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Exposure Assessment for Asbestos Contaminated Vermiculite

Versar, Inc., Springfield, VA

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16. Abstract (Limit: 200 words)

This document is an exposure assessment for asbestos-contaminated vermiculite. Such exposure is found to occur mainly via inhalation: ingestion and dermal adsorption are insignificant routes of exposure. Vermiculite is released to the air during mining, milling, exfoliation, transport, and use. These operations may also release some asbestos fibers, which are readily transported through the atmosphere.

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by

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FOREWORD

This document is an exposure assessment for asbestos-contaminated vermiculite, developed for the U.S. Environmental Protection Agency (EPA), Office of Toxic Substances (OTS). It reviews the available exposure data for asbestos in vermiculite, and estimates asbestos exposures to workers and consumers who come into contact with asbestos-contaminated vermiculite.

OTS has long been concerned about human exposure to asbestos. OTS became interested in asbestos-contaminated vermiculite as a result of its concern for exposure to asbestos.

Information for the exposure assessment was sought through a literature search, discussions with U.S. Government regulatory agencies, discussions with a consultant to the vermiculite industry, and a limited asbestos sampling and analysis study conducted for EPA at several sites working in the vermiculite industry. Many information gaps exist in this exposure assessment. As of its writing, however, this report is believed to represent the most up-to-date attempt at characterizing human exposures to asbestos in asbestos-contaminated vermiculite.

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Vermiculite is a micaceous hydrate of magnesium, iron, aluminum, and silica. It often coexists in nature with asbestiform minerals, and the asbestos may remain as a contaminant through processing to end use. The major processing step, exfoliation, involves heating the mineral to drive off part of the hydration water; this produces small, lightweight, low-density pieces. Most vermiculite products use the exfoliated mineral and fall into one of three categories: lightweight aggregates, insulation, and horticultural and agricultural products.

Exposure to vermiculite contaminated with asbestos occurs via inhalation; ingestion and dermal absorption are insignificant routes of exposure. Vermiculite is released to the air during mining, milling, exfoliation, transport, and use. These releases also involve release of asbestos fibers, which are readily transported through the atmosphere. Exposure to asbestos-contaminated vermiculite is an occupational and consumer concern, and occurs via ambient air near point sources.

Occupational asbestos exposure levels may reach 1.9 f/cc in mining, 9.7 f/cc in beneficiation, and 0.38 f/cc in exfoliation. These exposures affect a relatively small population of about 2,400 people. A much larger number of persons may encounter asbestos during trade or commercial use of vermiculite products, but are expected to receive lower exposure.

A large number of consumers use vermiculite products that may be contaminated with asbestos. Over 74 million persons use lawn and garden fertilizers each year. If the fertilizer is vermiculite-based, estimated exposure levels of 4.4 $\mu g/m^3$ and 28 $\mu g/m^3$ could result from lawn treatment and gardening, respectively. A time-weighted average exposure level of 6800 $\mu g/m^3$ asbestos is estimated for consumers insulating their attics with loose-fill vermiculite; this could affect 188,000 persons per year. These estimated consumer exposures are based on the worst-case assumption that vermiculite contains 1 percent asbestos.

A large population is exposed to asbestos in ambient air near vermiculite point sources. Approximately 13 million persons are estimated to live near exfoliation plants, and their asbestos exposure level may reach 0.025 $\mu g/m^3$. A smaller number of persons live near mines and mills and receive an unknown asbestos exposure.

This exposure assessment represents the best possible estimate of exposure to asbestos from vermiculite. Many of the scenarios are based upon very broad assumptions since definitive data are lacking in many areas.

2. INTRODUCTION

2.1 Background

Vermiculite is a micaceous mineral, a hydrate of magnesium, iron, aluminum, and silica. The raw ore, when heated, expands (exfoliates) to form low-density pieces. Exfoliated vermiculite is used primarily in lightweight concrete aggregates (21.4 percent of total production), as an aggregate and for fireproofing in construction premises (11.3 percent), as loose-fill or block-fill insulation (13.9 and 15.9 percent, respectively), for horticultural uses (13.2 percent), and as a carrier for agricultural chemicals (15.4 percent) (JRB 1982). Crude (unexfoliated) vermiculite is used in gypsum wallboard (6.7 percent) and has numerous minor uses (JRB 1982).

Vermiculite has been mined in the United States since 1929; four mining sites are currently in operation. W.R. Grace and Company, the largest domestic supplier and user of vermiculite, acknowledged in 1971 the presence of asbestos contamination in the ore mined at their Libby, Montana facility. Even after the ore was processed to remove impurities (beneficiated), some amphibole asbestos was detected in the vermiculite (USEPA 1980a).

The Libby ore was used for some years by the O.M. Scott and Sons Company in their manufacture of agricultural chemicals. In 1978, O.M. Scott and Sons reported health problems experienced by employees involved in vermiculite processing. Bloody pleural effusions had been detected in 4 of 350 workers; a follow-up study by the Occupational Safety and Health Administration (OSHA) found 32 cases of pleural or interstitial abnormalities. The nature of these illnesses was similar to conditions seen in individuals with asbestos-related diseases (USEPA 1980a).

These findings led to a Priority Review Level 1 study (PRL-1), performed by EPA's Assessment Division in 1980. The PRL-1 preliminary exposure assessment identified numerous data gaps that could be filled only by an intensive monitoring effort.

This monitoring effort was begun under the direction of the Exposure Evaluation Division of EPA in late 1980. It was designed to determine the degree and type of asbestos contamination found in vermiculite from various sources and in various states of processing. The scope of the monitoring study was altered after a priority shift within EPA. Most of the samples were taken from vermiculite mining and milling operations, with a few samples taken from vermiculite exfoliation (MRI 1982).

