Fenceline PM4 crystalline silica concentrations near sand mining and processing facilities in Wisconsin

by J. Richards and T. Brozell

Abstract ■ Communities near sand mines and processing facilities in Wisconsin have raised concerns regarding possible exposure to ambient respirable (PM4) crystalline silica. Fenceline PM4 (particulate matter captured with a 50 percent cut size of 4 micrometers aerodynamic diameter) crystalline silica concentration data were compiled at Fairmount Santrol Inc., Mathy Construction Inc. and U.S. Silica facilities. The long-term average PM4 crystalline silica concentrations ranged from 0.05 to 0.45 micrograms/m^3 when sample values below the limit of quantification were treated as zeros. All of the long-term average concentrations were less than 20 percent of the Minnesota Department of Health's and California Office of Environmental Health Hazard Assessment's PM4 crystalline silica chronic reference exposure level of 3.0 micrograms/m^3. The measured concentrations were consistently within the local background concentration range.

Air Control Techniques P.C. compiled the sampling data using Thermo Fisher Scientific Inc. Partisol 2000i PM2.5 samplers meeting the requirements of 40 CFR Part 50, Appendix L. These samplers were adapted to capture particulate matter with a 50 percent cut size of 4 micrometers. The use of polyvinyl chloride filters allowed for crystalline silica X-ray diffraction analysis by NIOSH Method 7500. The combined use of adjusted PM2.5 filter-based samplers with Method 7500 crystalline silica analyses provided for a highly sensitive limit of quantification of 0.31 micrograms/m^3 of PM4 crystalline silica.

Mining Engineering, 2015, Vol. 67, No. 10, pp. 53-59.
Official publication of the Society for Mining, Metallurgy & Exploration Inc.

Background

In 2005, the California Office of Environmental Health Hazard Assessment (OEHHA, 2005) adopted a 70-year chronic reference exposure level (REL) for PM4 (particulate matter having aerodynamic diameter of 4 micrometers or less) crystalline silica. The REL was extrapolated from occupational hygiene epidemiological studies, essentially all of which were based on in-plant PM4 crystalline silica measurements. No well-established ambient sampling technique for PM4 crystalline silica was available at the time that OEHHA adopted its REL. The personal samplers used for the National Institute for Occupational Safety and Health (NIOSH) Method 0600 in-plant sampling of employee exposure were designed for concentrations higher than ambient levels. The limit of quantification (LOQ) of PM4 crystalline silica on NIOSH 0600 filters was too high for the effective sampling of ambient air.

In 2006, in response to the need for an ambient sampling technique for PM4 crystalline silica, we developed a sampling method based on the U.S. Environmental Protection Agency's (EPA) design and operating requirements for PM2.5 samplers (Richards and Brozell, 2006). The sample flow rates in Thermo Fisher Scientific Inc.'s Partisol 2000i low-vol PM2.5 Federal Reference Method (RFPS-04980117) samplers were adjusted from 16.7 L/min to 11.1 L/min to change the 50 percent cut size of the sharp cut cyclone to 4 micrometers (aerodynamic) rather than 2.5 micrometers. The Teflon membrane filter used for PM2.5 sampling was replaced with a polyvinyl chloride filter to allow for NIOSH Method 7500 crystalline silica analysis. The use of a PM2.5 sampler with adjusted sample flow rate along with NIOSH Method 7500 X-ray diffraction (XRD) analyses provided a LOQ for PM4 crystalline silica of 0.31 micrograms/m^3. This LOQ value was based on (1) a 15.98-m^3 sample volume obtained in a 24-hr sampling period as measured by the

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Resumen ■ Las comunidades cerca de canteras de arena y plantas de procesado en Wisconsin han notificado su preocupación sobre la posibilidad de estar expuestos a sílice cristalino respirable (PM4). Los datos de concentración de sílice cristalino PM4 colindante con comunidades (material en partículas capturado con un 50 por ciento de tamaño de 4 micrómetros de diámetro aerodinámico) fue compilado en las plantas de Fairmount Santrol Inc., Mathy Construction Inc. y U.S. Silica. Los datos de concentraciones promedio a largo plazo eran de sílice cristalino PM4 eran de 0.05 a 0.45 microgramos por metro cúbico cuando los valores de las muestras por debajo del límite de cuantificación eran tratados como ceros, y todos los valores promedios a largo plazo eran menores a 20 por ciento al nivel de exposición crónica referencial de 3.0 microgramos sílice cristalino PM4 por metro cúbico del Departamento de Salud de Minnesota y la Oficina para la Evaluación del Peligro de Salud Ambiental de California. Las concentraciones medidas fueron consistentes dentro de los antecedentes de rango de concentración local.

