Final Release

Health Consultation

Exposure Assessment

Western Mineral Products Site

City of Minneapolis, Hennepin County, Minnesota

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Prepared by:

The Minnesota Department of Health
Under Cooperative Agreement with the
Agency for Toxic Substances and Disease Registry

FOREWORD

This document summarizes public health concerns at a hazardous waste site in Minnesota. It is based on a formal site evaluation prepared by the Minnesota Department of Health (MDH). For a formal site evaluation a number of steps are necessary:

- *Evaluating exposure:* MDH scientists begin by reviewing available information about environmental conditions at the site. The first task is to find out how much contamination is present, where it is found on the site, and how people might be exposed to it. Usually, MDH does not collect its own environmental sampling data. We rely on information provided by the Minnesota Pollution Control Agency (MPCA), U.S. Environmental Protection Agency (EPA), and other government agencies, private businesses, and the general public.

- *Evaluating health effects:* If there is evidence that people are being exposed—or could be exposed—to hazardous substances, MDH scientists will take steps to determine whether that exposure could be harmful to human health. Their report focuses on public health; that is, the health impact on the community as a whole, and is based on existing scientific information.

- *Developing recommendations:* In the evaluation report, MDH outlines its conclusions regarding any potential health threat posed by a site, and offers recommendations for reducing or eliminating human exposure to contaminants. The role of MDH in dealing with hazardous waste sites is primarily advisory. For that reason, the evaluation report will typically recommend actions to be taken by other agencies—including EPA and MPCA. If, however, an immediate health threat exists, MDH will issue a public health advisory warning people of the danger, and will work to resolve the problem.

- *Soliciting community input*: The evaluation process is interactive. MDH starts by soliciting and evaluating information from various government agencies, the individuals or organizations responsible for cleaning up the site, and community members living near the site. Any conclusions about the site are shared with the individuals, groups, and organizations that provided the information. Once an evaluation report has been prepared, MDH seeks feedback from the public. *If you have questions or comments about this report, we encourage you to contact us*.

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Summary

This document estimates potential exposures to asbestos fibers through a variety of exposure pathways from the processing of vermiculite ore at the former Western Mineral Products/W.R. Grace site in Northeast Minneapolis, Minnesota. It is based on the findings of a previous health consultation (MDH 2001) and work being conducted by the U.S. Environmental Protection Agency (EPA) and the Agency for Toxic Substances and Disease Registry (ATSDR) in Libby, Montana. This document is also intended to help facilitate the evaluation of potential exposures and the communication of health recommendations to study participants in the Northeast Minneapolis Community Vermiculite Investigation (NMCVI). With funding from ATSDR, MDH is conducting the NMCVI, to 1) assess potential exposures to asbestos fibers from the site in Northeast Minneapolis and 2) develop a cohort of exposed persons.

MDH estimates that the highest exposures occurred in the past to plant workers, their household contacts, and people who played in, handled, or otherwise had direct contact with wastes from the site. Residents who lived very near the plant also may have been exposed to asbestos-containing dust in the air from plant emissions. Lower level exposure occurred from the use of asbestos contaminated waste materials from the site in yards, gardens, and driveway surfaces and may be ongoing, but are being addressed through cleanup activities conducted by the EPA.

I. Background and History

The Western Mineral Products site, located at 1720 Madison Street NE and 1815 Jefferson Street NE, operated from the mid-1930s to 1989. The location of the site is shown in Figure 1. In approximately 1963 W.R. Grace took over the plant, and at the same time purchased the mine and associated processing facilities in Libby, Montana. The plant produced vermiculite through the use of two expansion furnaces from ore mined and processed in Libby. Existing documentation from W.R. Grace indicates that while it operated, the plant processed well over 100,000 tons of vermiculite ore. Because the records are incomplete, the actual amount could have been much higher. The raw vermiculite ore mined in Libby was contaminated with amphibole asbestos of the actinolite-tremolite-winchite-richterite mineral series (hereinafter ‘Libby asbestos’) at concentrations of up to 25% or more. Actual concentrations in the ore shipped to the various expansion plants across the country were probably lower due to the processing of the ore (‘beneficiation’) in Libby prior to shipment. The ore was usually shipped by rail.

Exposure Pathway Evaluation

In an earlier health consultation (MDH 2001) MDH identified the following exposure pathways to Libby asbestos fibers from contaminated vermiculite wastes or products from the site:

- workplace exposure by former workers at the site (and the subsequent exposure of their families),
- playing in or handling of wastes from piles of “stoner rock” dumped outside the facility,
- inhalation of Libby asbestos fibers from stack and fugitive dust emissions,

- exposure to asbestos fibers from the disturbance of waste materials used at residential properties,
- infiltration of dust into buildings, and
- ingestion of fibers from contaminated soil, dust, or food products grown in contaminated soil.

A conceptual model of exposure pathways to Libby asbestos from the site is attached as Figure 2. Also, an additional exposure pathway has since been identified, which is exposure through the handling or disturbance of vermiculite insulation used in homes or businesses.

Workers and their Families

MDH has reviewed workplace air monitoring data collected by W.R. Grace from 1972 to 1988 (HRO 2000). Area samples and personnel monitoring samples were collected, usually on an annual basis. Appendix I contains a summary of the available data. For personnel samples, several short-term (30 minutes to 2 hours) air samples were typically collected over the course of a work shift. These were averaged to determine the time-weighted average (TWA) for comparison to Occupational Safety and Health Administration (OSHA) workplace limits. In Appendix I, only the highest reported individual sample concentration for a given workday is reported. The concentration therefore likely represents a higher than usual fiber concentration than would have existed for the entire shift. The plant air samples were collected in areas thought to be representative of general exposures, or exposures in specific areas such as the bagging station or lunchroom. They were usually collected within a person's breathing zone. The air samples were analyzed for total fibers by phase contrast light microscopy (PCM). The measured fiber concentrations reported in Appendix I are close to those Amandus et al (1987) estimated to have existed in similar workspaces in the mining and ore processing facilities in Libby.

Workplace exposures (as measured by personnel samples) as high as 19 fibers per cubic centimeter of air (f/cc) were found in the early 1970s (HRO 2000). Short-term air concentrations in the range of 1 to 10 f/cc were common in the early and mid-1970s. The highest fiber concentration observed in any sample (57.57 f/cc) was found in 1974 in a short-term area sample collected just outside the open door to the ore storage bins during unloading of Libby ore #3. These results generally correspond with data described in an EPA report (EPA 1991), which indicated that the highest airborne fiber exposures in a vermiculite processing facility in Ohio were found in the vermiculite expanders area, and in railroad car and truck unloading areas. By the early 1980s, workplace fiber concentrations were lower—generally less than 0.5 f/cc in short-term samples. The lower fiber concentrations were presumably a result of improved ventilation or equipment modifications at the facility. Specific workplace operations, such as the product mixing and bagging stations, were clearly locations where elevated fiber concentrations were common throughout the life of the facility. No data are available prior to 1972; fiber concentrations could have been higher at that time than those observed later. It is important to note that fibers other than asbestos fibers could have been present in the air samples, and contributed to the total fiber count.

A continuing source of high fiber counts was associated with an area of the plant where the stoner rock was loaded into wheelbarrows for disposal (often identified as the "waste rock hopper"). In a 1978 short-term sample, fiber concentrations in this area were 13.53 f/cc. As late as 1984, fiber concentrations were 1.65 f/cc. A water spray was in use to try to reduce dust levels at the time the air samples were collected. In several W.R. Grace memos, equipment problems were also noted in this area (HRO 2000).

In a sample collected in 1978, fiber concentrations measured in the lunchroom—located 60 feet from the bagging station—were 3.0 f/cc. A sample collected in 1981 was lower—0.09 f/cc. In January 1978, in a presumed test of the effectiveness of plant ventilation equipment and techniques (such as leaving the windows open), samples collected from several areas of the plant while it was in operation were repeated the next day, when the plant was not in operation. The results show that the ventilation in the plant was somewhat effective at reducing fiber concentrations during periods of shutdown. The results are presented in Table 1:

Table 1: Airborne Fiber Concentrations Inside the Western Mineral Products Plant, 1978 Ventilation Test

Workplace Area	PCM Fiber Concentrations in f/cc, January 25, 1978	PCM Fiber Concentrations in f/cc, January 26, 1978
#2 Furnace Room	5.3	0.7
3rd Floor Bagging Station	5.6	1.20
Lunchroom	3.0	0.87

From: HRO 2000

The results in Table 1 suggest even when the plant was not in operation, short-term fiber counts may have been elevated due to the cumulative effect of operations and disturbance of dust.

PCM is unable to distinguish fiber type. Thus some of the fibers observed throughout the years of sampling might not have been asbestos, or perhaps not Libby asbestos. For instance, some materials produced at the plant such as “Monokote” fire proofing compound contained, in addition to vermiculite, commercial (chrysotile) asbestos. Prior to bagging, the commercial asbestos was mixed with vermiculite and other products—apparently in open mixers. As described in the air permit information submitted to the MPCA (HRO 2000), this mixing operation was vented through a roof stack.

It should be noted that in terms of fiber detection, PCM has limitations. As stated above, PCM cannot determine fiber types. Fibers detected and counted by PCM methods are generally equal to or longer than 5 micrometers (µm), have a thickness of approximately 0.25 µm or greater, and an aspect ratio (length to width ratio) of at least 3:1. On the other hand, transmission electron microscopy (TEM), with energy dispersive X-ray analysis, is capable of determining fiber types and can characterize fiber sizes much smaller than those detected by PCM. To facilitate comparisons between results of the two analytical methods, TEM results are often reported as PCM fiber equivalents, indicating that only those fibers with the dimensions detectable by PCM are reported. At this time, PCM results are generally more applicable for determining risk. Although inadequate, current risk assessment methods (see below) are based on PCM fiber measurements—the required testing method in occupational settings.

Unfortunately, due to a lack of data the exposures to workers' families cannot be estimated. Several difficult-to-estimate behavior-specific factors—such as laundry habits—would likely have determined exposure. Still, exposure to asbestos resulting in asbestos-related disease in family members of asbestos industry workers has been well documented (Anderson et al 1976, Kilburn et al 1985). In Libby, Montana, an elevated prevalence of pleural abnormalities was also observed in the household contacts of workers at the mine and associated vermiculite processing facilities (ATSDR 2002).

It appears that in 1989 W.R. Grace conducted some cleanup of the building interior at the site prior to selling it. This was documented in a memorandum (HRO 2000) by MDH. The memorandum was in response to concerns raised by a small company hired by W.R. Grace to remove the machinery from the plant. MDH inspected the site and recognized that while the vermiculite processed at the site contained tremolite asbestos, it was generally less than 0.1% and was "not ordinarily considered to be an asbestos-containing material" (HRO 2000). MDH staff collected three debris/dust samples at the site, one of which was determined to contain 1% richterite asbestos. By the time MDH collected the samples, most of the equipment removal and cleanup had been done. MDH concluded that the work being done at the site "did not involve removal of asbestos," so no further actions were taken. But while they were involved with the cleanup, the workers could have been exposed to Libby asbestos.

Approximately 1 month after the 1989 MDH site visit, W.R. Grace's Environmental Health Group collected air samples to "document the effectiveness of plant clean-up procedures after equipment removal and plant wash down was completed." (HRO 2000). Five air samples were collected and analyzed by PCM from the bagging station (0.0012 f/cc), furnace area (0.0091 f/cc), stoner rock separator area (0.0004 f/cc), warehouse (0.0032 f/cc), and from along Madison Street NE just southeast of the main building (0.0008 f/cc). All five samples were collected over about a 3-hour period, and contained low fiber counts.

Multiple air and dust samples collected inside of the site building in 2000 showed very low levels of Libby asbestos fibers, confirming that the 1989 Grace building cleanup was mostly successful (see MDH 2001). Fugitive dust emissions from contaminated outdoor parking and storage areas remained, however. Thus, even after W.R. Grace sold the site in 1989, workers at several small, on-site or adjacent businesses could have been exposed to low levels of Libby asbestos (see below).

Exposure from Waste Piles

Plant employees, children, and others were likely exposed to Libby asbestos from handling or playing in the piles of "stoner rock" dumped outside of the plant. W.R. Grace records indicate that the stoner rock contained between 2% and 10% Libby asbestos. A sample of what appeared to be stoner rock was collected by MDH staff from a bag of it reportedly saved by a former resident of Northeast Minneapolis. This sample contained 10% tremolite/actinolite asbestos by Polarized Light Microscopy (PLM) analysis. Exposures would have occurred from jumping or playing in the waste piles, or when area residents loaded the waste rock into containers or vehicles and used it at their homes. Using personal air monitors placed on workers engaged in cleanup activities at two of the former ore processing facilities, researchers have measured using PCM methods the potential exposure from the disturbance of wastes piles in Libby, Montana

(Weis 2001a). The concentration of Libby asbestos in the Libby waste materials ranges from less than 1% up to 10% by mass—similar to that reported for the Western Mineral Products stoner rock. The work activities monitored in Libby at the former ore screening and export plants included sweeping, bagging, and moving of contaminated soil and wastes. Analysis using TEM methods confirmed the presence of Libby asbestos fibers. Data from this study are presented in Table 2 (Weis 2001a).

Table 2: PCM Fiber Concentration in Air Associated with Waste Pile Disturbance

Sample Location	Average, f/cc	Maximum, f/cc
Screening Plant	0.07*	1.72
Export Plant	0.14†	1.60

* Non-detects evaluated by assuming a value equal to the detection limit. From: Weis 2001a

† Detection limit not reported; non-detects evaluated by assuming a value of zero.

Because of the similarity in the activities, residents of Northeast Minneapolis who reported taking waste materials from the piles for use at their homes likely experienced levels of exposure in the same range as the average concentrations in Table 2. For those residents who played in the waste piles as children, the estimated exposures could have been higher due to the closer contact they would have had with the waste materials. The photograph of the two young children playing in the waste pile at the site that is in a previous health consultation graphically illustrates this point (see MDH 2001). Children are smaller than adults, their breathing rate is proportionally higher than adults, and their breathing zones are closer to the ground. Thus for them, exposures could have been closer to the maximum fiber concentrations listed in Table 2. In children, there also may be physiologic differences that affect the amount of particulates (or fibers) that reach the lungs (ATSDR 1999). Their respiratory clearance mechanisms may still be developing. Because of these factors, and the long latency period associated with asbestos-related disease, those who reported significant exposure during childhood could also have a higher risk of adverse health effects during their lifetime.

Airborne Emissions

During its operation, Libby asbestos was released from the plant in emissions from the two furnace stacks and a product mixing operation vent stack (described above). It was also released from fugitive dusts generated during the unloading and handling of ore, loading of products, disturbance of waste piles, and other sources. While the plant was in operation, the only known air sample collected outside the plant was in 1972 (HRO 2000). The sample location was described as “on fence, downwind of outside stoner scrap pile,” and the result over a 56-minute sampling period was, by PCM analysis, 0.3 f/cc. This location was likely near the property line along Jefferson Street NE, on the western edge of the site. EPA reported asbestos fiber exposure levels of 0.00005 micrograms of asbestos per cubic meter of air (approximately 0.000002 f/cc) near active vermiculite exfoliation plants (EPA 1991). The background concentration of asbestos fibers in ambient air ranges from 0.000003 f/cc in rural areas to 0.003 f/cc near specific industrial sources such as asbestos mines (ATSDR 1999).