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This exposure assessment addresses the data found in vermiculite industry records, the information in the PRL-1, the monitoring data obtained by EPA, and other sources to provide an estimate of the extent of exposure to asbestos from mining, processing, and use of asbestos-contaminated vermiculite. The assessment will provide information for any future estimation of risk and for subsequent regulatory action.

2.2 Scope of Work

The objective of this task is to prepare a comprehensive assessment of the exposure of asbestos-contaminated vermiculite to humans through occupational, consumer, and ambient-related pathways. The exposure assessment covers five major components: sources, environmental pathways and fate, population studies, monitoring and modeling of environmental concentrations, and integrated exposure analysis.

Section 3, General Information, explains the geology, mineralogy, and physical and chemical properties of vermiculite. Section 4 is a summary of sources of asbestos-contaminated vermiculite; it is based upon a materials balance (JRB 1982). Environmental pathways and environmental fate are addressed in Section 5. Section 6, Monitoring and Modeling, discusses data from an OSHA survey and from EPA-sponsored monitoring (MRI 1982), as well as estimates of environmental concentrations prepared by Versar, EPA's Chemical Fate Branch, and General Software Corporation. Populations exposed to asbestos from vermiculite are identified and enumerated in Section 7; this section includes workers, consumers, and residents exposed via the ambient environment. The available concentration estimates, monitoring data, and population figures are integrated in the exposure analysis (Section 8).

In the absence of data, many assumptions were made in estimating releases, levels of exposure, and exposed populations. Most assumptions were designed to provide estimates of exposure in plausible worst-case scenarios, and all such assumptions are fully explained in the text of this report. It should be noted that no effort has been made to estimate the proportion of asbestos-contaminated vermiculite to which people are exposed. Monitoring data (Chatfield and Lewis 1979) indicate that not all vermiculite is contaminated with asbestos; however, the exposure calculations and population estimates of numbers assume that all vermiculite mined and used in the United States is contaminated with asbestos.

3. GENERAL INFORMATION

The following sections present background information on the mineralogy, geological occurrence, and properties of vermiculite. Section 3.1 deals with the mineralogical characteristics of importance to vermiculite. Section 3.2 discusses the geology of vermiculite, and explains the coexistence of vermiculite and asbestos minerals in ore bodies. Section 3.3 briefly summarizes the physical and chemical properties of vermiculite, with emphasis on the beneficiated, exfoliated mineral.

3.1 Mineralogy of Vermiculite

The first report of vermiculite was made in 1824 for a deposit near Worchester, Massachusetts (Bureau of Mines 1980). Although some small scale mining and use occurred in the early 20th century, it was not until 1921 that the modern vermiculite industry was started with the opening of the Zonalite Corporation mine near Libby, Montana (Bureau of Mines 1980).

Vermiculite is unique among minerals in its ability to exfoliate when heated. Exfoliation is the separation of successive sheets or laminae from a massive rock during weathering or other physicochemical processes (Myers 1960). In its natural state, vermiculite has a perfect basal cleavage and is easily split into laminae. It is a soft mineral (hardness varies from 1.5 to 2 or more), has a feel like talc, and is sometimes soapy when wetted (Myers 1960). Exfoliation from heating results in expansion at right angles to the cleavage planes, and is accompanied by an increase in volume of 800 to 1,200 percent (Myers 1960). Vermiculite can also be exfoliated by chemical processes, such as soaking in hydrogen peroxide, weak acids, and other electrolytes (Deer, Howie, and Zussman 1962).

The vermiculite crystal is composed of two silicate layers connected by a hydrous layer. The thickness of the unit cell in fully hydrated materials is about 14 Argstroms (Gruner 1934). Thermal analysis has shown that the water associated with vermiculite is released in three characteristic temperature ranges; the water thus released is designated as "unbound water," "bound water," and "hydroxyl water" (Myers 1960). Unbound water is released at temperatures up to 300°F and is apparently in equilibrium with environmental water (i.e., vapor or ground water) because its release is reversible. Unbound water can be removed without destroying a crystal's capability to exfoliate, but the amount of unbound water present does affect the degree of exfoliation. Bound water, which is removed at temperatures up to 500°F, is the water that must be removed to permit exfoliation. Hydroxyl water is released at about 1,600°F; it is not removed in commercial exfoliation processes because its removal results in disintegration of the vermiculite into particles too small for commercial use (Kresten and Berggren 1978).

3.2 The Geology of Vermiculite Occurrences

Macroscopic and microscopic types of vermiculite deposits differ in some basic aspects. Macroscopic vermiculites are trioctahedral and have a relatively narrow range of cation exchange capacity. Microscopic or clay vermiculites may be either trioctahedral or dioctahedral and are much more variable in composition and cation exchange capacity, making them difficult in many instances to distinguish from montmorillonite (Bassett 1959). The non-minable microscopic vermiculite-clay minerals are not discussed in this report.

Macroscopic vermiculite occurs in four types of host rocks: (1) ultramafic and mafic, (2) gneiss and schist, (3) carbonate rocks, and (4) ganite rocks (Deer, Howie, and Zussman 1962; Petrov 1962). Each of these has characteristic features. All of the major commercial deposits belong to the first category, and the material that is mined is mixed-layer vermiculite-biotite or vermiculite-phlogopite (Petrov 1962). In the gneiss-schist type, the vermiculite occurs as layers in banded metamorphic sequences. In the third category, vermiculite flakes close to the magnesium and member are sometimes found distributed through marbles ranging from calcite to magnesite composition. The fourthcategory refers to biotite in granite rocks that has weathered to an expanded or partially expanded alteration product of biotite and that puffs when heated in a flame (Petrov 1962).