La compañía Air Control Techniques P.C. compile los datos de muestras mediante el uso de toma muestras Thermo Fisher Scientific Inc. Partisol 2000i PM2.5, que cumplen con los requisitos de 40 CFR Part 50, Apéndice L. Estos toma muestras fueron adaptados para capturar partículas con un porcentaje de 50 por ciento de tamaño de 4 micrómetros. El uso de filtros de cloruro de polivinilo permitió el análisis por difracción de rayos X de sílice cristalino usando el Método de Prueba NIOSH 7500. El uso combinado de toma muestras adaptados PM2.5 con filtro con análisis de sílice cristalino con Método 7500 arrojaron un límite altamente sensible de cuantificación de 0.31 microgramos de sílice cristalino PM4 por metro cúbico.

Partisol 2000i and (2) a 5-microgram crystalline silica minimum detectable limit specified by R.J. Lee Group Inc. for NIOSH Method 7500 XRD analyses (R.J. Lee Group Inc., 2014). The 15.98-m^3 sample volume was based on the 11.1-L/min sample flow rate of the Partisol 2000i sampler calibrated with a Chinook Engineering Inc. NIST-traceable Streamline Pro Multical flow rate calibrator.

This combination of the EPA reference method sampler and the NIOSH Method 7500 XRD analytical capability also allowed for the use of well-established EPA and NIOSH quality assurance procedures associated with these methods.

Shortly after developing the ambient PM4 sampling method in 2006, we conducted short-duration sampling programs upwind and downwind of sand and gravel plants in San Diego and Tracy, CA (Richards et al., 2009). The South Coast Air Quality Management District independently developed a similar ambient PM4 crystalline silica sampling program (SCAQMD, 2006, 2008) at approximately the same time. Our 2009 studies in Tracy and San Diego and a study conducted by SCAQMD in Duarte, CA, provided data confirming that the PM4 crystalline silica sampling method had sufficient sensitivity for the measurement of ambient concentrations at or near sand-producing facilities.

Study procedures

Facility and sampling network characteristics. Fairmount Santrol Inc., Mathy Inc. and U.S. Silica Inc. independently conducted ambient PM4 crystalline silica sampling at four sand mines and processing facilities, described in Tables 1 and 2.

The Downing facility operated two sampling sites oriented west to east. One sampler was installed near the facility's eastern property line at a location that was 610 m (2,000 ft) downwind of the quarry and storage piles. A collocated sampler used for quality assurance purposes was 2 m (6.6 ft) from the sampler at the East sampling location. Figure 1 shows the East sampling location with these two identical samplers. A third sampler was installed 30 m (100 ft) inside the western property line at a location 46 m (150 ft) from the edge of the quarry.

Table 1

Facilities in Wisconsin where ambient PM4 sampling was conducted.

Company	Facility	No. of sampling locations	Sampling dates
Fairmount Santrol	Maiden Rock, WI	3	March 2013 – March 2014
Mathy Construction	Downing, WI	2	August 2012 – September 2013
	Cataract Green, WI	1	September 2012 – September 2013
U.S. Silica	Sparta, WI	1	September 2012 – March 2014
Total		**7**	

The Downing plant is located between farms on the north and south and is in a rural area dominated by agriculture.

U.S. Silica located a sampler in a community park that was approximately 457 m (1,500 ft) outside of the plant fenceline. The sampler was 107 m (350 ft) from the edge of a large residential community located to the east.