As referenced earlier, even after the plant was shut down and sold by W.R. Grace in 1989, residual on-site contamination continued to generate fugitive dusts. In 1989 W.R. Grace staff collected an ambient air sample to document the effectiveness of the cleanup of the former plant.

The sample, collected over 198 minutes from along Madison Street NE just southeast of the main building had, by PCM analysis, a fiber count of 0.0008 f/cc. Ambient air samples collected by EPA in 2000 at several locations within one to two blocks of the plant and analyzed using TEM methods showed few detections of Libby asbestos fibers (MDH 2001). When Libby asbestos was detected, the concentrations were typically around 0.001 f/cc. Differences in sample collection methods, analytical methods, and weather factors could be some of the reasons the fiber count was higher in the 2000 samples than in the 1989 sample.

MDH staff have worked with staff of the Minnesota Pollution Control Agency (MPCA) to develop an air dispersion model using the EPA ISC-Prime software package (Pratt 2002). Input data for the model were developed from W.R. Grace documents, MPCA records, and assumptions made about plant operation. The model output has been divided into several time periods, corresponding with various phases of operations at the site: start of operation to the installation of the baghouse filters (1936-1972), installation of the baghouse filters until plant shutdown (1972-1989), post plant shutdown (1989-1999), and post expansion of the Electramatic building (1999-2001). The expansion of the Electramatic building (on the north portion of the former Western Mineral Products site) covered an area of contaminated soils, eliminating it as a source of fugitive dusts. The model also includes some of the contaminated residential properties identified by EPA as additional sources of fugitive dusts in the neighborhood around the site. Fugitive dusts represented an increasing proportion of the overall emissions over time, especially after the 1972 installation of the baghouse filters. A description of the modeling procedures and a summary of the input parameters are presented in Appendix II.

While for many reasons uncertainty exists in the air dispersion model, the model represents the best available tool for estimating the extent of potential areal emissions from the site. The numeric estimates of fiber concentrations in ambient air and fiber deposition could be less reliable—except for areas relatively close to the site. They are best used for relative comparison of exposures within the modeled area as opposed to absolute comparison against a given air quality criterion. The model output should be considered as the "best central estimate" of the actual value (Pratt 2002). Potential sources of uncertainty include 1) the applicability of the meteorological data used for the model, 2) reliability of W.R. Grace historical information, 3) the variability in the Libby asbestos concentration in the vermiculite ore received from Libby, and 4) the assumptions made regarding the generation of fugitive dusts, the applicability of the model with regard to fiber dispersion versus particulate dispersion, and the mass conversion of particles to fibers. Further discussion of uncertainties in air dispersion modeling is presented later in this document.

The nominal long-term airborne Libby asbestos concentrations and overall estimated deposition of fibers for the four scenarios described above have been calculated for each property within the entire NMCVI study area and beyond. The NMCVI study area is within the rectangle defined by Broadway Street NE on the south, Central Avenue NE on the east, 27th Avenue NE on the North, and University Avenue NE on the west. The estimated maximum average long-term and 1-hour air concentrations and the overall percent fugitive emissions for the four modeling scenarios are presented in Table 3.

Table 3: Estimated Maximum Long-Term Average and 1-Hour Air Concentrations of Libby Asbestos, Nominal f/cc

Modeling Scenario	**Max. Long-Term Concentration***	**Max. 1-Hour Concentration**	**Percentage Fugitive Emissions**
1936-1972	0.026	0.89	2%
1972-1989	0.0027	0.19	28%
1989-1999	0.00038	0.029	100%
1999-2001	0.00013	0.010	100%

*24 hours per day, 365 days per year

From: Pratt 2002

These maximum air concentrations were found generally at the site, near the emission points. The estimated maximum long-term average air concentrations, which represent 24-hour per day, 365 days-per-year concentrations, vary by approximately an order of magnitude over the first three modeling scenarios. The estimated maximum 1-hour concentrations represent the worst-case situations immediately at the site. A frequency distribution calculated for a 5-year time period during the 1936–1972 modeling scenario estimated that ambient air concentrations of 0.1 f/cc occurred approximately 1.6% of the time on the site itself.

For display purposes the results of the air dispersion model have been incorporated into Geographic Information System (GIS) software. The average nominal long-term fiber concentrations estimated by the model for the four modeling scenarios are presented in Figures 3 through 6. Figure 5a shows the average nominal long-term air concentrations for 1989–1999 together with the locations of contaminated properties to illustrate the effect of these properties on the overall model results. As can be seen from the figures, the estimated nominal average fiber concentrations drop off exponentially with distance from the site. Note that the isopleths in Figures 5 and 6 are centered slightly to the north of the site. This is due to the fact that stack emissions had ceased and fugitive dusts had become the sole emission source. The main sources of fugitive dust were the large gravel parking / storage lots on the north side of the site (the Electramatic area).

The estimated nominal total deposition of Libby asbestos fibers (in fibers per square meter) over the area around the site from 1936–2001 is presented in Figure 7. The majority of the estimated fiber deposition (96 %) is from the time period of 1936–1972, before the installation of air pollution control equipment at the site (Pratt 2002). The maximum estimated deposition is on the order of 10 billion fibers per square meter in areas near the site, and in the hundreds of millions even at some distance from the site. Because the majority of the fiber deposition occurred before 1972, it has not been possible to validate the model results with field data from the area. Asbestos fibers deposited from airborne emissions are subject to environmental factors over time, e.g., stormwater runoff, re-entrainment into the air, mixing with soil or other organic matter, and human and mechanical disturbance. These factors explain the general lack of a "background" level of asbestos contamination in soil in the area around the site. Soil samples collected by EPA to define the extent of contamination at residential properties where waste materials from the plant were used (see below) invariably find non-detections, even at sites near the plant.

Exposure to Waste Materials used at Residential Properties

As of October 14, 2002, the EPA had identified a total of 260 properties as being contaminated by waste materials (primarily Libby asbestos) from the former Western Mineral Products site (EPA 2002). The majority of these properties are within the NMCVI study area, and are relatively close to the plant. Several sites are located in distant suburbs, however. The locations of the properties near the site are shown in Figure 8. Since the summer of 2000, EPA has been engaged in the investigation and cleanup of these properties. Over 1,600 residential, commercial, and recreational (park) properties were inspected by EPA staff. The NMCVI protocol also involved an inspection of the majority (over 1,600) of the residential properties within the study area defined above.

The waste materials were generally used by local residents for fill in driveways or yards, as landscape rock, or as a soil amendment. The waste materials supplied (generally stoner rock) were contaminated with between 2% and 10% Libby asbestos, which often remains visible as small, white fibrous grains where the waste materials were used. To confirm the presence of Libby asbestos and define its extent, the EPA typically collects soil samples in the area, excavates the waste materials to a maximum depth of 18 inches, restores the area, and disposes of the contaminated soil in a local landfill. If contamination extends below 18 inches, a layer of geotechnical fabric is placed at that depth as a marker. The work is done according to OSHA requirements for asbestos cleanup, including the use of personal protective equipment, decontamination areas, and air monitoring.

Area residents could have been exposed to Libby asbestos if the waste materials were disturbed through such activities as gardening, lawn mowing, or playing on a contaminated yard, driveway or alley. Disturbance of the waste materials, especially in dry conditions, would likely re-entrain asbestos fibers into the air where they could be inhaled. In Libby, Montana, the EPA simulated the exposure from tilling a garden contaminated with approximately 1% Libby asbestos using a personal air monitor (Weis 2001b):

Table 4: Concentration of Fibers in Air Associated with Rototilling

Analytical Method	Mean Concentration of Detects, f/cc
PCM	0.23
TEM*	0.07

*Transmission Electron Microscopy, PCM fiber equivalents. From: Weis 2001b

The samples were presumably short-term, and were analyzed using both PCM and TEM methods. A lower fiber count was observed using TEM, indicating that some of the fibers observed using PCM may not have been asbestos fibers. But the soil in the garden where the simulation was conducted was at the low end of the typical range for contaminated properties in Northeast Minneapolis (<1% to 8%; Weston 2002), and the samples collected by EPA were analyzed using light microscopy methods. Thus it might be more appropriate to use the PCM results to estimate exposure. These concentrations might also be reflective of other types of activities that could result in exposure under dry conditions, such as lawn mowing or intensive hand gardening.

Weis (2001a) has studied the release of Libby asbestos fibers from gravel roads subject to vehicle traffic in Libby. Surface materials used on the roads included in the study contained concentrations of Libby asbestos of up to 5%—again within the range observed in driveways and alleys at properties in Northeast Minneapolis. Stationary monitors were used in the study, and were operated for extended time periods so that the resulting data represents long-term concentrations from short releases produced by passing vehicles followed by longer intervals when no vehicles were present. The data are as follows (Weis 2001a):

Table 5: PCM Fiber Concentrations in Air from Stationary Road Monitors

Average, f/cc*	Maximum, f/cc
0.001	0.02

*Average value calculated using zero for non-detects. From: Weis 2001a

As the data show, Libby asbestos fibers are released by the passing of vehicles over contaminated surfaces. Asbestos fibers would have been released at residential properties where driveways or alleys were contaminated with waste materials from the Western Mineral Products site, adding to the exposure of residents at those properties. This contribution is reflected in the air dispersion modeling effort discussed above, although the total number of contaminated properties included at the time the model was run was approximately ½ the total number of contaminated properties eventually discovered.

Disturbance of Vermiculite Insulation

One of the primary commercial products of the Western Mineral Products/W.R. Grace plant was vermiculite insulation. The insulation was widely used in residential and commercial buildings in Minneapolis and potentially throughout the upper Midwest. Vermiculite insulation produced from Libby ore invariably contains residual trace amounts of Libby asbestos. The majority (73%) of samples of vermiculite insulation collected from homes in Libby showed detectable levels of Libby asbestos, ranging from a trace (<1%) to 5% by weight (Weis 2001b). A sample of vermiculite insulation collected from inside the former office of the Western Mineral Products building contained 0.3% tremolite asbestos by weight (BRW 2001). A vermiculite insulation sample collected by MDH staff from the attic of a home in Northeast Minneapolis contained a trace (<1%) of tremolite/actinolite asbestos.

Using personal air monitors, the EPA has measured air concentrations of Libby asbestos over short time periods associated with the disturbance of vermiculite insulation in homes in Libby (Weis 2001b). The studies were designed to simulate the exposure of homeowners who engaged in activities in attic areas or contractors who might encounter vermiculite insulation in the course of their work. The results are shown in Table 6 (Weis 2001b).

Table 6: Fiber Concentrations in Air Associated with
Disturbance of Vermiculite Insulation

Analytical Method	Mean Concentration, f/cc	Range, f/cc
PCM	0.57	0.12-1.62
TEM*	0.31	0.04-1.06

*Transmission Electron Microscopy, PCM fiber equivalents. From: Weis 2001b

The results of the study show that relatively high concentrations (in excess of current OSHA standards) of Libby asbestos fibers can be produced from the disturbance of vermiculite insulation in an enclosed space such as an attic. In 1980, W.R. Grace conducted studies of asbestos exposure during installation of vermiculite insulation in attics (described in EPA 2000). Using personal air monitors and PCM methods, W.R. Grace technicians measured fiber concentrations of 0.971 to 2.597 f/cc over short time periods. Exposure durations for typical homeowners are likely to be relatively short as well, unless statistically significant quantities of insulation are spilled into living areas where re-entrainment of the fibers can occur from routine cleaning or household activities. Certain tradespeople, however, such as plumbers, electricians, and telephone or cable TV workers, could experience more frequent exposures if their work involves entering attics with vermiculite insulation.

One unusual situation can be seen in Figure 9, where a furnace has been installed in the attic of a home previously insulated with vermiculite insulation. Analysis of an insulation sample collected by MDH showed a trace (<1%) of tremolite/actinolite asbestos. The effect on the potential exposure to residents in the home from having a furnace in the attic is not known. It is also not known how many structures in Northeast Minneapolis contain vermiculite insulation. Some locations have, however, been identified through the NMCVI field investigation.

Vermiculite is no longer used for building insulation but is sold for other consumer and commercial uses, primarily in agriculture. When the mine in Libby shut down in 1989, other vermiculite mines became the major sources, including mines in South Carolina, Virginia, and even South Africa. The ore from these mines typically contains only trace levels of asbestos fibers. An EPA study of commercially available vermiculite products from across the country (including Minnesota) showed trace amounts of asbestos fibers through both PLM and TEM analysis (EPA 2000). Nevertheless, those who are exposed to large quantities of vermiculite on a regular basis could still be exposed to small quantities of asbestos fibers.

Indoor Dust

Libby asbestos fibers could have entered buildings within the NMCVI study area through a variety of pathways. While it was in operation, airborne emissions from the plant were substantial, especially in areas close to the plant. Asbestos laden dust could have entered homes through windows, doors, air intakes, or other routes of entry. Anecdotal reports of dust from the plant entering homes were recorded in several complaints received by the city of Minneapolis in the 1960s and 1970s (see MDH 2001). Asbestos fibers could also have been brought into homes on the clothes of workers at the plant, or tracked into homes from waste materials used in driveways, gardens, or yards. Vermiculite insulation can also serve as a source of asbestos fibers if it is disturbed, or is spilled into living spaces.

EPA collected dust samples from homes in Libby and analyzed the samples using TEM methods (Weis 2001b). Libby asbestos fibers were detected at 25% of all residential and commercial locations where dust samples were collected. Fiber concentrations ranged from 20 to 22,645 asbestos structures per square centimeter—the common unit for reporting asbestos concentrations in dust. Unfortunately, no statistics are available as to the potential source(s) of the asbestos containing dust found in Libby structures; thus there is no way to relate the data to a source such as worker clothing, on-site sources such as a contaminated yard or driveway, or airborne emissions. Staff from MDH, EPA, and ATSDR have drafted a proposal for EPA to determine whether homes in Northeast Minneapolis contain asbestos contaminated dust, and if so, to determine the relative contribution of the various potential sources. To date, no action has been taken by EPA to implement the proposal.

EPA also measured short-term air concentrations in homes where asbestos-containing dust was found under common conditions that could result in disturbance of the dust, again using personal air monitors (Weis 2001b). Two scenarios were tested: routine household activities and active cleaning. The data are presented in Table 7.

Table 7: Fiber Concentration in Air Associated with Household Activities

Scenario	**Analytical Method**	**Mean Conc. f/cc**	**Range, f/cc**
Routine Activity	PCM	0.007	0.001-0.014
	TEM*	0.035	0.023-0.048
Active Cleaning	PCM	0.112	0.014-1.017
	TEM*	0.010	0.004-0.013

*Transmission Electron Microscopy, PCM fiber equivalents. From: Weis 2001b

The results of the testing indicate that even routine household activities are capable of generating measurable airborne concentrations of Libby asbestos fibers in homes with asbestos-containing dust. Active cleaning can generate higher fiber concentrations, at least when measured using PCM methods. The data for this study are unusual, and show that different analytical methods can produce different results due to possible interference from non-asbestos fibers or other factors.

Ingestion of Asbestos from Contaminated Soil

Incidental ingestion of soil containing asbestos fibers, either through direct contact or through the ingestion of contaminated produce, is likely to be a minor exposure pathway compared to the inhalation route. In addition, the potential health risk from ingestion of asbestos fibers is not well understood.