A perennial problem in the study of macroscopic vermiculite is the question of hydrothermal versus supergene origin (Bassett 1959; Boettcher 1966). This problem is relevant to the question of asbestos contamination and the question of fibrous vermiculite formation. It would appear that commercial deposits, at least, are of supergene origin. A hydrothermal origin of vermiculite would provide temperatures and pressures too high to allow for the survival of the asbestiform minerals; also, formation of fibrous vermiculite would not be possible. Therefore, only deposits formed supergenically could contain fibers or asbestiform minerals. The petrological relationships for the deposits of interest suggest that pyroxenes, amphiboles, (both asbestiform and nonasbestiform) and olivines in ultramafic rocks (both igneous and metamorphic) were first altered by solution and volatilization from intrusive syenites, carbonatites, and pegmatites to form biotite, phlogopite, perpentine (both chrysotile and the non-fibrous varieties), and chlorite (Bassett 1959, Hunter 1950). Vermiculite was subsequently formed by the action of ground water on supergenes which leached out alkalis, redistributed magnesium, and added interlayer water molecules (Bureau of Mines 1980).

The most common parent mineral in vermiculite deposits is biotite. Other minerals commonly present include quartz, feldspar, apatite, corundum, chlorite, asbestos, talc, and clays (Bureau of Mines 1980). Biotite and vermiculite have crystal structures that are quite similar; this similarity permits molecular interlaying in a series that extends from pure biotite to pure vermiculite. Verieties in the series containing 10 to 15 percent vermiculite are called hydrobiotite (Bureau of Mines 1980).

The world's largest vermiculite deposit is in Libby, Montana. This deposit, which was formed roughly 100 million years ago, is a zoned-pyroxenite pluton that cuts Precambrian sedimentary rocks (Bureau of Mines 1980). The ore body is situated in an augite pyroxenite which has been altered to tremolite-actinolite asbestos, as well as the biotite-vermiculite series (Bureau of Mines 1980). The tremolite-actinolite asbestos cut through the pyroxenite in many thin veins (each approximately one inch). The thicker veins were mined in the 1920's for asbestos and are now absent from the ore body. The asbestos differs from the original augite in that it contains water and has a higher silica content. Therefore, the processes which created the vermiculite created the asbestos as well (Bassett 1959; Boettcher 1966). The body in which the vermiculite and asbestos occur forms a hill over 1,000 feet high and about 1,600 acres in area.

Another major commercial deposit, the Palabora deposit in South Africa, cuts Precambrian rocks which have a petrologic suite resembling those in the Libby deposit. The asbestos content of this deposit is much lower, probably concomitant with much lower silica concentration in supergene waters (Bureau of Mines 1980).

The most numerous deposits of the United States are in ultramafic layered metamorphic rock (characteristically biotite schists) and are cut by pegmatites. Although these may be hundreds of feet long, they are only a few feet thick and contain from a few hundred to several thousand tons. At some of the deposits (e.g., those in the Enoree district of South Carolina), amphibole asbestos has been found associated with the vermiculite along with talc, chlorite, chromite, actinolite, and rutile (Hunter 1950). The deposits of the Blue Ridge Mountains exemplify the last type of deposit. These are the ultramafic intrusives that are cut by pegmatites and other intrusive rocks (Bureau of Mines 1980). Vermiculite typically occurs in these deposits as lenses up to five feet thick and 60 feet long (Bureau of Mines 1980). A few lenses in Green Springs, Virginia are 20 feet thick and more than 100 feet long (Gooch 1957).

Although it is clear that asbestos and vermiculite can coexist in deposits, it is unclear how the minerals can coexist in a single crystal. Mifsud et al. (1977) showed that chrysotile could be grown from the top layers of vermiculite plates at places where elongated crevices were seen and where the plates are strained. This was seen in the basement of a deposit in Malawi and is probably the result of mild hydrothermal conditions after the genesis of the vermiculite. What was observed was a topotatic alteration of the vermiculite plate itself. The alterations occurred in three steps, according to Mifsud et al. (1977): (1) surface cracks developed along well-defined crystallographic directions (Si-O-Si chains); (2) the vermiculite folded back at the edges of the rocks; and (3) the looser vermiculite ribbons were transformed to crysotile, undergoing chemical changes mainly by a removal of Fe and an enrichment in Mg and OH.

Thus, vermiculite and asbestos can coexist in separate veins or be interlayered in the same vein. Only the study of each mineral deposit could shed light on how the commercial vermiculite and asbestos coexist. Such a study would provide insight into the question of whether the asbestos can be separated and, if so, whether it can be separated more easily before exfoliation.

3.3 Chemical and Physical Properties

Vermiculite varies in chemical composition; a useful formula for vermiculite is:

$$(Mg,Ca)_{0.7-1.0}\ Mg_{3.5-5.0}\ (Fe^{+3}, Al)_{2.5-1.0}$$

$$(Al_{2.0-3.5}, Si_{6-5.5})\ O_{20}\ (OH)_4 \quad (H^2O)_{7-9}$$

Crude vermiculite has a loose bulk density of 640 to 1000 kg/m^3; exfoliated vermiculite expands to a bulk density of 56 to 192 kg/m^3 (JRB 1982). This low density is important to its uses as an aggregate in concretes and plasters and in some insulation and packing applications.

Another important characteristic of vermiculite is its significant capacity for reversible cation exchange. Many cations can be substituted, principally for the magnesium and calcium (Deer, Howie, and Zussman 1962). This permits use of vermiculite as a fertilizer and soil additive. The cation exchange capacities, expressed a milli-equivalents per 100 grams of vermiculite, range from 35 to 70 for unexfoliated ore and from 20 to 60 for exfoliated vermiculite (JRB 1982).

