PM_{10}
			1 fenceline location upwind	5.4–16.3		
Richards et al. 2009	California (Carroll Canyon, Vernalis)	2 sand and gravel facilities	2 fenceline locations downwind, and 1 fenceline location upwind	0–2.8	3 consecutive 24-h periods	PM_4
MPCA May 2015	Minnesota (Winona, Stanton)	Diesel truck traffic and sand mining	Winona – fenceline urban location near facility	Most < LOD; 2 samples: ~0.3	24 h every 6 d for 1 year	PM_4
			Stanton – reference location not near facility	Most < LOD; 10 samples > LOD; UCL-95 = 0.4		
MPCA Oct. 2015	Minnesota (Jordan)	Shakopee Sand sand mining facility	1 fenceline location		24 h every 12 d for 17 months	PM_{10}
			7 samples pre-permit	Most < LOD; 1 sample ~1.9		
			37 samples post-permit	Most < LOD; 1 sample ~1.4		
MPCA Dec. 2015	Minnesota (North Branch)	Titan Lansing sand processing facility	2 opposite fenceline locations	UCL-95 values of 1.7 and 1.8 at each monitor	24 h every 6 d for 68 weeks over the course of 2 years	PM_4
MPCA 2018	Minnesota (Mankato)	Jordan Sands sand mining and processing facility	2 opposite fenceline locations	Most < LOD; maximum = 1	24 h every 6 d for 3 years	PM_4
Richards and Brozell 2015	Wisconsin (Chippewa and Barron Counties)	3 fracking-sand mines and 1 fracking-sand processing plant	At each facility: 2 fenceline locations downwind and 1 fenceline location upwind	0.22–0.33 (range of annual average of all 4 facilities)	23–25 h every 3 d for 2 years	PM_4
Peters et al. 2017	Wisconsin (Trempealeau County)	Sand mining facility	17 homes within 800 m of facility	All samples <0.4	48 h, 17 samples collected	PM_4

Abbreviations: MPCA, Minnesota Pollution Control Agency. PA DEP, Pennsylvania Department of Environmental Protection. PM, particulate matter. USEPA, U.S. Environmental Protection Agency.

a. Includes Dallas and El Paso, Texas

CONCLUSION

TCEQ has reviewed ambient air crystalline silica levels measured near APOs in various locations throughout the United States where data are available. These data indicate that the contribution of crystalline silica from these facilities to ambient levels of particulate matter and respirable crystalline silica is negligible or minimal and that the levels generally are below the health-based AMCVs for crystalline silica developed by the TCEQ.

For respirable crystalline silica (PM_4), the 24-hour AMCV is 24 µg/m^3, and the long-term AMCV is 0.27 µg/m^3. In urban areas throughout the United States, average annual ambient air concentrations of crystalline silica in $PM_{2.5}$ and in PM_{10} were 0–1.9 µg/m^3 and 0.3–5.0 µg/m^3, respectively. The range of respirable crystalline silica (PM_4) measured in samples collected for 24 or 48 hours near APOs ranged from 0 (many samples were below the limit of detection) to 2.8 µg/m^3. Levels of crystalline silica in PM_{10} near APOs were higher, as these measurements include larger particles that are not respirable and will not reach into the human lung. Additionally, some PM_{10} crystalline silica levels near APOs reflect a duration of sampling significantly shorter than 24 hours, which is the sampling duration that provides an average concentration reflective of a 24-hour period and provides a direct comparison to 24-hour comparison values, as well as the duration of sampling specified in the EPA method for measurement of PM_{10}.

Health-based AMCVs are safe levels at which exposure is unlikely to result in adverse health effects. When compared to TCEQ's AMCVs for crystalline silica, the ambient air concentrations of crystalline silica near APOs are generally not likely to cause acute or chronic adverse health effects and are not associated with silicosis. While there is no federal requirement for TCEQ to measure ambient levels of crystalline silica, federal standards for PM, a component of which may include silica, are in effect for $PM_{2.5}$ and PM_{10}.

It is important to note that APOs in Texas require an air permit prior to start of operation and must meet federal standards for $PM_{2.5}$ and PM_{10}. In October 2019, TCEQ began installing ambient air $PM_{2.5}$ monitoring sites located within one mile of APOs in central Texas. There are currently five sites near APOs that are located predominantly downwind of these facilities. The available data currently show the concentrations of $PM_{2.5}$ at these monitoring sites near APOs follow the general regional trend for $PM_{2.5}$. The data also indicate that APOs do not appear to have an impact on measured $PM_{2.5}$ concentrations.

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