II. Discussion

Asbestos-related disease (with the possible exception of mesothelioma) is likely the result of the accumulation of a dose (or "burden") of asbestos fibers sufficient to cause long-term inflammation of lung or pleural tissues, resulting in fibrosis, scarring, or tumors. For this reason, exposure estimates expressed in units of fibers per volume unit of air might not be the most accurate measurement of exposure. They do not take into account fiber clearance mechanisms, the biopersistence of the fibers, or individual differences. A metric that incorporates overall fiber burden in the lung, either estimated or measured directly (something done only with great difficulty in living persons) may be a more appropriate measure of dose, especially for environmental exposures (Case 2001). Epidemiological studies of asbestos workers sometimes use units of fiber-years per cc to represent cumulative exposure.

The accumulation of fibers can occur as a result of high-level exposure over a short period of time, or lower level exposure over a long period of time. A recent journal article describes the case of a 65-year old worker who died from asbestosis as a direct result of a relatively brief, high level exposure to vermiculite products, wastes or both some 50 years earlier (Wright et al 2002). The worker had been employed in a vermiculite expansion plant, likely similar to the facility in Northeast Minneapolis, for two consecutive summers in the early 1950s. Job activities included unloading vermiculite ore, operating a forklift, and shoveling ore into bags or into the expansion furnaces. From the data collected at the Northeast Minneapolis plant, some of these activities could have resulted in substantial fiber exposures, perhaps in excess of 50 f/cc over short time periods. The worker's subsequent career did not involve working with asbestos products, although the worker did smoke cigarettes for approximately 20 years. The worker remained essentially asymptomatic until the last 6 months of life, when lung function declined rapidly. After death, the concentration of tremolite asbestos fiber bodies in the worker's lungs was determined to be 5.94 million fibers per gram of dry lung tissue. An asbestos fiber body is formed when the body, in an attempt to isolate or destroy the fiber, coats or encapsulates it with organic material. An elemental comparison of the fiber composition from the worker's lungs with a sample of vermiculite from Libby showed remarkable consistency.

A similar case was reported by Hiraoka et al (2001). A person who was exposed to asbestos during military service some 50 years before was diagnosed with lung cancer. The person, also a smoker, had not been exposed to asbestos after military service. Analysis of lung tissue specimens showed a fiber burden of 3,348 asbestos fiber bodies per gram of dry lung tissue, with amphibole asbestos, including tremolite, predominating. Extensive pleural plaques were also noted in this case.

There is also evidence that environmental exposure to tremolite asbestos could result in asbestos related disease. A past study of asbestos related disease from exposure to tremolite asbestos cited a case of asbestosis and lung cancer in a person who lived near a vermiculite processing plant for the first 20 years of life, and reportedly sometimes played in piles of vermiculite tailings (Srebro and Roggli 1994). Upon autopsy, the fiber burden of tremolite asbestos in the lungs was approximately 124,000 fibers per gram of wet lung tissue. Environmental exposure to tremolite asbestos has also been associated with elevated rates of mesothelioma in certain areas of the world where tremolite asbestos (or similar minerals) is naturally occurring, such as Turkey (Emri et al 2002, Zeren et al 2000), New Caledonia (Luce et al 2000), and elsewhere (Britton 2002). In some of these areas, however, tremolite asbestos was used in a whitewash mixture inside of buildings, creating fiber concentrations that could be more characteristic of occupational settings than true "environmental" exposures.

Animals can also serve as indicators of environmental asbestos exposure. In a study of Corsican goats grazed in areas with naturally occurring asbestos outcrops, asbestos fibers were found in the lungs of all of the goats; but no fibers were found in the lungs of goats grazed in control areas (Dumortier et al 2002). The ratio of tremolite to chrysotile asbestos (both occurred in the outcrops) was significantly higher in the pleura than in the lungs, indicating that tremolite was deposited to a higher degree in the pleura as opposed to being retained in or expelled from the lungs.

The difficulties inherent in assessing cancer and non-cancer risks from exposure to asbestos are discussed in a previous report (MDH 2001). The currently accepted method of estimating the cancer risk from exposure to asbestos is based on human epidemiological studies and animal studies. The exposure estimates in the studies were generally made on the basis of PCM measurements of fiber concentrations, or estimated from particulate counts or other measurements. Therefore, even though TEM fiber counts could be more accurate in terms of fiber types and sizes, PCM data is generally used for exposure estimation purposes.

That said, however, exposure estimates based on PCM data do not account for all the asbestos fibers that could be present. In Libby, only about ⅓ of the fibers observed by TEM were countable using PCM methods (Weis 2001b). The only source of TEM fiber data for the Western Mineral Products site comes from dust and waste samples collected inside the buildings at the site (BRW 2001). Figure 10 is a graph of the size distribution of approximately 80 fibers identified as tremolite (Libby) asbestos in the dust and waste samples. While the proportion of fibers that could be detected using PCM methods is much higher than in the Libby data set, the Minneapolis data set itself is considerably smaller. The samples were collected inside a building, so the Western Mineral Products site fibers were generally not exposed to the elements where the fibers could be weathered (increasing the proportion of smaller fibers) as were the majority of the Libby fibers. Therefore, comparison might not be valid. Still, a comparison can in fact be useful because it suggests that originally, Libby asbestos fibers released from the site could have been longer and possibly more toxic.

Evidence suggests that fiber length and type could play a role in toxicity, with longer fibers being considerably more potent. Amphibole asbestos fibers (which include Libby asbestos), which the body has a more difficult time breaking down than the more common chrysotile asbestos used commercially, could also be more potent, particularly in terms of the induction of mesothelioma (Berman et al 1995). In fact, evidence suggests that tremolite and other amphibole asbestos fibers are present at elevated levels in the lungs of a substantial proportion of mesothelioma patients (Roggli et al 2002). EPA is currently developing an updated risk assessment model that could try to account for differences in fiber size and type (Berman and Crump 1999), but it might not be available for a number of years.

Exposure Assessment

Exposure estimates from the various exposure pathways described above have been summarized in Table 8 and are presented by decreasing order of magnitude, rounded to two significant digits where possible. For consistency, PCM data have been used as described above, and mean concentrations used where available. Note that the ambient air fiber concentrations predicted by the air modeling effort are computer generated, but actual levels may be different. An estimate of the overall uncertainty (high, medium, or low) associated with the data for each exposure pathway is also included in Table 8. Sources of uncertainty, primarily within the air dispersion model, are discussed in more detail below.

Table 8: Exposure Data Summary

Exposure Pathway	Exposure Concentration, f/cc	Exposure Duration	Level of Uncertainty¶
Plant Workers	5.3*	Long-term	Low
Waste Piles, Childhood Exposure (playing in)	1.66†	Short-term	Medium
Disturbance of Vermiculite Insulation	0.57	Short-term	Low
Residential Properties, Disturbance of Yards and Gardens	0.23	Short-term	Medium
Household, Active Cleaning	0.11	Short-term	Low
Waste Piles, Adult Exposure (handling of)	0.11‡	Short-term	Medium
Ambient Air (long-term average)	0.026§	Long-term	High
Household, Routine Activities	0.007	Long-term	Low
Residential Properties, Disturbance of Driveways and Alleys	0.001	Long-term	Medium

* Fiber concentration for #2 furnace room, c. 1978.
† Mean of maximum values, Table 2.
‡ Mean of average values, Table 2.
§ Best estimate of maximum long-term average concentration, 1936-1972.
¶ See below.

The summary shows that activities that involve direct contact, disturbance or both of the raw Libby ore, waste products from processing the ore, vermiculite insulation, or asbestos contaminated dust results in mean fiber concentrations in excess of 0.1 f/cc. Passive contact through ambient air, household dust, or a contaminated driveway (where the disturbance is due to passing vehicles) results in lower levels of exposure, less than 0.1 f/cc. Although prior to 1972, peak levels of fibers in ambient air could have exceeded 0.1 f/cc with some regularity on or near the site. This number corresponds to the current OSHA occupational limit for an 8-hour workday. The OSHA criterion is designed to limit exposure of workers but is not protective of the general population. It is intended for healthy workers exposed for 40 hours per week, and at the OSHA level there is still a risk of adverse health effects. The results in Table 8 confirm that specific behaviors drive exposure. Low-level exposures can, however, occur just because asbestos is present.

There are several other points to be considered when evaluating the data in Table 8. The data in Table 8 represents a mix of long and short-term exposure measurements, as well as high and low level intensity exposure. The occupational exposure of site workers consists of long-term, high level exposures and therefore represents the highest category of relative risk. Morbidity and mortality among exposed workers in the mine and associated facilities in Libby are well documented (Amandus and Wheeler 1987). Employees who worked at the plant exclusively after about 1980, when apparent improvements were made to the equipment and ventilation and the use of commercial asbestos was phased out, were likely exposed to lower levels of asbestos fibers as the data in Appendix I indicates.

The cumulative exposure to some residents from multiple short-term, high-level exposures could be equal or greater to that of other, longer-term exposures. Those who reported that they frequently played on waste piles or those who reported extensive, frequent contact with contaminated yards or gardens could have had cumulative exposures in excess of some plant employees. Residents of homes very near the site, especially before 1972 when the pollution control equipment was installed and even after 1972 were likely exposed to high levels of fibers on multiple short-term occasions—at least while the plant still operated. The exact frequency and duration of short-term exposures that could have reached high levels (defined as in excess of the OSHA standard) is unknown. For this reason, residents who lived or worked within an approximately one to two block radius of the plant from 1936–1989 are considered to have had potential exposures on a par with those who have reported frequent direct contact with Libby asbestos containing wastes from the site.

It also must be noted that in many cases the exposures would be additive, because residents could have been exposed through multiple pathways. For instance, many residents of Northeast Minneapolis would have been exposed through ambient air. Additional exposures could have occurred if the resident also worked at the plant, played in waste piles, lived at a contaminated property, or disturbed vermiculite insulation in their home.

The ranking of the exposure estimates generally corresponds with the results of medical screening conducted by ATSDR in Libby, Montana in 2000 and 2001. Over 7,300 current and former residents of Libby underwent medical testing that included an interview, chest x-rays, and a lung function test to determine if they showed signs of pleural abnormalities (an indicator of asbestos exposure) or asbestos-related disease. In a separate study, ATSDR had determined that mortality from asbestosis in Libby is 40–80 times higher than expected (ATSDR 2000). Pleural abnormalities typically take the form of pleural plaques, which are circumscribed areas of fibrosis (that may or may not be calcified) in the pleural membrane. Such plaques are a known marker of past asbestos exposure (Hiraoka et al 2001, Hillerdal 2001). The interview was designed to help ascertain how those tested might have been exposed to asbestos-contaminated products or wastes from the mine and associated processing facilities in Libby. Waste materials from the mine and processing facilities were used as fill or surfacing materials in many areas around Libby, similar to Northeast Minneapolis. The key risk factors associated with the occurrence of pleural abnormalities or asbestos related disease included (ATSDR 2002):

- worked at the mine or associated processing facilities,
- household contact of (lived with) a worker,
- lived in Libby 34+ years,
- played in vermiculite piles,
- male sex,
- higher body mass index,

- cigarette smoking,
- military asbestos exposure, and
- increasing age.

The highest prevalence (51%) of pleural abnormalities occurred in former W.R. Grace workers, which is consistent with published studies (see Amandus and Wheeler 1987). The contribution of some of these exposure pathways to the overall risk of a person having pleural abnormalities or asbestos related disease, such as military exposure, is unclear or difficult to quantify. The association of higher body mass index with an increased likelihood of pleural abnormalities can be misleading, as thoracic fat deposits common in people with a higher body mass index can mimic pleural plaques on x-ray (Hillerdal 2001).

Many of the risk factors are interrelated. The apparent increased risk that occurs with increased residence time in Libby, where many sources of contamination exist, could be simply a reflection of having a longer period of time to be exposed through one or more critical pathways. The same could be true of age. Both could be a reflection that a sufficient latency period from first exposure to the appearance of clinical effects has elapsed. But it is not clear from the data if exposure in childhood confers added risk due to greater susceptibility; age at first exposure was not measured.

The interrelation of risk factors is further reflected in the fact that the likelihood of finding signs of asbestos exposure or disease increased when multiple exposure pathways were reported. A roughly linear correlation between the number of exposure pathways and the likelihood of pleural abnormalities was found, with those reporting four to seven exposure pathways having a roughly 15% chance of pleural abnormalities, and those reporting exposure through 12 or more pathways a nearly 35% chance of having pleural abnormalities (ATSDR 2002).

The fact that 6.7% of study participants who reported no apparent exposure through the identified pathways had pleural abnormalities indicates that other pathways of exposure not discussed in the screening interview could exist in Libby. While this number could have been inflated if greater numbers of sick people were screened (as opposed to the entire population), it is much higher than the reported range of pleural plaques in the general population, which is 0.2%–2.3% (ATSDR 2002). It is also suggestive of a broader exposure, such as through ambient air.

Sources of Uncertainty

For this report, exposure estimates generated in Libby for both workplace and environmental exposures have been adapted to represent exposure pathways in Northeast Minneapolis. Specifically, workplace measurements of fiber exposure from handling piles of wastes in Libby were used to represent exposure estimates for children playing in waste piles and adults handling waste materials—critical exposure pathways as identified by the medical testing results in Libby. Exposure measurements for just one outdoor activity, rototilling of a contaminated garden, were used to represent a whole range of activities involving direct contact with contaminated waste materials or soil. In Table 8, the exposure estimates for the above pathways are described as medium in terms of their overall uncertainty, primarily due to the use of one activity to represent a range of potential exposure activities. Data collected in Libby from simulated exposure activities such as disturbance of vermiculite insulation or exposure to indoor dust should be representative of similar exposures in Northeast Minneapolis; the exposure estimates for these pathways are therefore considered low in overall uncertainty. Actual W.R. Grace workplace exposure data for the expansion plant in Northeast Minneapolis is available (Appendix I); it is considered representative of worker exposures, and the estimates are therefore also considered to be low in overall uncertainty.

The exposure pathway with the largest overall level of uncertainty is ambient air; an EPA approved air dispersion model was used to simulate past environmental exposures. The task of assessing environmental exposures through ambient air is complicated by the fact that environmental exposures are strongly influenced by environmental factors and by seasonal or daily lifestyle preferences, work and travel habits, and indoor/outdoor concentration differences (Esmen and Marsh 1996). Many of these factors can be difficult to quantify on an individual, much less a community-wide basis. In the past, environmental exposures in a community from a specific source could have been estimated by several methods including length of residence, proximity to the contaminant source, or a combination of the two. These approaches assume an inverse relationship between distance from the source and exposure—a likely oversimplification (Esmen and Marsh 1996). The use of air dispersion modeling represents an improvement in that it can be used to estimate long-term average concentrations when both emissions and meteorological data exist, it can account for deposition from particulate matter, it can be used to estimate levels in ambient air from single or multiple sources, and it can produce results for a virtually unlimited number of locations (Dent et al 2000).

The accuracy of an air dispersion model relies on the quality of the information used as inputs. In particular, estimation of past emissions could be more difficult because it is not known how representative the selected emission factors are (Dent et al 2000). In the case of the Western Mineral Products site, information primarily gleaned from W.R. Grace documents—modified or replaced by professional judgment where needed—has been used as input to the model for the stack emissions (see Appendix II). There is no easy way to confirm the accuracy of the information. To partially account for this, lower and upper bounds were developed and used to generate a range of data from which a central estimate could be calculated. The fugitive emissions were estimated using very limited information and considerable professional judgment, especially in terms of the estimated number of disturbances of fugitive dust sources per year. Five years of meteorological data were used in the model (as is typically used in such models), although a study by Esmen and Marsh (1996) indicated meteorological data collected over a period of 7 years or longer is generally more stable and accurate.