The Maiden Rock facility is in a valley surrounded on both the north and south sides by hills that start at the edge of the Mississippi River and are oriented southwest to east-northeast. The underground mine is in the upper part of the valley. The sand processing plant is in the lower part of the valley close to State Road 35. The Northeast site sampler was in the upper part of the valley approximately 183 m (600 ft) downwind of the mine vents and 305 m (1,000 ft) downwind of the processing plant. A second sampler was at an in-plant location on the southwest side of the valley. Due to the valley and ridge lines, the winds often moved either upslope toward the Northeast site sampler or downslope toward the Southwest site sampler.

A third sampler was located along County Road S in the middle of the village of Maiden Rock. This sampler was in a residential area and within 12 m (40 ft) of a public road. This sampling location was also in a valley between two southwest-to-northeast ridge lines.

The sampling location in Cataract Green was a grass-covered field scheduled to open as a mine in the future. There

Figure 1

East sampling location at Downing.

Table 2

Facility and sampling location characteristics.

Facility	Approximate production rate	Sampling location designation	Characteristics of sampling locations	Sampling location distances to roads and facility dust emission sources
Maiden Rock	7,200 t/d (7,937 stpd), approximately 300 operating days per year.	Northwest	Residential area along County Road S.	12 m (40 ft) southeast of County Road S and 914 m (3,000 ft) north of the center of the processing plant.
		Northeast	Hill above the mine and processing facility.	305 m (1,000 ft) northeast of the processing plant.
		Southwest	Bottom of a valley within the facility fenceline.	61 m (200 ft) south of facility process equipment, 76 m (250 ft) east of State Road 35, and 152 m (500 ft) southeast of the rail load-out.
Downing Sand Mine	2,750 t/d (3,031 stpd), approximately 300 operating days per year.	West	Within the plant fenceline and near County Road W.	46 m (150 ft) west of the edge of the quarry and haul road.
		East	Within the plant fenceline and along County Road Q.	610 m (2,000 ft) east of haul roads, storage piles, and quarry.
Cataract Green	No production.	Cataract Green	Open, grass-covered field in middle of planned mine site.	No sources nearby.
Sparta	3,000 t/d (3,307 stpd), approximately 300 operating days per year.	Sparta	In a public park near a residential area.	457 m (1,500 ft) outside of the facility fenceline and 107 m (350 ft) from a residential community.

Table 3

Sampling frequencies.

Facility	No. of samplers	Sampler operating frequency	No. of collocated samplers	Collocated sampler frequency
Maiden Rock	3	Once every third day.	0	Not applicable.
Sparta	1	Once every sixth day.	0	Not applicable.
Cataract Green	1	Once every sixth day.	0	Not applicable.
Downing	3	Once every sixth day.	1	Every twelfth day.

was no farming or mining activity during the sampling period. The processing facilities operated 24 hr per day while the sand mines operated 8 to 12 hr per day. The production rates at the three operating facilities ranged from 800 kt/a to more than 2.1 Mt/a (882,000 to more than 2.3 million stpy) of sand.

Sampling was conducted on either a once-every-third-day or once-every-sixth-day frequency as indicated in Table 3. The sampling days matched the once-every-third-day and once-every-sixth-day calendar schedule used in the U.S. EPA and state agency air monitoring networks. Accordingly, the data generated using the ambient PM4 particulate matter samplers could be compared with data generated simultaneously by U.S. EPA and state agency PM2.5 samplers in areas away from the sand-producing facilities.

Air Control Techniques designed the studies, specified the sampling and quality assurance procedures, selected the sampling locations, trained the sampler operators and summarized the results. A plant employee and a resident of the Maiden Rock area shared responsibility for operating the samplers at Maiden Rock. Mathy hired an independent contractor to operate the samplers at Cataract Green and Downing. A plant employee operated the samplers at Sparta. R.J. Lee prepared the polyvinyl chloride filters and shipped them directly to the sampler operator for each company. On a routine basis, the sampler operator returned the filters to R.J. Lee for crystalline silica analysis.

Sampling and analytical procedures. All four facilities used Partisol 2000i samplers to measure PM4 crystalline silica. During filter changes, the sampler operator performed required maintenance of the system's inlet and PM4 sharp cut cyclone. The sampling time was maintained between 23 and 25 hr, as required by 40 CFR Part 50 Appendix L Section 3.3.