Vermiculite has a very low thermal conductivity. This property permits wide usage of vermiculite as a heat-resistant insulator in steelwork and castable refractories. Selected properties of expanded vermiculite are listed in Table 1.

Beneficiated vermiculite is available in a wide size range. W.R. Grace separates it into five size grades: Grade 1 is the largest and

Table 1. Selected Properties of Exfoliated Vermiculite

Property	Value
Thermal conductivity (Btu in hr^{-1} ft^{-2} $°F^{-1}$)	0.43 - 0.45
Thermal conductivity (W m^{-1} $°C^{-1}$)	0.62 - 0.065
Thermal diffusivity (ft^2/hr)	0.025
Specific heat at 0°F (cal g^{-1} $°C^{-1}$)	0.20
Specific heat at 300°F (cal g^{-1} $°C^{-1}$)	0.24
Specific heat capacity (J kg^{-1} $°C^{-1}$)	840
Specific gravity	2.6
Fusion point (°C)	1,200° - 1,300°
Melting point (°C)	1,315°
Sintering temperature (°C)	1,260°
Cation exchange capacity (milliequiv/100 g)	
Vermiculite ore (S. Carolina)	70
Vermiculite ore (Montana)	35
Expanded vermiculite (S. Carolina)	20 - 60
Expanded vermiculite (Montana)	20 - 30

Source: JRB 1982.

Grade 5 is the smallest. Although company specifications were not obtained, measurements of graded samples obtained in a monitoring effort (MRI 1982) are presented in Table 2.

Table 2. Physical Properties of Graded Vermiculite from W.R. Grace and Company, Libby, Montana Mine

Grade no.	Approximate maximum dimension (mm)	Approximate number of particles/g	Approximate weight/ average particle
1	5 - 10	23	42 mg
2	3 - 5	130	7.4 mg
3	1 - 3	1,700	0.58 mg
4	0.5 - 1	11,000	91 ug
5	0.2 - 0.5	130,000	7.6 ug

Source: MRI 1982

4. SOURCES

The following section presents a summary of the Level II vermiculite materials balance performed for EPA's Exposure Evaluation Division (JRB 1982). The materials balance estimates the amount of vermiculite processed and released during every step of production. JRB's release data have been tabulated into four charts, each expressing a major step in production: mining and milling, exfoliation, transportation, and consumer uses. Little detail is presented in this section of the exposure assessment. Further data are available in the materials balance report.

4.1 Releases from Mining and Milling (JRB 1982)

Table 3 shows the vermiculite releases during mining and beneficiation of the vermiculite ore. Beneficiation removes the vermiculite from the gangue (waste or impurities). In Table 3, the amount referred to is the amount of ore, which includes the gangue.

There are four vermiculite mines in the U.S. One million tons (1.2×10^6 kkg) of vermiculite ore were mined and beneficiated in 1979 to produce 314,000 kkg of crude vermiculite. JRB estimated that 802 kkg were released to the air, 89,300 kkg were released to water, and 2,490 kkg were released as solid waste (see Table 3). The water releases were disposed of in settling ponds, and the water was recycled. The air releases were fugitive releases from the dust control equipment. The solid wastes were the particulates collected in the dust control system, and were landfilled.

Three different techniques are used to mine and beneficiate the ore. No data were available for the Virginia Vermiculite mine, so for Table 3 it was assumed that Virginia uses the same techniques as W.R. Grace in Enoree, South Carolina. The largest releases from mining and beneficiation are water releases from wet processes. The particular steps associated with the greatest releases are concentration and secondary screening, since these procedures remove most of the gangue. (Note that Patterson Vermiculite does not use wet processes.) Any step with a large air release is assumed to have dust control equipment.

4.2 Releases from Exfoliation (JRB 1982)

Ninety-four percent of crude vermiculite is exfoliated. Table 4 identifies all the releases during exfoliation. Note that some crude vermiculite is imported from South Africa. The exfoliation processes used are the same, but since the incoming feeds contain different amounts of vermiculite, they have different release rates. Ninety percent of the releases are expelled in the exfoliation step.

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Table 3. Vermiculite Releases from Mining and Beneficiation of Vermiculite Ore

W.R. Grace, Libby, Montana

Process[a]	Amount[b] (kkg)	Air[c] (kkg)	Water[c] (kkg)	Solid[c] (kkg)
Mining	748,000			
Overburden removal		25.6		
Breaking & loading ore		6.73		
Hauling ore		20.2		
Conveying		1.18		
Dumping & stockpiling		5.39		
Primary screening	748,000			
Primary screening		108.		
Crushing		6.31		
Conveying		1.17		
Secondary screening	710,000			
Conveying/blending		1.17		
Secondary screening		55.5	9,350	
Concentration	522,000			
Wet flotation		128.	23,800	
Dewatered/drying[d]		23.2		1,140
Sizing/storage	181,000			
Conveying		4.69		
Loading		28.6		
Hauling				
Dumping		21.5		
Screening/sizing[d]		5.76		202
Storage				
TOTALS	181,000	443.00	33,200	1,420

Product: 74% Vermiculite
Ore: 22.5% Vermiculite

Virginia Vermiculite, Louisa, Virginia & W.R. Grace, Enoree S.C.

Process[a]	Amount[b] (kkg)	Air[c] (kkg)	Water[c] (kkg)	Solid[c] (kkg)
Mining	439,000			
Overburden removal		24.1		
Breaking & loading		6.36		
Hauling		165.		
Dumping & stockpiling		5.09		
Primary washing	439,000			
Ore feeding		6.36		
Primary washing		14.8	5,488	
	32[illegible],000			
Secondary washing				
Grinding		19.1		
Secondary washing		14.3	8,780	
Flotation	285,000			
Wet flotation		74.6	42,400	
Dewatered/drying		17.5		861
Sizing/storage	128,000			
Conveying		3.54		
Screening/sizing[d]		4.35		215
Conveying		3.54		
Storage				
	128,000	359.00	56,670	1,074

Product: 79% Vermiculite
Ore: VA 40% Vermiculite
SC 30% Vermiculite

Patterson Vermiculite, Enoree S.C.