One critical source of uncertainty is the conversion of the model output data from particulate-based to units of Libby asbestos fibers per cc of air. Air dispersion models model the behavior of gases or particulate matter, typically roughly spherical particles less than 10 micrometers in diameter (PM_{10}). The output of the model, as expressed in mass per volume or air (typically micrograms of PM_{10} per cubic meter), was converted to fibers per unit volume of air using a conversion factor of 3.3×10^7 fibers per milligram, a figure cited by EPA (EPA 1986). No other estimates of asbestos fiber density were found in the literature. There is some question as to whether once released into the air, fibers present in the particulate matter would have behaved in a similar fashion to the particles themselves, and therefore whether the model results are accurate in terms of overall fiber concentrations. In addition, comparison of the model results to results obtained from actual air sampling or to occupational standards is not appropriate. The estimated concentrations are not for a given fiber size range, such as the results of PCM analysis yield. For this reason, the model results are perhaps best used for relative comparison rather than comparison with other exposure data or air quality criteria.

Anthamatten (2002) has discussed uncertainty in the use of an air dispersion model for the site. Included in that discussion are parameter uncertainty (such as uncertainty regarding the air emission factors), model uncertainty (uncertainty within the air dispersion model itself), and decision-rule uncertainty (uncertainty over how the output of the model is used). Several mechanisms are identified for reducing uncertainty, including the use of a Monte Carlo simulation to refine the output. But given the already extensive computational needs of the air model, the use of such tools, while attractive, is not practical.

There is no clear way to confirm the accuracy of the air dispersion model. Still, ambient air samples collected by W.R. Grace during the operation of the plant and after it shut down, and by EPA in 2000, generally fall within the range of concentrations predicted by the model in Table 3 and shown in Figures 3 through 6.

The relationship between outdoor, ambient air concentrations of contaminants and indoor concentrations is not well understood. This relationship is, however, critical to understanding contaminant exposure from ambient air. Few people spend even a majority of their time outdoors, especially in the winter months. In the 1950s, the U.S. Army conducted a series of experiments across the United States and Canada to determine the effectiveness of dispersion mechanisms for chemical/biological weapons in urban areas using a surrogate test compound, zinc cadmium sulfide (NRC 1997). This compound was sprayed as a fine dust under varying conditions and seasons over urban areas, including Minneapolis. Measurements of the resulting air concentrations of zinc cadmium sulfide were then collected indoors and outdoors in various locations. The Minneapolis data showed that detectable quantities of the test compound penetrated houses, office buildings, and schools. In the winter, a median of 11.5% of the outside dose of the compound penetrated homes, 15% of the outside dose penetrated an office building, and 23% of the outside dose penetrated a school. In the summer, the median percentages were 58% for homes and 31% for office buildings (no data was available for schools in summer). The data from the U.S. Army tests indicates that airborne particulates were capable of penetrating homes. The tests were done at the same time the Western Mineral Products/W.R. Grace vermiculite expansion plant was in operation and releasing asbestos-containing dust into the same general community. The U.S. Army tests suggest that for short periods in homes, workplaces, and schools located close to the site, indoor fiber concentrations, especially in the summer months, could have been substantial.

NMCVI

The NMCVI is being conducted to identify a cohort of individuals with a history of one or more of the above exposure pathways. To date MDH has conducted personal interviews with over 4,000 current and former residents of the NMCVI study area. This study will provide an estimate of the number of people exposed through each pathway and will allow for communication of health information and advice to exposed individuals. The study will also provide information necessary to determine the feasibility of measuring health outcomes in a follow-up study. Follow up could include an assessment of medical records, death records, or cancer registry data for the occurrence of asbestos related disease in the cohort. Alternately, health screening for pleural changes, progressive loss of pulmonary function or both could be feasible in a prospective study.

Children's Health Considerations

ATSDR recognizes that the unique vulnerabilities of infants and children make them of special concern to communities faced with contamination of their water, soil, air, or food. Children are at greater risk than are adults from certain kinds of exposures to hazardous substances at waste disposal sites. They are more likely to be exposed because they play outdoors and they often bring food into contaminated areas. They are smaller than most adults, which means they breathe dust, soil, and heavy vapors close to the ground. Children also weigh less, resulting in higher doses of chemical exposure per body weight. If toxic exposures occur during critical growth stages, the developing body systems of children can sustain permanent damage. But most important is the fact that most children depend completely on adults for risk identification and management decisions, housing decisions, and access to medical care. Thus to protect their children, those adults need accurate health information.

Children who lived in the community around the site were likely exposed to Libby asbestos containing wastes. Children were known to play on the piles of stoner rock or waste vermiculite, and were reportedly allowed to even play inside the plant at times while it was operating (MDH 2001). Children could also have been exposed to asbestos in particulate emissions from the plant, or in dust carried into homes and schools from air emissions. Children could have been exposed to dust carried home on the clothing of a parent who worked at the plant. Ongoing exposure could be occurring in locations where vermiculite wastes were used as fill. It could also be ongoing at the ground surface, in homes where asbestos wastes could have been tracked into homes, or in homes where substantial disturbance of vermiculite insulation has occurred. The long latency period (between 10 and 40 years) of asbestos-related diseases likely places children at greater risk of developing disease earlier in life. The ability of children as compared to adults to clear fibers from the lungs is also unknown.

Public Comment

This document was issued for public review and comment on June 4, 2003. Comments were accepted until August 22, 2003. Specific technical comments made by MDH staff were incorporated into the final document. Other general comments received included positive feedback on the NMCVI study, MDH's outreach activities, and the residential cleanups being conducted by EPA, concern over the potential extent of asbestos exposure in the neighborhood around the former Western Minerals plant, and a request for a class-action lawsuit.

III. Conclusions

Residents of Northeast Minneapolis have been exposed to Libby asbestos from the former Western Mineral Products/W.R. Grace facility at 1720 Madison Street NE through a number of exposure pathways. The highest exposures occurred in the past to plant workers, their household contacts, and people who played in, handled, or otherwise had direct contact with wastes from the site. These past exposures represent a public health hazard. Lower level exposure could be ongoing from the use of waste materials from the site in yard soil, garden soil, and driveway surfaces. Potential exposures from these waste materials represent an indeterminate health hazard. Due to lack of data on the presence of Libby asbestos in indoor dust and vermiculite insulation in the area of the site, potential exposure from these materials also represents an indeterminate public health hazard.

The amount of fibers released into the air (and the resulting airborne concentration) depends on the concentration of fibers in the source material and the nature of the disturbance. While there is currently no acceptable, peer-reviewed risk assessment model available to quantify the health risks from exposure to Libby asbestos fibers, the risks are likely proportional to the concentration of fibers in air, the frequency and duration of exposure, and the number of pathways through which a person is exposed. As noted previously, due to the long latency period of many asbestos related diseases, those who were exposed as children could also be at a higher risk today.

The ranking of exposure estimates in this document is consistent with the interpretation of results of medical testing conducted for residents of Libby, Montana. This suggests that former W.R. Grace workers (and their household contacts), those who had direct contact with asbestos wastes, and those who had contact through multiple exposure pathways have a higher prevalence of pleural abnormalities—a hallmark of asbestos exposure. The Libby results also suggest the potential for asbestos-related disease in the population of Northeast Minneapolis, from the operation of the former Western Mineral Products/W.R. Grace vermiculite processing plant.

IV. Recommendations

1. To eliminate potential exposures from asbestos contaminated wastes, the EPA should complete the cleanup of impacted residential properties as soon as possible.
2. The proposal drafted by EPA, ATSDR, and MDH staff to assess the potential for indoor exposure to Libby asbestos from environmental sources or vermiculite insulation should be implemented.
3. Additional funding for, and a mechanism to conduct, the cleanup of contaminated properties that might be identified in the future should be established by the MPCA, EPA or both.
4. The use of deed notices or some other mechanism of notifying future property owners of the presence of Libby asbestos contamination should be considered for properties where Libby asbestos contamination has been left in place.

V. Public Health Action Plan

The EPA is currently taking steps to eliminate outdoor sources of contamination on residential properties in the area around the site. This work is expected to be completed at all identified properties (260 as of October, 2002) in 2003. It is believed, however, that an unknown number of contaminated properties will remain unidentified and will not be addressed by the EPA as a part of this effort. MDH is also conducting an exposure investigation (the NMCVI) to develop a cohort of potentially exposed individuals for possible follow up.

MDH's Public Health Action Plan for the site consists primarily of continued consultation with state and federal agencies involved with the investigation and cleanup of the site (and similar sites around the country) and surrounding community, and participation in public outreach activities. MDH should complete the exposure investigation (NMCVI) of current and former residents of the area around the site (which includes recommendations to participants for follow up based on the exposure estimates in this document), and continue its program for educating physicians and other medical personnel on the recognition of asbestos-related lung disease. MDH should evaluate the scientific value and feasibility of conducting a follow-up health study to measure health outcomes of the exposed cohort of current and former residents enrolled in NMCVI. Further information on asbestos exposure can also be found on the MDH Web site at http://www.health.state.mn.us/divs/dpc/han/asbestos.html

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CERTIFICATION

This Western Mineral Products Site Health Consultation was prepared by the Minnesota Department of Health under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR). It is in accordance with approved methodology and procedures existing at the time the health consultation was begun.

Alan W. Yarbrough
Technical Project Officer, SPS, SSAB, DHAC
ATSDR

The Division of Health Assessment and Consultation, ATSDR, has reviewed this public health consultation and concurs with the findings.