R.J. Lee conducted the NIOSH Method 0600 gravimetric analyses and the NIOSH Method 7500 XRD crystalline silica analyses of the filters used in the sampling program. The XRD analyses included quartz, cristobalite and tridymite.

Each of the sampling network operators at the four facilities performed sampler audits every two weeks — a frequency that was twice as high as required by 40 CFR Part 50 Appendix L and the EPA quality assurance handbook. All eight of the samplers (seven primary samplers, one collocated sampler) used in these various studies successfully passed all of the sample flow rate, air temperature, filter temperature, ambient pressure and sample gas pressure audits. In addition to the operator audits, Air Control Techniques conducted an independent audit of each sampler on a quarterly basis. All eight of the samplers used in these four sampling programs passed each of these quarterly audits.

Air Control Techniques conducted three-point calibrations using a Chinook Engineering Inc. NIST-traceable calibrator. These calibrations were conducted at the beginning and at the 12-month point in each study.

The Partisol instruments logged the sample flow rate, ambient temperature, filter temperature, ambient pressure and electrical operating conditions every five minutes during sampling. The 5-min data logs along with the biweekly and quarterly audit and leak check data confirmed that all the samplers worked well throughout the sampling programs.

Every 10th filter was installed in the sampler and immediately recovered. These blank filters were analyzed to check for any filter damage or contamination problems. More than 98 percent of the blanks had crystalline silica levels below the LOQ. There were small variations in the PM4 particulate matter levels in a small fraction of the blanks. The results of the blank filter analyses demonstrated that the filter handling procedures were consistent with good practices.

The data availability of the sampling project was quite good. Each of the samplers operated more than 98 percent of the scheduled sampling days and 100 percent of the time during an especially severe winter in 2012-2013.

Davis Vantage Vue weather stations monitored the wind speed, wind direction, air temperature and precipitation quantities. The sensors were mounted at 4-m (13-ft) elevations at each facility. Air Control Techniques compiled and reviewed the meteorological data as 2-hr averages.

Ambient PM4 crystalline silica sampling results

There were a total of 657 24-hr sample values from a total of seven different sampling locations. The long-term average ambient PM4 crystalline silica concentrations were low at all of the sampling locations.

Table 4 provides a summary of the ambient PM4 crystalline silica concentration data. Each of the seven data sets covers a period of more than one year. All of the data sets with the exception of the Maiden Rock Southwest site data set had values above the LOQ less than 25 percent of the sampling days. The average concentrations summarized in Table 4 were calculated in two alternative ways: (1) using zeros for values below the LOQ and (2) substituting a value

calculated as the LOQ divided by the square root of 2 for values below the LOQ. The latter approach is based on the procedures of Hornung and Reed (1990).

The weighted arithmetic average PM4 crystalline silica concentration for the combined set of 657 observations is 0.15 micrograms/m^3 when values below the LOQ are treated as zeros and 0.32 micrograms/m^3 when values below the LOQ are treated as the LOQ divided by the square root of 2.

All of the long-term average PM4 crystalline silica concentrations at all seven locations at the four facilities were less than 20 percent of the OEHHA REL of 3.0 micrograms/m^3.

Wilcoxon-Mann Whitney nonparametric analyses of the data were used due to the skewed data distributions. These analyses indicated that there are no significant differences in the arithmetic average values of five of the data sets ($U = -0.787$ to 0.909, $p = 0.363$ to 0.876) compared with the Cataract Green greenfield site. There is a significant difference ($U = 5.482$, $p = 0.000$) at the 95 percent confidence level for the Maiden Rock Southwest site, having an average concentration of 0.45 micrograms/m^3, and the Cataract Green site, having an average concentration of 0.07 micrograms/m^3. The long-term average PM4 crystalline silica concentrations at all of the sampling sites were low.

No significant differences in PM4 crystalline silica concentrations were observed as a function of the wind speed. Concentrations were slightly higher in the spring and summer than in the winter due to snow cover and reduced activity of farms and other sources contributing to background concentrations. The seasonal variations were small.