Process[a] (kkg)	Amount[b] (kkg)	Air[c] (kkg)	Solid[c] (kkg)
Mining	9,660		
Overburden removal		0.03	
Breaking & loading		0.79	
Hauling		0.370	
Dumping & stockpiling		0.063	
Conveying	9,660	0.014	
Primary screening		2.56	(neg.)
Conveying	9,370	0.014	
Storage			
	9,370	3.24	(neg)

Product: 33% Vermiculite
Ore: 40% Vermiculite

a All numbers from JRB, 1982.
b These amounts are the total amounts being processed: gangue plus vermiculite.
c These releases are only amounts of vermiculite released.
d Dust control system.

Table 4. Vermiculite Releases From Exfoliation of Vermiculite

	W.R. Grace, Virginia and South Africa vermiculite releases				Patterson vermiculite releases			
Exfoliation Process	Amount of vermiculite (kkg)	Air (kkg)	Water (kkg)	Solid (kkg)	Amount of vermiculite (kkg)	Air (kkg)	Water (kkg)	Solid (kkg)
Conveying	216,000	2.97		4.51				
Screening/sizing	27,500	23.4		35.57				
Conveying	27,500	0.387		0.56				
Exfoliation	216,000	2,780	5,680 (steam)	4,233.6	1,970	52.4	107 (steam)	77.0
Conveying	205,000	2.87		4.37				
Destoning	158,000	16.0		396.2	1,800	0.138		26.2
Bagging	130,000	51.0		77.42	1,770	0.69		1.07
Bulk loading	6,220	6.22						
Premixes	68,300							
Dust control		89.4				1.61		
Totals		2,972.2	5,680	4,752.2		54.8	107	104.3

Source: JRB 1982.

JRB assumed that every step had dust control equipment that was 98 percent efficient. It is estimated that 4,500 kkg of asbestos collected in the dust control equipment, while 4,500 kkg are released as steam either directly to the air or into the dust collector. Three thousand tons (3,027 kkg) were released as fugitive releases to the air. The exfoliated product is transported to manufacturer in bags or bulk loads, or as an ingredient in premixes.

4.3 Releases During Transportation (JRB 1982)

Table 5 shows transportation releases. Domestic crude vermiculite is transported from the mill to the exfoliation plant by railroad or truck. Imported and exported vermiculite are transported by ship and rail. Exfoliated vermiculite destined for consumer use is transported in bags or bulk loads. The estimated transportation releases are negligible. Thirty-nine kkg are released to the atmosphere, and 125 kkg are released to the land due to spillage.

4.4 Releases During Consumer Use (JRB 1982)

Exfoliated vermiculite is used in three major types of consumer products. It is used in place of sand as a lightweight insulating material in concrete; it is used as loose-fill and block-fill insulation; and it is used agriculturally as a growing medium or a pesticide carrier. Unexfoliated vermiculite is used to make gypsum board (drywall). The largest release from these uses is the solid release to the land. As a component of agricultural products, vermiculite is applied to the soil directly; it is released to land from other products as the result of spillage. JRB estimates that releases of vermiculite are insignificant after installation of the end-use product.

Table 6 summarizes releases from consumer use of vermiculite products. These release data apply equally well to commercial and industrial use of the products.

Table 5. Estimated Vermiculite Releases While Transporting

	Amount transported (kkg/yr)	Vermiculite releases	
		Air (kkg/yr)	Solid (kkg/yr)
Crude vermiculite			
Domestic	302,000	10.8	-
Imported	27,200	15.1	-
Exported	31,700	0.15	-
Total		25.9	
Exfoliated vermiculite			
Transport in bags	132,000	6.22	-
Transport in bulk	6,220	6.60	125.0
Used at plant	68,300	-	-
Totals		38.8	125.0

Source: JRB 1982.

Table 6. End Uses of Exfoliated and Unexfoliated Vermiculite

Exfoliated use	Percent of total production[a]		Quantity[b] (kkg)			Vermiculite releases (kkg)		
			Total	Vermiculite	Gangue	Air	Water	Solid
Aggregates	36.2		83,300	74,900	8,470			
Concrete		23.0	52,900	47,600	5,380	14.8	0.462	445.1
Plaster		1.02	2,350	2,110	239	153.8		242.2
Premix		12.2	28,100	25,300	2,850			
Insulation	31.2		71,800	64,600	7,300			
Loose fill		14.9	34,300	30,800	3,490	31.6		4,025.2
Block fill		16.2	37,300	33,500	3,790	33.5		345.1
Packing		0.07	151	145	16	0.0725		144.5
Agricultural	30.7		70,600	63,500	7,180			
Growing media		14.2	32,700	29,400	3,320	33.8	0.11	29,400*
Carrier for agricultural chemicals		16.5	38,000	34,200	3,860	0.24		50.1
Other	1.71		3,930	3,540	400	3.54	0.011	499
Totals	99.8		230,000	207,000	23,400	271.4	0.6	35,150.
Unexfoliated use								
Gypsum board	100.00		19,400	14,700	4,700	11.1		922.
Total			249,400	221,700	28,100	282.5	0.6	36,070.

[a]Percentage derived from data in Bureau of Mines 1980 (JRB).
[b]Quantity = (total product) x (percent).
*Numbers do not add due to rounding.

Source: JRB 1982.