Roberta Erlwein
Chief, State Program Section, SSAB, DHAC, ATSDR

Figure 1: Site Location

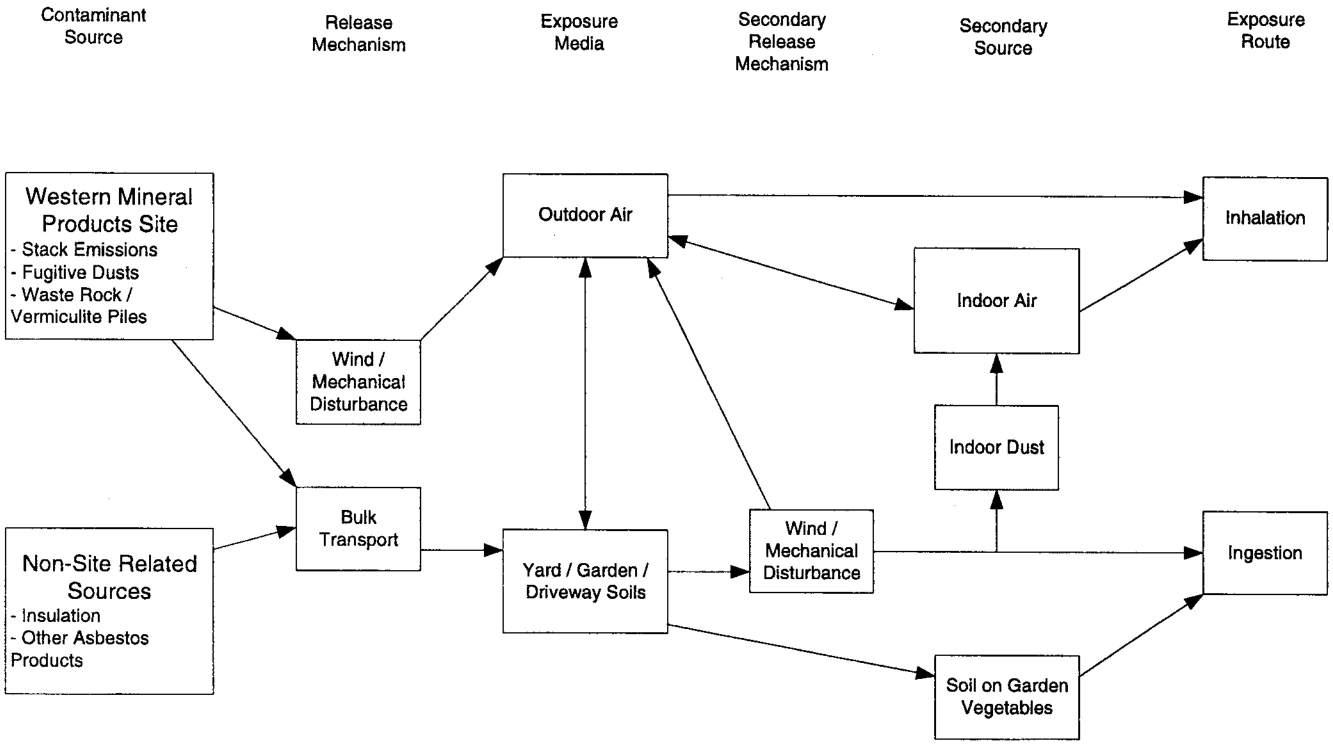


Figure 2: Conceptual Model of Exposure Pathways

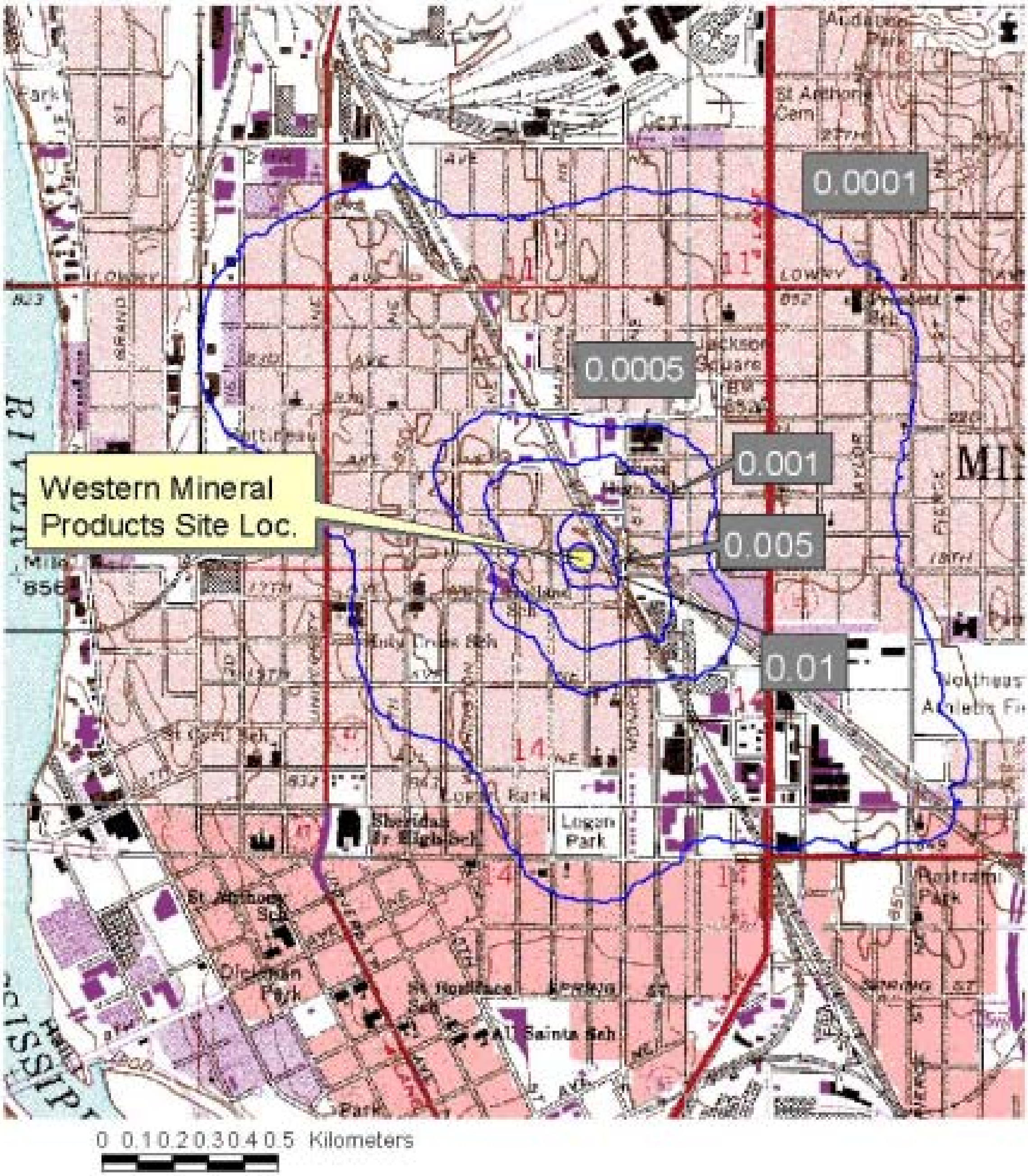


Figure 3: Nominal Long-Term Air Concentrations 1936-1972, f/cc

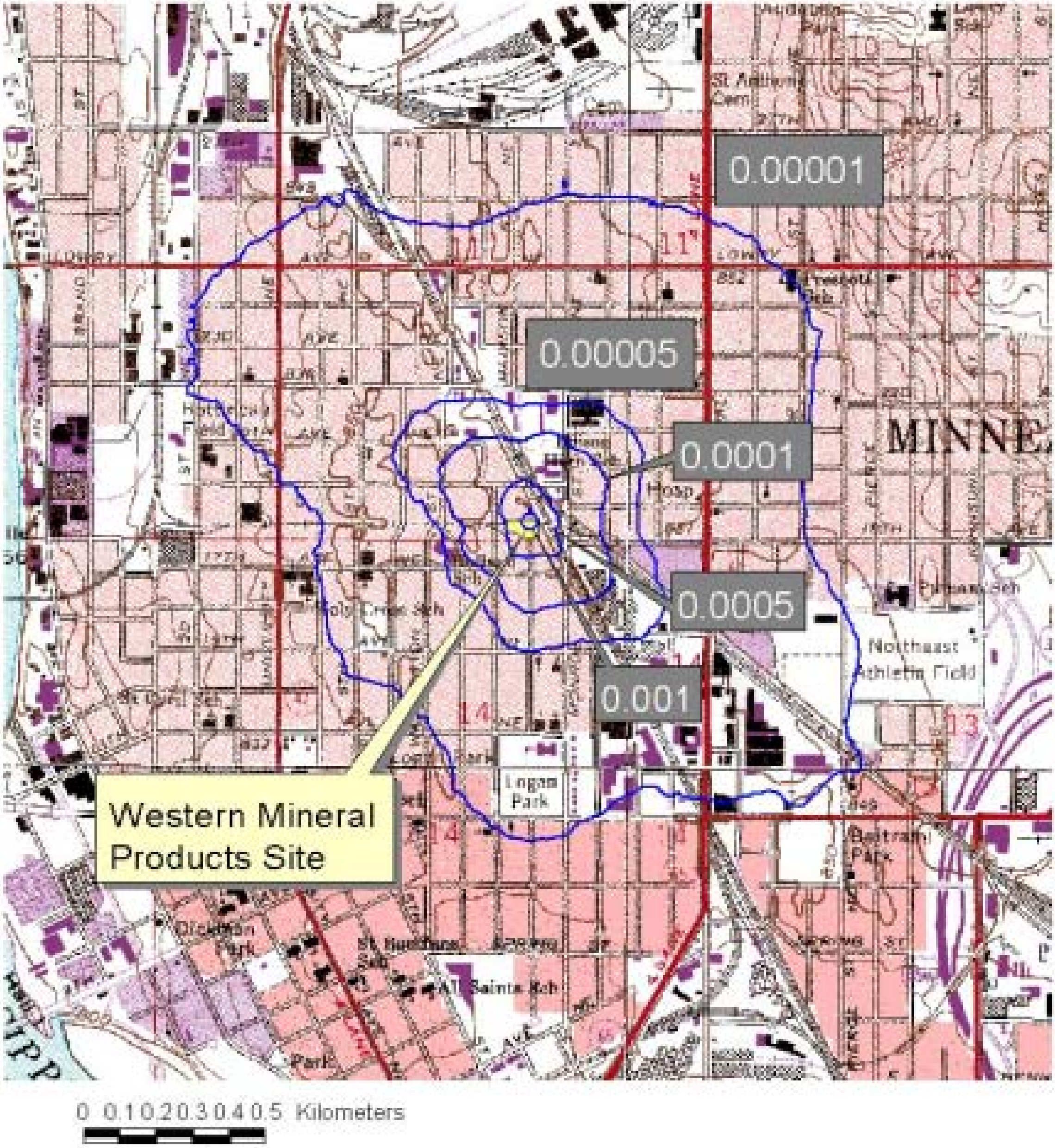


Figure 4: Nominal Long-Term Air Concentrations 1972-1989, f/cc

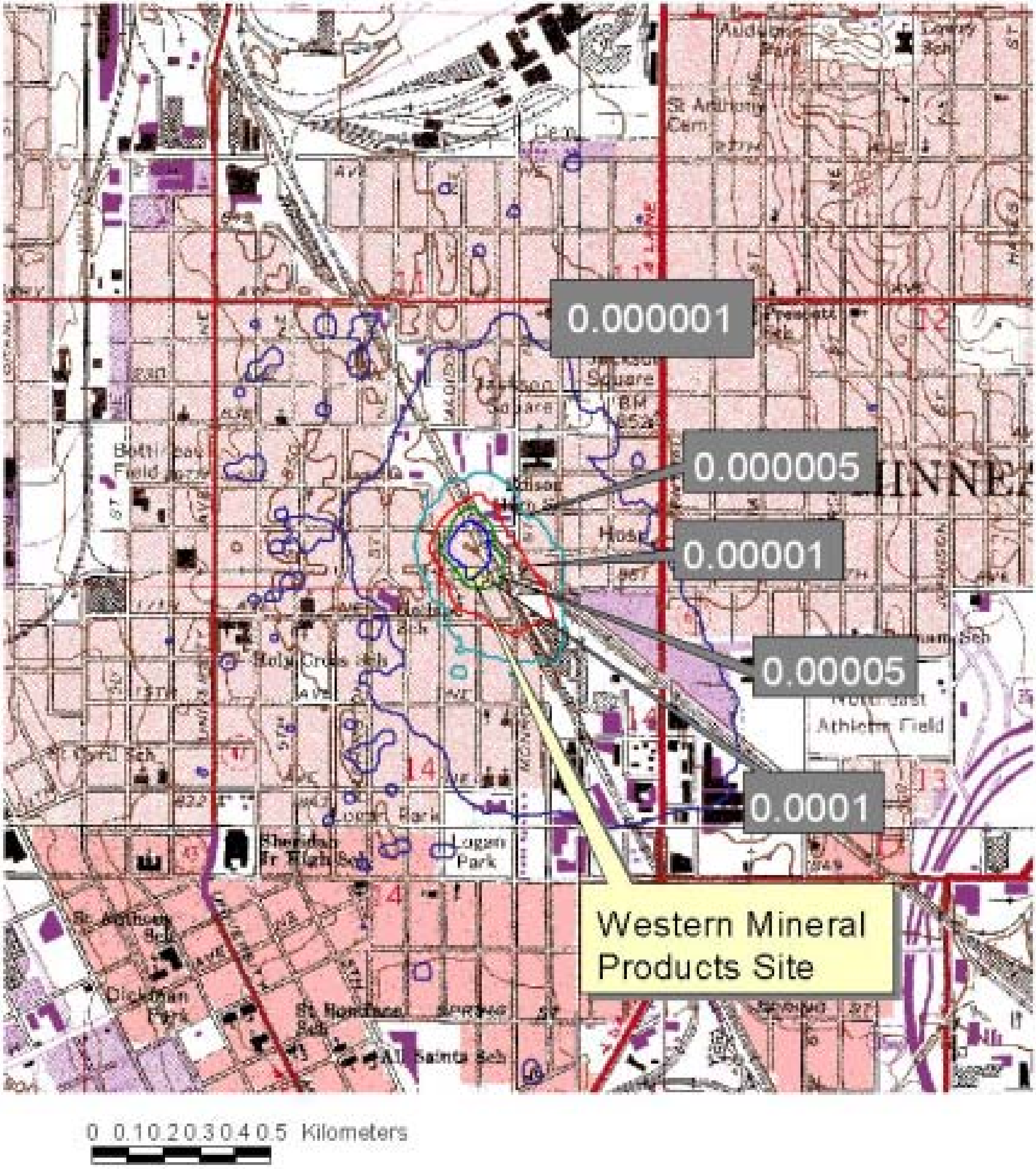


Figure 5: Nominal Long-Term Air Concentrations 1989-1999, f/cc

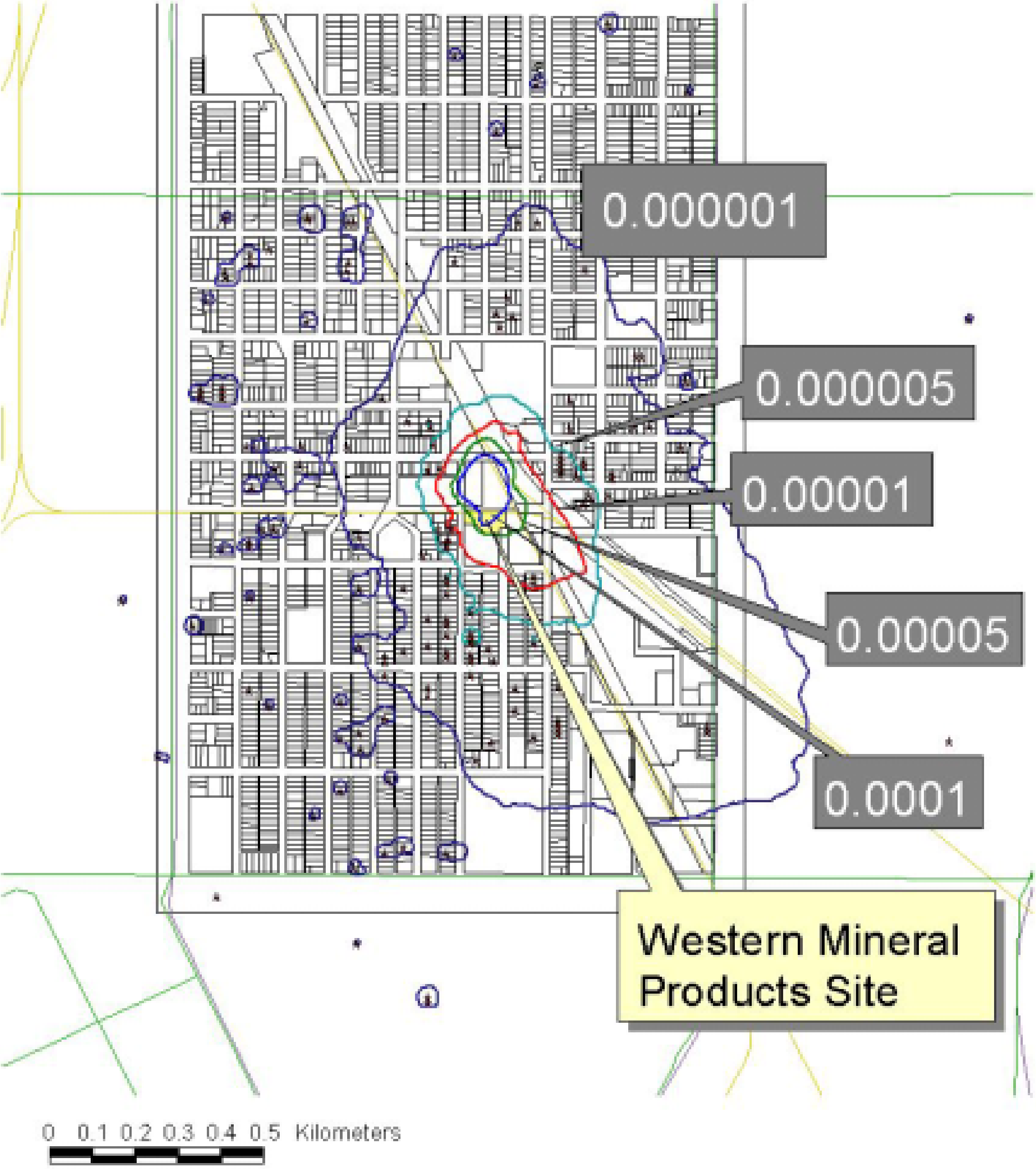


Figure 5a: Nom. Long-Term Air Conc. 1989-1999, f/cc

★ = Impacted Property

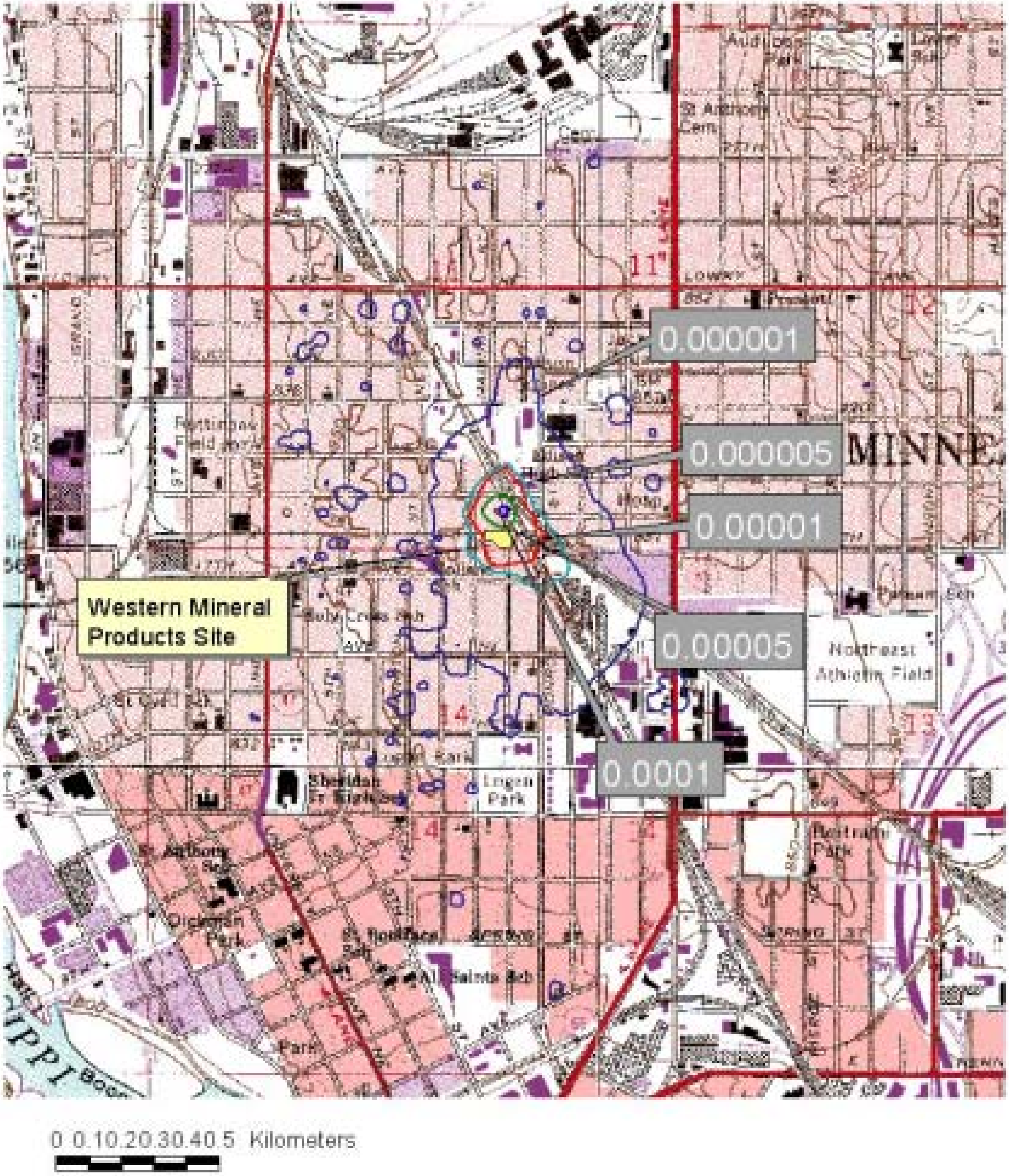


Figure 6: Nominal Long-Term Air Concentrations 1999-2001, f/cc

Figure 7: Nominal Fiber Deposition 1936-2001, f/m2

Figure 8: Impacted Residential Properties
10/14/02

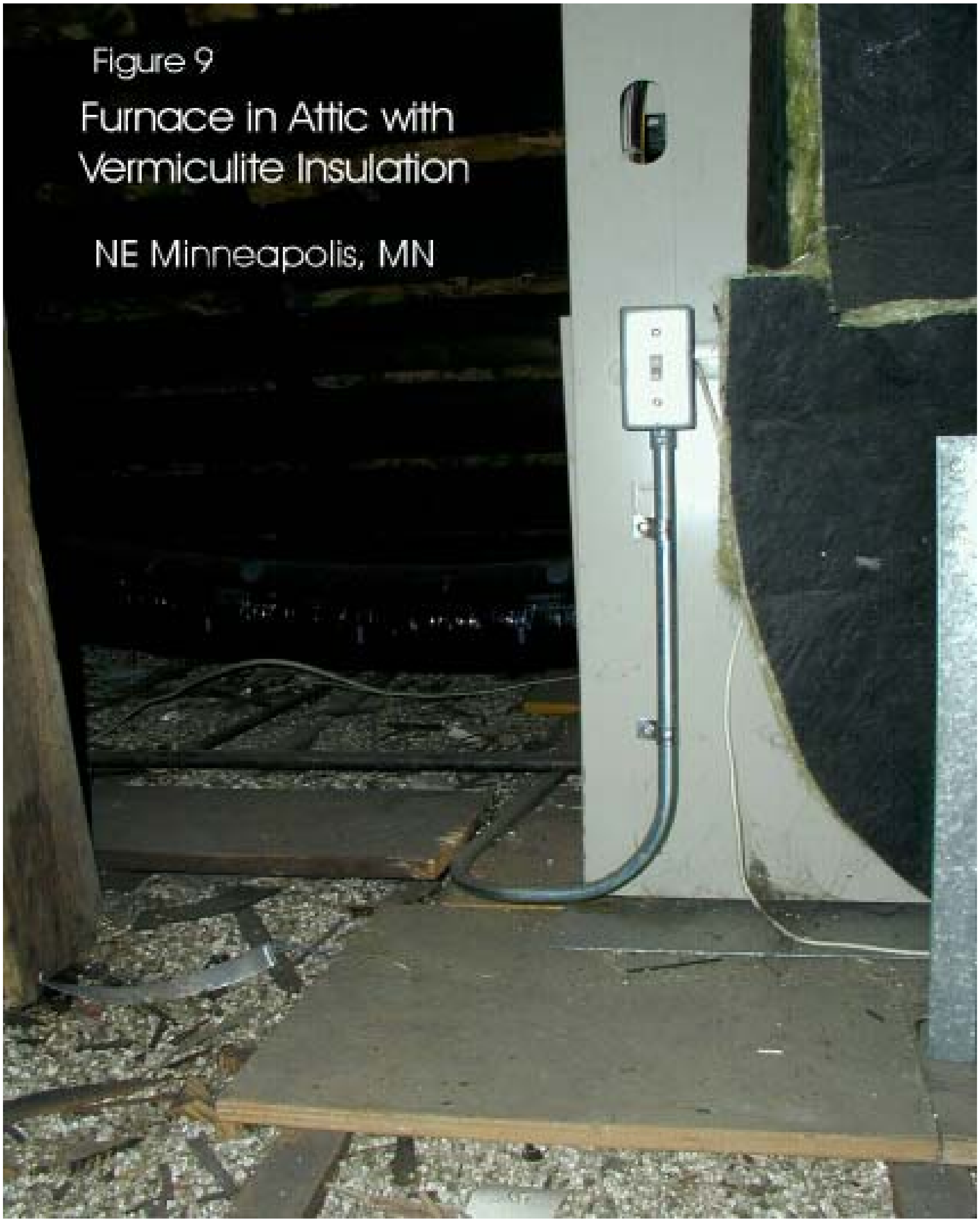


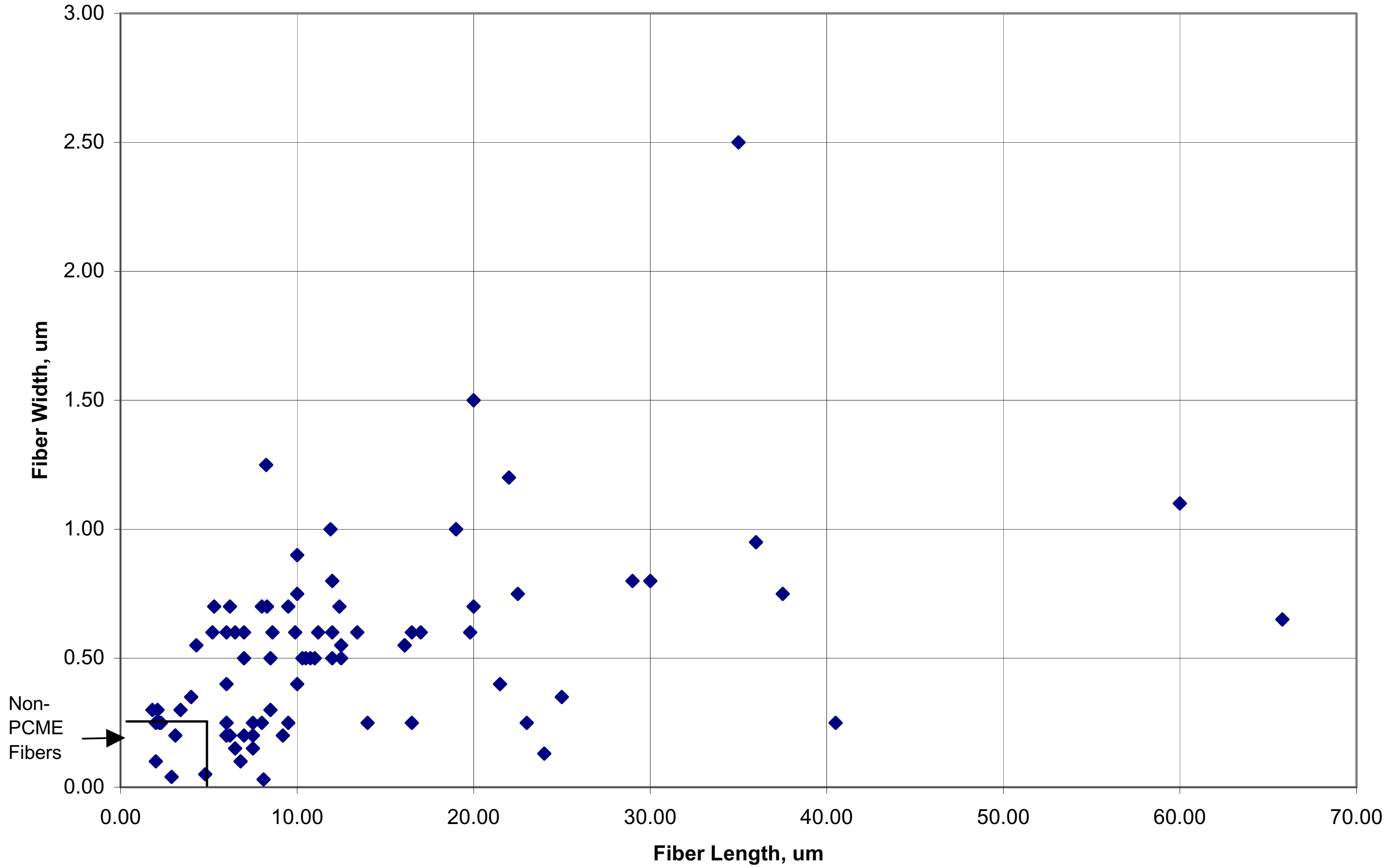
Figure 9

Furnace in Attic with Vermiculite Insulation

NE Minneapolis, MN

Figure 10

Western Mineral Products Tremolite Fiber Size Distribution (TEM Data)



Appendix I: Personnel and Plant Air Monitoring Data

Personnel Air Monitoring Data

Date	Job Location	Notes	Sample Time (min)	Results (f/cc)
5/20/1974	Bagging concrete aggregate	visible dust during sampling	16	0.00
	Operating lift truck		18	19.00
	Bagging Bar-B-Sorb		15	15.00
	Enter ore storage bin	while ore unloading, drove lift truck	16	17.46
	Bagging con AG		15	11.02
	Mixing and bagging MK-5		16	3.21
	Bag stitching MK-5		18	2.22
	Lead man, sweeping	around stoner	20	8.84
5/21/1974	Mixing and bagging MK-5		16	3.92
	Bag stitching MK-5		18	9.50
6/23/1976	Model A#2 Bagger	Libby #3 ore	16	3.42
	Monokote Bagger	Libby #3 ore	23	2.58
10/6/1976	Bagger #1station	attic insulation - Libby #1	15	0.80
	Bagger #2 station	plaster aggregate - Libby #3	15	2.05
	Mixing and bagging MK	Libby #3 ore	15	0.34
1/5/1978	Model A#2 Bagger	Libby #2 ore	14	7.82
	Model A#1 Bagger	Libby #1 ore	28	3.58
	Bagger MK#4	Libby #3 ore	26	5.26
	Special job cleaning baghouse	very dusty	14	11.40
	location unknown		32	4.13
4/26/1978	Bagging masonry fill	#2 furnace, Libby #3 ore	30	<0.15
	Mixing and bagging MK-4	Libby #3 ore	22	<0.21
	Mixing and bagging MK-4	Libby #3 ore	20	<0.23
10/3/1979	Bagging station - furnace #1	Attic insulation - Libby #2	61	0.15
	Paper bagging MK	Libby #3 ore	55	0.17
	Loading & #2 furnace bagging		56	0.16
4/24/1980	Bagging masonry fill, #2 furnace	Libby #3 ore	56	0.12
	Assorted jobs	Hauling and loading product	36	0.14
	Mixing and bagging MK-5	Libby #3 ore	51	0.20
11/14/1983	Bagging masonry fill, #2 furnace		125	0.01
	Bagging Terralite, #1 furnace		60	0.16
	Hauling masonry fill & cleaning		117	0.06
	Bagging Terralite		63	0.14
	Bagging masonry fill		35	0.52
	Hauling masonry fill		121	0.51
	Bagging Terralite		46	0.08
12/6/1984	Bagging masonry insulation	also loading trailers	137	0.09
	Bagging masonry insulation		120	0.07
	Loading trailers		89	0.32
	Bagging masonry insulation		87	0.33
8/13/1985	Furnace #1 bagger/operator		95	0.04