During the time period of sampling, no mining or farming was underway at the Cataract Green site. Furthermore, there was no truck traffic into the site. Accordingly, the PM4 crystalline silica concentrations measured at this site were entirely due to the local background concentrations in this area. The data summarized in Table 4 indicate that the measured PM4 crystalline silica concentrations at all the sampling locations were similar to local background concentrations.

To evaluate the contributions of the local background, the upwind-to-downwind differences in the PM4 concentrations were evaluated for the Downing facility. The upwind and downwind concentrations each sampling day at Downing were determined based on the wind direction data measured at the Downing East sampling location. A plot of the upwind-to-downwind differences shown in Fig. 2 indicates that there was no detectable difference in the PM4 crystalline silica concentrations on most of the sampling days. There is no significant difference in the means of the upwind and downwind concentrations at Downing. The observed upwind-to-downwind differences were probably due in part to slight, localized variations in the local background concentrations.

Previously, in the absence of directly measured ambient crystalline silica data, the Wisconsin Department of Natural Resources (2011) used elemental silicon in the PM2.5 size fraction as a surrogate to estimate maximum possible ambient crystalline silica concentrations. It summarized elemental silicon levels in PM2.5 particulate matter for three sites in southeastern Wisconsin over the period of 2001 through 2009. It calculated maximum crystalline silica concentrations of 0.10 micrograms/m^3 in Mayville in Dodge County, 0.14 micrograms/m^3 in Milwaukee in Milwaukee County and 0.32 micrograms/m^3 in Waukesha in Waukesha County. In

Table 4

Summary of 24-hr PM4 crystalline silica measurements.

Sampling location	No. of 24-hr samples	No. of samples above LOQ	Arithmetic average concentration (microgram/m^3), values < LOQ treated as 0.0	Arithmetic average concentration (microgram/m^3), values < LOQ treated as LOQ/$\sqrt{2}$	99th percentile concentrations (microgram/m^3)
Maiden Rock Northwest	126	18	0.09	0.28	0.67
Maiden Rock Southwest	128	74	0.45	0.54	1.69
Maiden Rock Northeast	128	27	0.11	0.28	0.97
Sparta	90	10	0.05	0.24	0.51
Cataract Green	60	8	0.07	0.26	0.70
Downing West	62	12	0.11	0.29	1.10
Downing East	63	13	0.10	0.27	0.72
Weighted average			**0.15**	**0.32**	

calculating these maximum concentrations, the department assumed that 100 percent of the elemental silicon was in the form of crystalline silica. The concentrations summarized in Table 4 compiled during this study are similar to those estimated by the department for these urban areas.

The low long-term average concentrations of PM4 crystalline silica measured at these four facilities were slightly lower than the 0.4 to 2.8 micrograms/m^3 concentrations that we measured in 2009 in San Diego and Tracy. The production rates of the California facilities were similar to those of the Maiden Rock facility. The samplers used in the California studies were all between 61 and 305 m (200 and 1,000 ft) of the quarry haul roads and processing equipment. The crystalline silica content of the material handled at the California plants was less than one-half of the levels at the Wisconsin facilities. The 12-to-18-month average concentrations measured in Wisconsin were also lower than the 0.4 to 1.1 micrograms/m^3 concentrations measured by the South Coast Air Quality Management District (2006, 2008) in Duarte, California. At Duarte, the samplers were between 1.9 and 4.0 km (1.2 and 2.5 miles) from four sand mines located to the northeast, east and southwest (two mines).

The data compiled in the sampling studies at the four Wisconsin facilities indicate that the PM4 crystalline silica concentrations at the fencelines of sand-producing facilities are within the range of local background concentrations. Sources contributing to the background levels of ambient crystalline silica include agricultural operations (Archer et al., 2002; Nieuwenhuijsen et al., 1999; Norton and Gunter, 1999; Stopford and Stopford, 1995), unpaved roads (Baker, 2003; Rice, 2000; Wisconsin Department of Natural Resources, 2011), construction activities (Rice, 2000), wind erosion (Gillette, 1997), and long-range transport of desert dusts (Syzkman, 2005; Van Curen and Cahill, 2011).