5. EXPOSURE PATHWAYS AND ENVIRONMENTAL FATE

The most important factor dictating the chemical fate of both vermiculite and asbestos (and, therefore, asbestos-contaminated vermiculite) is the chemical inertness of both minerals. Neither substance would be expected to undergo chemical transformation when released into the environment. Furthermore, their refractory nature precludes the effect of melting/boiling point, solubility, vapor pressure, octanol/water partition coefficient, etc. on their transport. Other than density, the only physicochemical property that is of importance in assessing the atmospheric fate of asbestos-contaminated vermiculite is particle size and shape (USEPA 1980a).

Terrestrial and fluvial transport processes affecting vermiculite are not well characterized. The following section summarizes what is known about the fate and transport of asbestos.

5.1 Transport and Fate

Vermiculite occurs naturally in many regions of the country, and can be released directly to the environment by all normal geological weathering processes. Rates of natural release can be altered by human activity such as road building, mining, and construction.

The asbestos fibers from vermiculite may enter the environment through such human activities as (1) mining and milling, (2) transportion, (3) manufacture and use of products containing vermiculite, (4) demolition of buildings in which vermiculite is a structural component, and (5) solid waste disposal of vermiculite-containing materials and mining and milling wastes. Asbestos fibers are not bound chemically to the vermiculite; rather, the minerals coexist in the same matrix which, when chemically or physically disturbed, may release the minerals.

Mining, milling, and exfoliation of vermiculite almost certainly account for the vast majority of the environmental release of asbestos from vermiculite. Virtually all of the mined deposits are in rugged country removed from heavily populated areas. Vermiculite is transported through the country in its unexfoliated state along all major routes of transportation. Atmospheric asbestos dust settles or is washed out by precipitation; it then returns to the soil and to waterways. Asbestos fibers are easily resuspended by wind and water and can be redistributed widely. Because of its stability, asbestos must be regarded as persistent in the environment with an ultimate sink in soils or sediments.

The following sections deal with all the processes affecting the environmental distribution of asbestos fibers. The actual vermiculite minerals are not addressed in this exposure assessment. The chemical fate processes affecting vermiculite may be similar to those affecting asbestos. Physical transport probably differs, however, since vermiculite particles entering the environment are probably larger than asbestos particles, and particle size is a major factor affecting transport.

5.1.1 Transport Processes

(1) Atmospheric Transport

(a) Turbulence and Diffusion. Asbestos fibers are restricted to the troposphere (i.e., the first 5 to 10 miles of the atmosphere), above which lies the relatively stable, nonconvective stratosphere. The vertical diffusion of fibers from a source may also be restricted by surface inversions or by an inversion layer lying above an unstable mixing layer.

A surface inversion usually occurs in the early morning when light cloud and wind conditions prevail. As the earth's surface is being heated, convective currents and turbulence increase near the surface. If the upper part of the original inversion layer persists, atmospheric diffusion is largely restricted to a mixing layer below the inversion layer (Wanta and Lowry 1976, Hewson 1976). Such mixing heights may range from essentially zero at night to several kilometers in the afternoon; typical seasonal means are 300 to 800 meters in the morning and 600 to 4,000 meters in the afternoon, depending on location (McCormick and Holzworth 1976).

Low mixing heights, low wind speeds, and the absence of precipitation suppress dispersion and lead to raised pollution levels; the persistence of all three conditions is associated with air pollution episodes. Figure 1 gives some indication of the frequency of such episodes. Air pollution episodes can be particularly acute in industrialized valleys where inversions are a dominant meteorological phenomenon.

Both turbulent diffusion and wind disperse asbestos from its point of emission. These processes mix released fibers with ever-increasing volumes of air, lowering concentrations in the region of release and dramatically reducing concentrations in areas peripheral to the asbestos source. Three scales of turbulence can be defined (Whelpdale and Munn 1976):

- Microscale: Small fluctuations responsible for the initial diffusion of asbestos in the first hour or so of its release.
- Mesoscale: Eddies with dimensions of several kilometers. This turbulence can be consistent, as in the case of a sea breeze or valley flow.

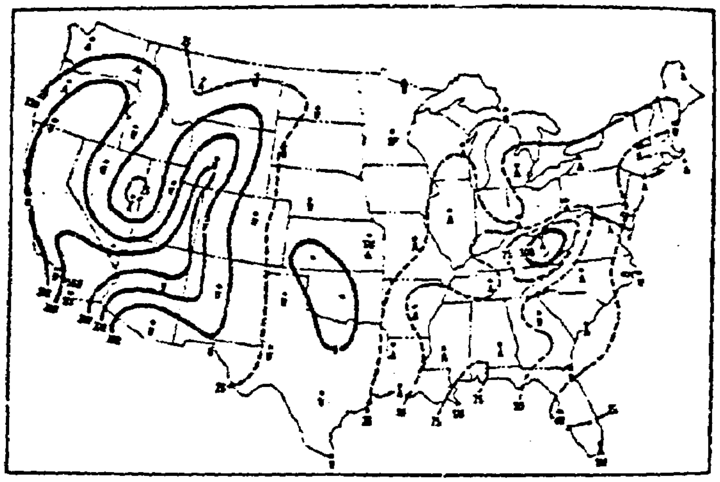

Figure 1. Isopleths of total number of episode-days in 5 years with mixing heights ≤ 1500 m, wind speed ≤ 4 m/sec, and no significant precipitation - for episodes lasting at least 2 days. Season with greatest number of episode-days indicated as winter (W), spring (SP), summer (SU), or autumn (A)

Source: McCormick and Holzworth (1976).

• **Macroscale:** Eddies of dimensions exceeding 500 km.

All three scales of turbulence can affect dispersion.