	Furnace #1 bagger/operator		90	0.15
	Furnace #2 bagger/operator		89	0.02
	Furnace #2 bagger/operator		81	0.10
	Foreman		95	0.04
	In furnace chute cleaning it		90	0.39

7/8/1986	Maintenance		78	0.12
	Loading bags	Libby #3 ore	24	0.29
	Bagging station - furnace #2		15	0.42
11/17/1986	#2 Bagging station		20	0.56
	Loader		20	0.91
11/18/1986	#2 Bagging station	Same employees	40	0.08
	Loader		41	0.09
11/19/1986	#2 Bagging station	Same employees	30	0.15
	Loader		35	0.09
7/6/1987	Furnace operator/bagger	Libby #3 ore, Masonry fill	40	0.09
	Loading trucks		45	0.06
	Forklift - truck loading		45	0.01
7/12/1988	Furnace operator	Libby #2 ore	45	0.03
	Bagger/warehouse	Libby #2 ore	69	0.02
	Maintenance	Libby #2 ore	40	0.05

Plant Air Monitoring Data

Date	Location	Notes	Sample Time (min)	Results (f/cc)
7/25/1972	Masonry fill bagging	Libby #3 ore, furnace #2 only	15	11.40
	Furnace room	upwind of furnace	15	7.60
	Masonry fill bagging		15	11.10
	Furnace room	downwind of furnace		15.20
	Perlite bagging	Vacuum pulled dust from vermiculite	15	3.70
	Lunch room			0.40
	3 ft from stoner		25	3.40
	3rd floor storage, general room		16	2.10
	On fence, downwind of outside stoner scrap pile		56	0.30
	2nd floor general room		17	5.40
	Mid RR warehouse		50	0.00
5/21/1974	General air, stoner area		15	4.18
	Just outside open door to ore storage bins	During unloading Libby #3	10	57.57
	General air, furnace room		15	9.50
6/23/1976	Model A#2 3rd Floor	Stoner Rock discharge		2.68
	Stoner waste	next to discharge	25	20.61
1/5/1978	20' in front of furnace #1		152	2.91
	#2 furnace room		29	1.57
	Stoner rock waste hopper	water spray on (wheelbarrow)	30	13.53
1/25/1978	2nd floor - 18' from furnace #2		102	5.30
	3rd floor -8' from bagging station		84	5.60
	Fan platform - furnace room		73	1.30
	Lunch room	60' from #2 bagger	162	3.00
1/26/1978	2nd floor - 18' from furnace #2	Plant not operating	71	0.70
	3rd floor -8' from bagging station	Plant not operating	69	1.20
	Sewing machine #2 bagging	Plant not operating	68	0.23
	Lunch room	Plant not operating	69	0.87
4/26/1978	No. 2 Furnace, Stoner Rock end	Running Libby #3	32	<0.14
	Furnace Room, near #2 Furnace		30	0.15
	Stoner Drop, #2 Furnace	Fines dropped into wheelbarrow, water spray & exhaust ventilation on	44	6.94
	Lunch Room		44	<0.10
	2nd Floor, Center of Bldng		30	<0.15
10/10/1979	Background sample	on phone books	193	0.14
	#1 furnace waste rock hopper		36	0.06
	#2 furnace waste rock hopper		34	0.13
	#2 furnace stoner prod end		26	0.35
	#2 furnace stoner rock end		33	0.41
9/24/1980	Stoner - rock end	#2 furnace	62	0.06
	Rock hopper (wheelbarrow)	#2 furnace	72	0.14
	Baghouse drop	#2 furnace	76	<0.02
	Background sample	furnace room	65	0.13
	Employees lunch room		54	0.03
	Office		77	<0.02
7/22/1981	Stoner - rock end		72	0.05
	Stoner - product end		72	0.06
	Waste rock hopper - wheelbarrow		79	1.00
	Baghouse #2		76	0.10
	Lunchroom		130	0.09
	Background sample	25' south of #1 bagging station	142	0.09
	Base of product elevator	furnace room	46	0.13
	Baghouse #1		36	0.24