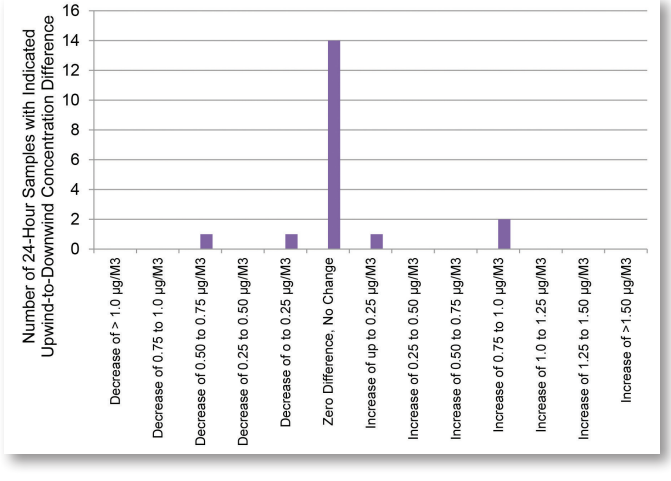
Additional sampling is needed to determine the variations in localized background PM4 crystalline silica concentrations in Wisconsin, in arid parts of the United States, in areas with high agricultural activity, and in areas with public unpaved roads with moderate traffic volume. Additional work is also needed to evaluate the contribution of the global transport of Gobi and Saharan dust to 24-hr average ambient PM4 crystalline concentrations.

The low PM4 crystalline silica concentrations observed in these sampling programs are consistent with the well-recognized hardness of crystalline silica. High energies are needed to grind crystalline particles down to the PM4 size range. The sand-processing operations evaluated as part of these sampling programs do not use sufficient energy to form large quantities of PM4 particulate matter. Most of the raw materials at the mine and prior to the sand dryers have minimal emissions due to an inherently high moisture content. After drying at processing facilities, the sand is handled in enclosed systems with high-efficiency dust collectors.

In their 2011 summary concerning ambient crystalline silica, the Wisconsin Department of Natural Resources (2011) stated that "...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." This statement echoed an earlier U.S. EPA (1996) statement concerning the lack of ambient crystalline silica sampling data. The sampling data summarized in this paper combined with data from other recent studies specific to fenceline PM4 crystalline silica concentrations is expected to help address these concerns.

Figure 2

Upwind-to-downwind PM4 crystalline silica concentration differences at Downing.



Summary

A total of 657 daily average PM4 crystalline silica measurements were completed at the fencelines of sand-producing facilities in Wisconsin. The long-term average concentrations measured at seven sampling locations in the set of four facilities were all 5 to 20 percent of the Minnesota Department of Health's and California Office of Environmental Health Hazard Assessment's 70-year chronic reference exposure level of 3.0 micrograms/m^3.

The low measured fenceline concentrations are within the range of background PM4 crystalline silica concentrations resulting from fugitive dust emissions from farms, public unpaved roads, various industrial sources, and natural sources. These low measured ambient PM4 crystalline silica concentrations are consistent with previous studies in California, the characteristics of the process operations, and the physical characteristics of crystalline silica.

The PM2.5 U.S. EPA Federal Reference Method samplers adapted for PM4 particulate matter sampling worked well in all of the sampling programs. All of the samplers passed routine audits conducted on both a biweekly and quarterly basis. Filter blank analyses confirmed proper field and laboratory procedures. The samplers operated reliably even under severe weather conditions. ■

Acknowledgments

The authors gratefully acknowledge the significant contributions of the numerous individuals who routinely serviced, audited and maintained the PM4 samplers and associated instruments. Fairmount Santrol Inc., Mathy Construction Inc. and U.S. Silica Inc. purchased the samplers and sponsored the contractors conducting the sampling and the filter analyses. Wisconsin Department of Natural Resources personnel provided valuable assistance in the review of

some of the sampling program protocols. R.J. Lee Group Inc. conducted the NIOSH Method 7500 analyses.

Disclosure statement

Air Control Techniques P.C. is an independent engineering and testing company. Air Control Techniques P.C. was paid consulting fees to select the sampling equipment, select the sampling locations, prepare the test program protocols, train the sampler operators, and reduce the data compiled throughout the sampling program. Air Control Techniques P.C. has no financial interests in the three companies participating in these studies.

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