(b) Dry Removal Processes. Gravitational settling rates have been determined experimentally for asbestos fibers in the absence of turbulence; these rates depend principally upon fiber diameter and are relatively independent of fiber length (Timbrell 1965). The same conclusion was reached by modeling fiber aerodynamics (Sawyer and Spooner 1978). The theoretical settling velocities are given in Figure 2. Typical fibers reportedly have diameters less than 1.5 µm (Dement and Harris 1979, Smith et al. 1973); single fibrils have diameters near 0.06 µm. From Figure 2, fibers 1.6 µm in diameter would theoretically fall three meters in about one hour while single fibrils would require over 15 days.

In the atmosphere, settling velocities for most asbestos fibers will be negligible in comparison with turbulent vertical velocities. This is true for fibers with equivalent sphere diameters of less than 20 µm* (Wanta and Lowry 1976), i.e., fibers with diameters up to 6.4 µm. Larger fibers and fiber clumps would be subject to gravitational settling. Inside buildings, turbulence generated by movement or air through flow prolongs particle settling.

Fibers undergoing turbulent motion may collide with and adhere to surface cover. The extent of fiber removal by impaction will depend on fiber size and velocity, the rate at which the fiber is supplied to the surface, and the degree to which various surfaces retain impacting fiber (Whelpdale and Munn 1976). This is a complex process for which no quantitative removal estimates exist for asbestos.

(c) Precipitation. Pollutants are removed from the air during rainfall at a rate proportional to their concentration (Wanta and Lowry 1976). Denoting the concentration at time t as C(t) and the initially observed concentration as C_0,

$$C(t) = C_0 e^{-wt}$$

where w, termed the washout coefficient, is a function of particle size and rainfall rate. Typical values of w are given in Figure 3. Evidently, a rainfall rate of 0.15 in/hr (3.8 mm/hr) reduces the concentration of spherical particles 4 µm in diameter by 50 percent in two hours. Larger particles are removed more efficiently, and this removal mechanism has

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*The equivalent sphere diameter is defined as the diameter of a sphere 1 gm/cm^3 in density having the same fall velocity as the fiber of interest. A 20 µm diameter sphere so defined falls at a rate of 1.2 cm/sec in the absence of turbulence.

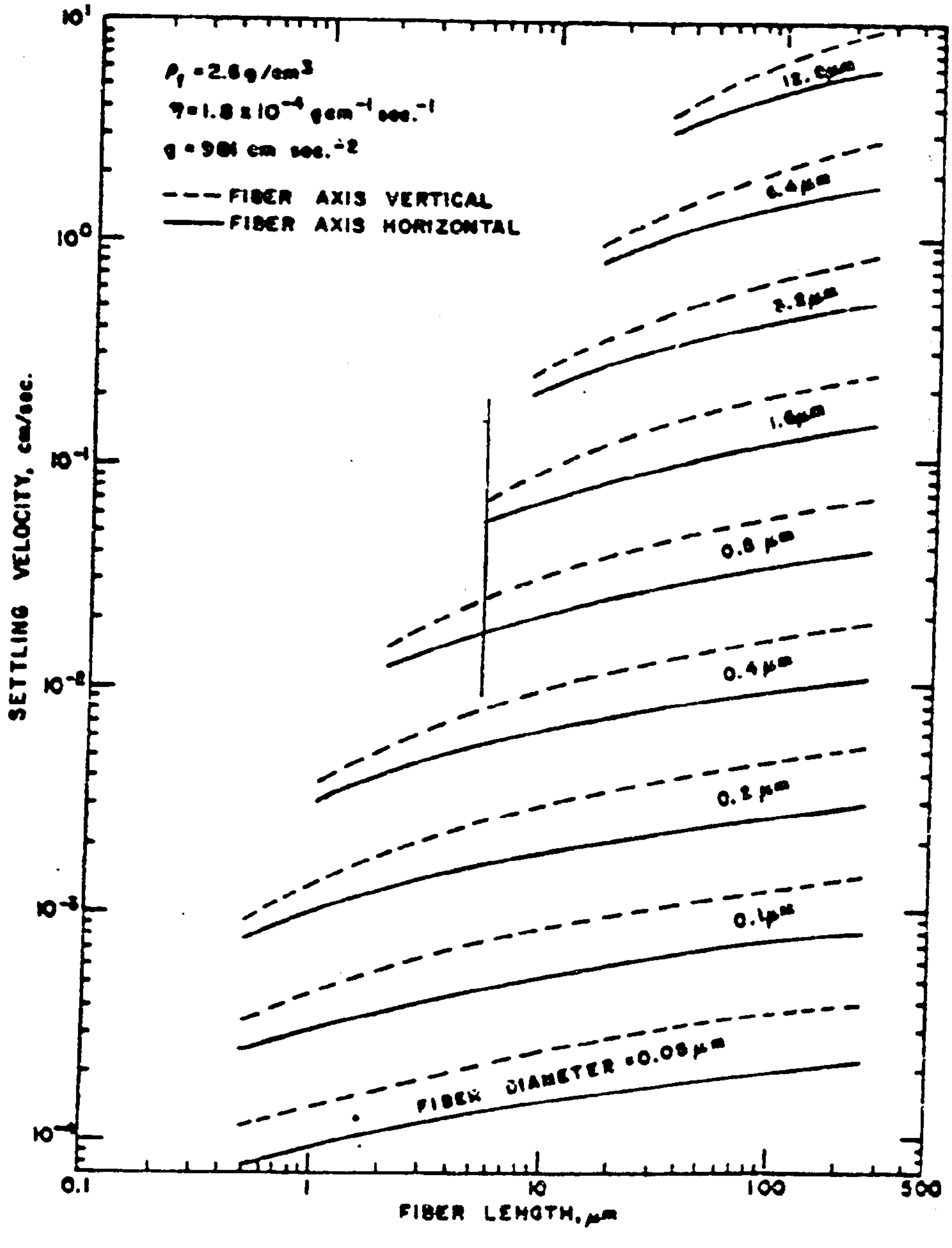

Figure 2. Theoretical Settling Velocities of Fibers

Source: Sawyer and Spooner (1978).