7/1/1982	Stoner - rock end		65	0.19
	Stoner - product end		69	0.18
	Background sample - 3rd floor	10' from MK-5 bagger	119	0.04
	Background sample - 2nd floor	18' from baggers	119	0.02
	Baghouse		45	0.25
	Waste rock hopper - #1		48	1.98
	Baghouse drop - corner of room		47	0.10
	Between furnaces		60	0.29
11/14/1983	Furnace #2 waste rock	wheelbarrow	64	0.10
	Stoner rock end	#2 furnace	72	0.11
	Stoner product end	#2 furnace	76	0.38
12/6/1984	Waste rock hopper		120	1.65
	Stoner - rock end		86	0.01
	Stoner - product end		72	0.08
8/12/1985	Waste rock hopper #1		73	0.02
	Waste rock hopper #2		73	0.04
	Open ore bins	where controls were	75	0.15
	Baghouse drop	#2 furnace	73	0.34
	Stoner - product end	#1 furnace	74	0.06
	Stoner - waste rock end	#1 furnace	49	0.01
	Stoner - product end	#2 furnace	50	0.03
	Stoner - waste rock end	#2 furnace	134	0.02
7/7/1986	One cubic yard hopper		90	0.09
	Stoner - product end		103	0.14
	Stoner - waste rock end		70	0.09
11/17/1986	One cubic yard hopper		80	0.03
	Stoner #2 - product end		65	0.06
	Stoner #2 - waste rock end		65	0.01
	One cubic yard hopper		70	0.01
	Stoner #2 - product end		70	0.06
	Stoner #2 - waste rock end		70	0.06
	#2 Bagging station		37	0.10
11/19/1986	One cubic yard hopper		50	<0.01
	Stoner #2 - product end		58	0.04
	Stoner #2 - waste rock end		72	0.13
	Stoner #1 - product end		65	0.08
	Stoner #1 - waste rock end		65	0.05
8/6/1987	Stoner - product end		65	0.02
	Stoner - waste rock end		60	0.03
	2nd floor baghouse flapper valve	common/augers	70	0.01
	2nd floor baghouse flapper valve	furnace room	75	0.03
	1st floor common baghouse	waste drop	60	0.01
	Furnace room		85	0.01

Appendix II: Ambient Air Modeling Procedures

DATE : October 8, 2002

TO : Jim Kelly
Minnesota Department of Health, Environmental Health

FROM : Gregory C. Pratt, Ph.D.
Research Scientist
Environmental Outcomes Division
PHONE : 612.296.7664

SUBJECT : AN UPDATE: Modeled Concentrations and Deposition of Tremolite Near the Western Mineral Products/W.R. Grace Facility

Introduction

This memo presents an update to a previous (June 12, 2001) air dispersion modeling study done to estimate airborne concentrations and deposition of tremolite asbestos fibers around the Western Mineral Products/W.R. Grace, Inc. vermiculite processing facility in Northeast Minneapolis. A description, photographs, and a site plan can be found in the June 12, 2001 memo. Since the June, 2001 study additional measurements have documented the presence of tremolite fibers in the soils at some 134 properties in the vicinity of the facility. These fibers may have been deposited to the soil by facility emissions or, more likely, most of the fibers were intentionally added as amendments for horticultural, landscaping, soil-stabilization, or other purposes. These soil-borne fibers may become airborne and constitute an additional source of airborne fibers not included in the June, 2001 study. New air dispersion modeling was done, taking into account emissions from the 134 properties, as well as the emissions from the facility.

Four cases were modeled:

1) Case 1 considers the estimated average emissions from the commencement of operation in 1936 until the installation of the baghouse control system in 1972;
2) Case 2 considers the scenario from 1972 until the end of operation in 1989;
3) Case 3 simulates the conditions from 1989 until 1999 when remediation activities began to reduce the amount of fibers available for release from contaminated sites; and
4) Case 4 simulates the conditions at the time of this modeling analysis when some of the contaminated sites had been remediated.

These cases were selected because they cover the range of emissions from the early years when the facility was operated with minimal dust control to the present-day situation with the facility shut down and clean-up activities occurring. Updating the modeling analysis was done as an effort to understand the importance of the tremolite fibers dispersed throughout the community in residents' lawns, gardens, and driveways. This new analysis also attempts to show the changes over time in the emissions and airborne concentrations of tremolite fibers as particle control technology was added to the facility, then the plant was shut down, and eventually clean-up activities were begun.

Estimation of Emissions

Facility emissions were not changed in this updated analysis. The procedure for estimating facility emissions is described in my earlier memo, and the calculations are included here as attachment 1 (which is identical to the earlier attachment 1).

Attachment 2 is a spreadsheet showing the methods and equations for calculating fugitive emissions. The calculations of fugitive emissions from the facility sources did not change. The fugitive emissions from soil-borne tremolite fibers from the nearby properties were calculated using the U.S. EPA emission factor for industrial wind erosion (AP-42, section 13.2.5-1). The starting point of soil tremolite concentrations was taken from measurements as documented in the Agency of Toxic Substances and Disease Registry Health Consultation (US-Department of Health and Human Services, ATSDR, Atlanta, 2001, Health Consultation for Western Mineral Products Site, Minneapolis, Minnesota).

The industrial wind erosion emission factor was judged to be the closest fit of any of the available AP-42 emission factors for estimating fugitive emissions from nearby contaminated properties, but since it is typically used to characterize sources such as coal and aggregate piles, it may not be perfectly applicable to emissions from the sources represented here. The industrial wind erosion method assumes that the erodible surface has a finite availability of erodible material, and that natural crusting of the surface binds the erodible material reducing the erosion potential. Therefore, the erosion potential is tied to the number of disturbances (in this case such as lawn mowing, tilling, driving on a driveway, etc.). The number of disturbances per year was assumed to be 30. This estimated number of disturbances is between the extreme situations of a garden bed that might be disturbed only once or twice per year and a driveway that could have multiple disturbances per day. Since information was not available about the precise location of the tremolite material on the contaminated sites, this mid-range value was assumed for all properties.

This method also assumes that erosion potential increases rapidly with increasing wind speed so that estimated emissions are related to the strongest wind gusts. The wind gusts were taken as the daily fastest mile in the local climatological data summaries from the MSP airport for year 2000. The erosion potential for each day was calculated from the daily fastest mile wind data. The 30 disturbances per year were assumed to occur randomly so that emissions only occurred when sufficiently strong wind gusts coincided with a disturbance. Based upon the judgement of Health Department staff each contaminated property site was assumed to consist of an area of 20 feet by 20 feed (37.2 square meters). The tremolite fiber measurements showed an average concentration of four percent. A single average value was used for the soil concentration of tremolite fibers because data were not available for individual properties. It was also assumed that emissions could occur twelve months of the year. This assumption likely overestimates emissions because snow, ice, and freezing temperatures during winter would presumably reduce the potential for emissions.

The sites were assumed to become contaminated with tremolite fibers gradually in proportion to the amount of ore processed at the facility. Over some 53 years of operation, the facility processed around 294,427 tons of ore containing nearly 25 million pounds of tremolite fibers. An assumption was made that the total fiber load measured at the contaminated sites today represents processing of 294,427 tons of ore. Using this logic, in 1972 at the end of the Case 1 period when 245,257 tons of ore had been processed, the amount fibers at the contaminated sites was assumed equivalent to the ratio of the amount of ore processed through 1972 to the total amount ore processed over the life of the facility:

$$1972\, fiberlevel = 2001\, fiberlevel \times \frac{245{,}257}{294{,}427} = 2001\, fiberlevel \times 0.83\, .$$

However, Case 1 includes the years 1936 to 1972, a period that begins with no fiber contamination of the soils and ends with the 1972 fiber level. This case was simulated as having emissions over the total period that were equivalent to those at the midpoint of the time period, i.e., when half of the 245,257 tons of ore had been processed. At that time the fiber content of the contaminated sites was estimated as:

$$Case1\, fiberlevel = 2001\, fiberlevel \times \frac{245{,}257 \div 2}{294{,}427} = 2001\, fiberlevel \times 0.42\, .$$

Similar calculations were made for Cases 2-4. In reality individual homeowners likely hauled contaminated material to their homes over a short period of time, contaminating the site in one fell swoop. However, since the available information is insufficient to characterize such contamination events on an individual site basis, the above methodology was used.

Table one gives the total emissions by source category for each case and the percentage of emissions from fugitive sources.

Modeling Procedures

The modeling procedures were the same as those described in the June, 2001 memo with three exceptions. First, since wind entrainment is a major factor causing emissions from the surface-based sources, emission scalars were used to scale the emission rates for these sources to the wind speed:

Wind speed upper bound (m/s)	6.71	8.05	9.39	10.7	12.1	no upper bound
Scalar	0	0.6	2	8	27	64

The wind speed categories were chosen to extend over the range at which wind entrainment of particles is expected to occur. The scalars were chosen so that the total mass of emissions calculated using the scalars and the wind speed data was equivalent to the emissions calculated in Attachment 2.

The second difference from earlier modeling is that a regular grid of receptors was not used. Instead, the Department of Health provided a set of receptors that included all properties within one mile of the facility. These 6,361 locations were used as receptors.

The third difference between past and present modeling has to do with deposition. Past modeling assumed the tremolite fibers were in one particle class of size PM_{10} with a density of 1.0 gram per cubic centimeter (g/cm^3). When modeled in this way the dry deposition velocity back-calculated from average concentration and deposition amounts was found to range from 0.03 to 9.48 centimeters per second (cm/s), with an average of 4.92 cm/s. Based upon my professional experience, this average deposition velocity seems high for PM_{10} particles. I would note that the tremolite fibers are long and slender, averaging about 0.5 micrometers (μm) by 25 μm. With this shape they might be expected to behave like submicron particles in a nonturbulent flow. On the other hand, in turbulent conditions, the tremolite fibers might be expected to behave like larger particles. In a model sensitivity analysis, when the particles were characterized as one particle class of size $PM_{2.5}$ the deposition velocity back-calculated from average concentration and deposition, dropped to about 1.5 cm/s on average. This seems to be a more realistic characterization of tremolite fiber deposition, and the modeling was done characterizing the particles as $PM_{2.5}$.

With a particle size of 0.5 μm by 25 μm and a mass of 3.3×10^4 fibers per microgram, the density of tremolite fibers is on the order of 6.2 g/cm^3. Model sensitivity tests using this higher density resulted in average back-calculated deposition velocities of 6.4 cm/s, or about 30 percent higher than with a density of 1.0 g/cm^3. At this higher density, the importance of gravitational settling is increased relative to other factors in the deposition velocity calculation. Characterizing the particles as having a density of 6.2 g/cm^3 was also taken into account in this updated modeling analysis.

One factor that was not taken into account is plume depletion. The plume depletion model option removes deposited material from the plume so that it is not available downwind. This model option is not one of the regulatory default options, and in addition, it is not often used because it is very computationally expensive. Test runs showed that the plume depletion option would result in run times on the order of 50 days to complete a one year simulation on my computer. Plume depletion may be important in this analysis because the sources are near ground level, and there are already strong concentration and deposition gradients without plume depletion.

The deposition analysis suffers from another shortcoming. The fibers were deposited over an extended period of time. During that time the deposited fibers were subject to phenomena like runoff into surface water, re-entrainment and movement downwind, mixing with soil and organic matter, and human disturbances like construction. These factors are difficult to simulate with certainty, making it very difficult to compare modeled deposition with the amounts of fibers now found in soils.

Modeling Results

Table 2 gives the minimum and maximum airborne tremolite fiber concentrations and deposition amounts over the model domain for each of the cases. The general trend was for the concentrations and deposition to decrease from Case 1 to Case 4, as expected. Figures 1 to 4 (editor's note: not attached, see Figures 3-6) show maps with isopleths of average concentrations for the four cases. The minimum value from Table 2 would fall outside the outer-most isopleth, and the maximum value would fall inside the inner-most isopleth. In Cases 1 and 2 the facility emissions dominated the ambient air concentrations of tremolite fibers. The concentration gradients in these two cases were relatively smooth. The gradients were also quite steep, as expected from a source with short stacks subject to building wake effects and significant ground-level fugitive emissions. Minimum and maximum one-hour average tremolite fiber concentrations are also given in Table 2.

In Cases 3 and 4, when stack and process emissions from the facility had ended, the concentration gradients were more heterogeneous, as emissions from the contaminated properties became a larger part of total emissions. Case 4 especially showed small areas of higher concentrations around the contaminated homes embedded within the gradient fields from the remaining facility fugitive emissions.

The differences in the scales on each map should also be noted. In Case 1 the highest concentration isopleth was 0.01 fibers per cubic centimeter (fibers/cc), inside of which the concentrations were above this level. This innermost isopleth covered an area of about a city block around the facility. The outermost concentration isopleth was 0.0001 fibers/cc. For comparison the OSHA (Occupational Safety and Health Administration) workplace level of concern of is 0.1 fibers/cc and the Minnesota Department of Health indoor level of concern is 0.01 fibers/cc. In Case 2 the concentration isopleths ranged from 0.001 to 0.00001 fibers/cc, and in Cases 3 and 4 from 0.0001 to 0.000001 fibers /cc.

Figures 5 to 9 (editor's note: not attached, see Figure 7 for total deposition) show maps with isopleths of deposition for the four cases and for the total deposition over the period 1936 to 2001. As with concentration, the isopleths for deposition in Cases 1 and 2 showed a fairly smooth but steep gradient due to the dominance of the facility emissions. Also, the minimum value from Table 2 would fall outside the outer-most isopleth, and the maximum value would fall inside the inner-most isopleth. In Cases 3 and 4 the deposition fields showed the greater influence of the contaminated properties after the facility process emissions had ended. The scales on the deposition maps are different, with the highest deposition isopleths in Case 1 and the lowest in Case 4. The total deposition for the period was dominated by Case 1 which accounted for 96 percent of the total deposition on average, meaning that most of the deposition occurred before 1972. This finding may account for the fact that few or no fibers are found in most soils in the area that were not intentionally contaminated because the fibers deposited such a long time ago were subject to the disruptive forces previously discussed.

The deposition amounts are the total of wet and dry deposition. Wet deposition, however, accounted for about three to seven percent of the total on average, depending on the source. It should also be noted that the deposition amounts are the totals over all the years of the case. The total number of fibers deposited per square meter are several orders of magnitude higher than the values reported in my June 12, 2001 memo. This discrepancy is due to an error in the calculation of fiber deposition in the earlier memo—a conversion of grams to micrograms was inadvertently omitted. This error has been corrected in the present work.

The detailed model results for each of the 6,361 receptors and the GIS shape files describing the contours shown in Figures 1-9 will be supplied on a compact disc.

Table 1. Apportionment of emissions between stack and fugitive sources. Values are in tons per year (tpy) of tremolite fiber emissions.

Case	Stack emissions (lb/y)	Fugitive emissions (lb/y)	Total emissions (lb/y)	Percent Fugitive
Case 1	921	23	945	2%
Case 2	61	24	85	28%
Case 3	0	6	6	100%
Case 4	0	2	2	100%

Table 2. Range of model-predicted airborne concentrations of tremolite fibers across the modeling domain for each of the cases and long-term deposition of tremolite fibers assuming a constant deposition velocity of 0.3 cm/s.

	Minimum Long-term Average	Maximum Long-term Average	Minimum 1-hour average	Maximum 1-hour average
CASE 1 (1936-1972)				
Concentration (fibers/cc)	1.78×10^{-5}	2.64×10^{-2}	6.78×10^{-3}	8.68×10^{-1}
Total Deposition (fibers/m2)	$6.39 \times 10^{+7}$	$9.51 \times 10^{+10}$		
Case 2 (1972-1989)				
Concentration (fibers/cc)	1.50×10^{-6}	2.66×10^{-3}	7.61×10^{-4}	1.85×10^{-1}
Total Deposition (fibers/m2)	$2.27 \times 10^{+6}$	$4.03 \times 10^{+9}$		
Case 3 (1989-1999)				
Concentration (fibers/cc)	2.70×10^{-8}	3.81×10^{-4}	4.72×10^{-5}	2.89×10^{-2}
Total Deposition (fibers/m2)	$2.80 \times 10^{+4}$	$3.97 \times 10^{+8}$		
Case 4 (1999-2001)				
Concentration (fibers/cc)	1.21×10^{-8}	1.26×10^{-4}	2.00×10^{-5}	1.02×10^{-2}
Total Deposition (fibers/m2)	$2.29 \times 10^{+3}$	$2.39 \times 10^{+7}$		
Average Concentration (1936-2001)	1.04×10^{-5}	1.57×10^{-2}		
Total Deposition (1936-2001)	$6.62 \times 10^{+7}$	$9.92 \times 10^{+10}$		

Editors Note: Only selected excerpts of this memorandum have been included to avoid duplication of the October 8, 2002 memorandum.

DATE : June 12, 2001

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Minnesota Department of Health, Environmental Health

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Environmental Outcomes Division
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SUBJECT : Modeled Concentrations and Deposition of Tremolite Near the Western Mineral Products/W.R. Grace Facility

Introduction

This memo documents an air dispersion modeling study done to estimate airborne concentrations and deposition of tremolite fibers around the Western Mineral Products/W.R. Grace, Inc. vermiculite processing facility in Northeast Minneapolis. The study consisted of two parts: 1) estimation of emissions; and 2) use of an air dispersion model to estimate airborne concentrations and fiber deposition onto surfaces in the vicinity of the plant. Two time periods were considered, the period 1936 to 1972 (from initiation of operations until the baghouse filtration system was installed) and the period 1972 to 1989 (from baghouse installation until the facility ceased operations). The following sections discuss emissions estimation, modeling procedures, and modeling results.

Estimation of Emissions

Two fifty foot stacks served the expanding furnaces and a third stack served the monokote mixer. In addition to these three point sources, four sources of fugitive emissions were identified: 1) rail unloading of raw material; 2) rail loading of finished product; 3) truck loading of finished product (including truck traffic on unpaved surfaces containing tremolite fibers); and 4) handling and wind erosion of the waste pile. Figures 1 and 2 are photographs of the facility from opposite angles taken in February, 2001. Figure 3 is a schematic diagram showing the locations of the buildings and sources as represented in the model.

Attachment 1 is a spreadsheet showing the stack parameters and emissions calculations for the stacks for each of the two time periods. Two options were possible for estimating stack emissions. The first option was to use the 1977 and 1985 reported stack emissions. The second option was to use the estimated baghouse loading and the estimated baghouse efficiency. The 1977 emissions inventory report shows emissions of 0.12 tons per year of (tpy) of total suspended particles (TSP) for stacks one and two and 0.10 tpy of TSP for stack three. These values were said to be based on stack test data although the reports do not specify a test date nor whether this facility or some similar facility was tested. The 1985 emissions inventory report shows emissions of 0.06 tpy of particles less than ten micrometers in diameter (PM_{10}) for stacks one and two and 0.02 tpy PM_{10} for stack three. These values were said to be based on stack tests of similar equipment. No documentation of the stack tests was available.

Several documents contained information about the configuration, operation, and efficiency of the baghouse, including the 1977 and 1985 emissions inventory reports, the 1972 plans and specifications for the baghouse submitted by the company to the Minnesota Pollution Control Agency (MPCA), the 1975 MPCA Operating Permit, a report to the U.S. Environmental Protection Agency from the company (date obscured) on emissions of hazardous air pollutants, and a 1986 internal company document entitled *Process Description and Waste Profile*. The permit-allowable particle emissions were considerably larger than the amounts in the emission inventory reports. Based on the baghouse configuration, operation, and efficiency as outlined in the aforementioned documents, I judged the amount of particle emissions to be larger than the amounts reported in the emissions inventory reports for 1977 and 1985. For that reason, the second option for estimating stack emissions was used for stacks one and two, i.e., estimated baghouse loading and the estimated baghouse efficiency. The only emissions information available for stack three were the emissions inventory reports, so those data were used for this stack.

The baghouse loading was given as between 15 and 20 pounds per hour (lb/hr), and the tremolite concentration of the baghouse inputs was given as 1-3%. These values were used to place upper and lower bounds on the stack emissions (see Attachment 1). The upper and lower bound values differed by almost one order of magnitude. The average of the upper and lower bound values was used as the modeled emission rate for each of the two timeframes. The documents mentioned in the preceding paragraph give conflicting information on the hours per day of operation of the facility. Some suggest that the facility operated two shifts per day, while the emissions inventory reports mention 24-hour per day operation. For this simulation the furnaces were assumed to be operating at full production for 16 hours per day (6:00 am to 10:00 pm). This assumption is warranted since, even if the facility operated longer hours on some days, it is unlikely that full production was maintained for more than the equivalent of 16 hours per day over an extended period of time. The model-predicted concentrations are not dramatically changed using this assumption.

Attachment 2 is a spreadsheet showing the methods and equations for calculating fugitive emissions. The rail unloading emissions were taken from the U.S. EPA emission factor document for vermiculite processing. No emission factors were available for rail or truck loading, so the emissions from these sources were taken as one-half of the rail unloading emissions. This estimate was a judgment based on the fact that the loaded product was packaged, thus preventing some emissions as compared to the unloading process. The wind erosion and materials handling emissions from the waste pile were taken from U.S. EPA emissions factors documents for industrial wind erosion and aggregate handling and storage piles, respectively. Emissions from traffic in the unpaved truck loading area were developed from U.S. EPA emissions factors for traffic on unpaved roads. All of the fugitive emissions sources were characterized as area sources. The lateral dimensions of each source can be seen in Figure 3. The waste pile was given an initial vertical dimension of two meters, while the other fugitive sources were given an initial vertical dimension of one meter.

The fugitive emissions estimates were based on total annual production. Apportioning the emissions to specific times of the day was not feasible since loading and unloading could have occurred at any time. Similarly, wind erosion from the waste pile was not limited to specific hours of the day. An often-used simplification was assumed in which the fugitive emissions were apportioned evenly throughout the hours of the year. This assumption does not significantly affect the model-predicted long-term concentrations; however, it may lead to some underestimation of the maximum short-term (e.g., 1-hour average) concentrations.

Modeling Procedures

The ISC-Prime model was chosen for this analysis. The ISC model is the currently recommended model for industrial sources in the U.S. EPA Guideline on Air Quality Modeling (40 CFR 51, Appendix W). ISC-Prime represents a new version of the ISC model that has been proposed for adoption as a Guideline model. This new version contains an improved algorithm for calculating building-wake effects, the Prime algorithm. Since the Western Mineral Products/W.R. Grace, Inc. facility stacks are subject to building wake effects, the use of the best available model for considering such effects was considered important.

The model was run using the regulatory default model options. Five years of meteorological data (1986-1990) from the Minneapolis-St. Paul International Airport (surface data) and from St. Cloud (upper air data) were used in the analysis. Both air concentrations and total (wet plus dry) deposition were calculated. Plume depletion was not used. A polar-coordinate grid system of receptors was used with receptors located at distances of 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, and 1500 meters at every ten degrees of the compass. In addition, a group of 656 discrete Cartesian receptors was specified, corresponding to all street addresses located within 500 meters of the facility. These discrete receptors were included so that concentrations could be predicted at each of the individual homes and businesses within the 500-meter radius. Terrain elevations were included. Predictions were made of the maximum one-hour, 24-hour (note: this run was dropped from the later model runs), and long-term average concentrations and the long-term deposition fluxes.

Sources of Error

As with all such undertakings, there are several sources of error that affect the estimated concentrations and deposition. The predicted concentrations and deposition should be thought of as the best central estimate with error bounds on either side. Exact numerical propagation of each of the sources of error through the entire modeling process is beyond the scope of this analysis; however, I will attempt to give some insight into the types and magnitudes of the possible sources of error.

The model itself is a mathematical representation of atmosphere and does not perfectly simulate all the processes that affect pollutant dispersion. It is often stated (see U.S. EPA Modeling Guideline, 40 CFR 51, Appendix W) that the current generation of regulatory air dispersion models are capable of accuracy to within a factor of two, given accurate information on the source release characteristics and representative meteorological data. Model accuracy is also known to be better for long averaging times (e.g., annual average) than for short averaging times (e.g., one-hour average).

In the present study, the meteorological data can be considered to be reasonably reliable and representative. It was taken from a contiguous five-year period at the Minneapolis-St. Paul airport (surface data) and from St. Cloud (upper air data). The surface data site is within 15 kilometers of the facility, and there are no significant terrain features between the locations that would dramatically affect airflow patterns. The upper air data site, while approximately 100 km distant, was the nearest source of upper-air soundings available. Use of this type of off-site, National Weather Service meteorological data is routine for this type of modeling study, and while there are undoubtedly some errors introduced by using off-site meteorological data, these errors are likely to be minor when compared to errors in source characterization.

The Western Mineral Products/W.R. Grace facility in northeast Minneapolis has been out of operation for about 12 years. The buildings are still standing, but the stacks have been removed. Information about the operation of the stacks was taken from older documents whose reliability is at least somewhat uncertain. The stack physical dimensions are likely to be accurate, but the temperature, airflow, and tremolite fiber concentrations in the stack gases were likely to have varied over time for multiple reasons. In addition, the loading to the baghouse was only given to within specified limits (15-20 lb/h). The data currently available on the stack emission parameters represent estimates taken once (or a few times), usually for the purpose of fulfilling a regulatory requirement (e.g., permit application or emissions inventory report). Some of the estimates were likely based on measurements made at the facility, some estimates may have been based on similar equipment operated elsewhere, and other estimates may have been based upon the equipment vendor's specifications.

Another source of error is the tremolite concentration in the raw materials supplied to the facility. The concentration likely varied from shipment to shipment, but such data were not collected. There is information about the range in the amounts of tremolite fibers typically seen in the various materials (Stoner Rock – 2% to 10%, Baghouse Fines – 1% to 3%, Vermiculite Screenings - <0.5%), but not for the actual individual shipments made to the Minneapolis plant. The bottom line is that the total range of uncertainty in the stack emissions may be on the order of a factor of ten.

The largest source of error in the source characterization is undoubtedly that for the fugitive sources. Fugitive sources represented one percent of the total emissions in the Pre-baghouse case and nine percent of the total emissions in the post-baghouse case. These emissions are quantified using information about the amounts of material handled (both raw materials and finished products), the amounts of tremolite fibers in the materials, the number of vehicles required to transport the products, and other factors. The emission factors were based on values developed for general industrial classifications and for generic process like wind-entrainment of dust and vehicle traffic on unpaved surfaces. The uncertainties in the fugitive source parameterizations cannot be accurately quantified.

Figure 1. Photograph of the Western Mineral Products/W.R. Grace facility taken in February, 2001. This photo shows the north side of the four-story, sheet-metal building that housed the expanding furnace. To the left are raw material storage silos, and to the right is the cement-block building for product handling and shipping.

Figure 2. Photograph of the Western Mineral Products/W.R. Grace facility taken in February, 2001. This photo was taken from the southwest side of the facility. The four-story, sheet-metal building that housed the expanding furnace can be seen in the background. To the right is the brick building which housed operations and some shipping, and to the left is the cement-block building for product handling and shipping. The waste pile was located at the far left end of the cement-block building.

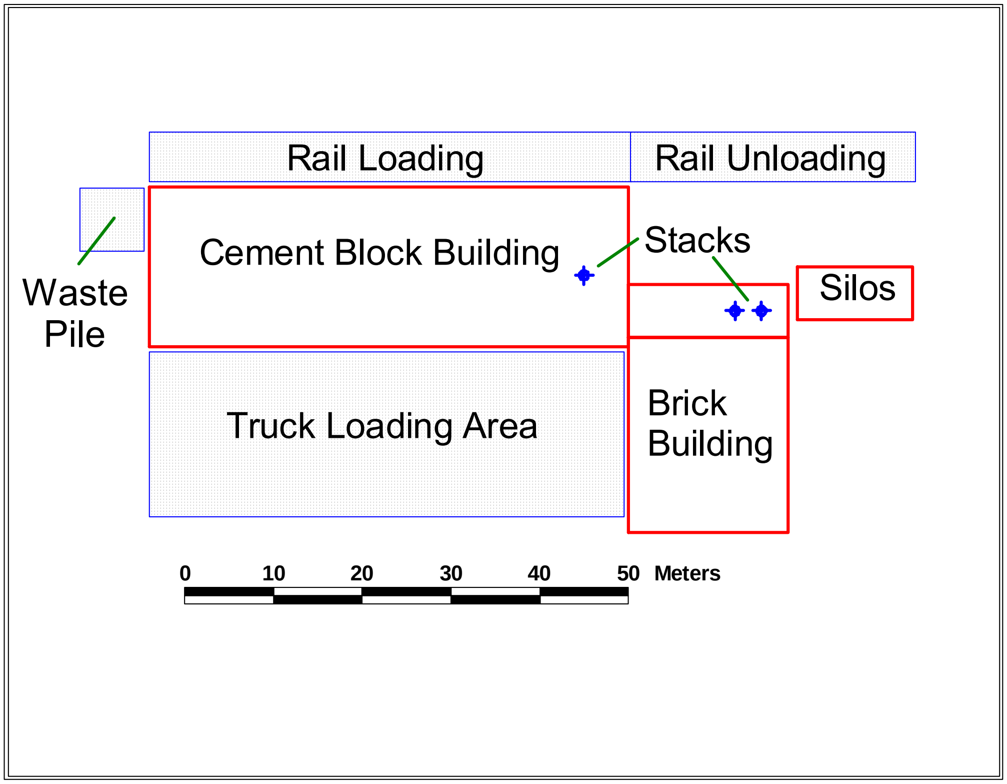

Figure 3. Schematic diagram of the Western Mineral Products/W.R. Grace, Inc. facility showing the locations of the buildings and the sources as represented in the air dispersion model. The three cross marks are the three stacks, two of which were located on the sheet-metal building and the third (monokote mixer stack) was located on the cement block building. The sheet-metal building, the only building not labeled in the diagram, is located directly north of the brick building.