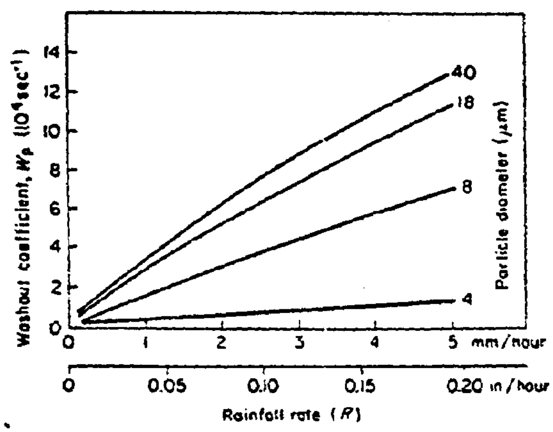

Figure 3. Typical Values of Washout Coefficient

Source: Wanta and Lowry (1976).

been found ineffective for spherical particles of diameter less than 2 µm (Haagen-Smit and Wayne 1976).

Results of a field monitoring effort for asbestos fibers seem to confirm this effect for asbestos fibers (Harwood and Blaszak 1974). After a week of precipitation, the concentration of fibers longer than 1.5 µm was significantly suppressed, while levels for fibers of length less than 1.5 µm appeared unaffected. Removal rates for nonspherical particles are unknown.

Reentrainment. Asbestos fibers may be reentrained by surface winds, vehicular traffic, or indoor movement. Indoor levels have been compared during periods of no activity and high activity (Sebastien et al. 1979); the levels differed by one to two orders of magnitude for each of three different rooms (Table 7).

Reentrainment of asbestos in environmental situations has not been studied directly except in the case of waste pile emissions. Nonetheless, field measurements in conjunction with these studies suggest that it may be an important secondary source, contributing significantly to ambient levels in some instances.

Emissions from waste piles are recognized as potentially important. During periods of high winds, asbestos has been observed at a playground and in houses near one dump (USEPA 1974). Atmospheric asbestos emissions from industrial dumps and mine tailing piles were investigated by Harwood and Blaszak (1974) and by Harwood and Ase (1977). Dumps were determined to be a significant and possibly hazardous source of asbestos fiber; the reentrainment of unbound asbestos fibers proved to be responsible for most of the emissions. Particulate emissions from tailing piles have been estimated under various climatic conditions by PEDCO (1973).

In summary, reentrainment of asbestos fibers does occur, and studies of waste pile emissions indicate that it is an important secondary source. Quantification of the effects of asbestos reentrainment has not been attempted except at waste piles. Reentrainment is responsible for the majority of asbestos emissions from waste piles and may also be particularly important in urban areas.

(e) Atmospheric Asbestos Burden from the Use of Vermiculite. Evaluation of changes in the atmospheric burden of asbestos from the use of vermiculite is inhibited by four factors:

1. A comprehensive inventory of asbestos emissions from vermiculite (as well as other sources) does not presently exist; only exfoliation plants as point sources have been well studied.

Table 7. Indoor Reentrainment Potential

Room without human activity (ng/m^3)	Room with human activity (ng/m^3)
15	750
3	630
1	62

Source: Sebastien et al. (1979).

2. The quantitative effects of asbestos removal mechanisms are presently unknown.

3. The contribution of asbestos reentrainment to the atmospheric burden has yet to be established.

4. Monitoring of asbestos in the environment cannot differentiate between the different sources of asbestos contamination.

In general, atmospheric asbestos from contaminated vermiculite can come from a series of sources.

Industrial sources, such as stack emissions from exfoliation plants and industrial users of vermiculite, probably contribute the bulk of asbestos from vermiculite. Waste pile emissions may be another source. Mining emissions, such as the dust produced from the strip-mining of vermiculite deposits, cause localized asbestos contamination of air. Workplace and other indoor sources may increase atmospheric asbestos levels.

Although these sources have been studied to some degree in past asbestos studies, it is still impossible to predict with any accuracy the atmospheric concentrations of asbestos from contaminated vermiculite.

(2) Fluvial Transport. Tailings from taconite mining dumped into Lake Superior by the Reserve Mining Company at Silver Bay, Minnesota, have provided the only opportunity to study the transport of asbestos in the aquatic environment. These tailings contained more than 50 percent quartz and about 40 percent cummingtonite-grunerite (mean chemical composition ($Fe_5Mg_2Si_8O_{22}$). Tailings were dumped into the lake at the rate of about 60,000 to 70,000 kkg per day; the water slurry containing the tailings was released at a rate of about 2.4×10^6 m^3/day (cook 1973). As a result, asbestos has been detected in the drinking water of Duluth, Minnesota, about 75 miles distant (Cook 1975).

It has been shown that although the asbestos fibers are traveling great distances in the water column, they are being coagulated and sedimented in the western part of the lake near the tailing delta (Kramer 1976). If this process were not going on, according to the calculations of Kramer, 3.5×10^6 fibers/liter should be found distributed evenly throughout the volume of Lake Superior. In actuality, however, only 1×10^6 fibers/liter are present in the eastern part of Lake Superior. Kramer found, as well, that the greater the distance from the tailings themselves, the richer in magnesium the asbestos became. This effect was attributed to the magnesium-rich asbestos having a more sensitive zeta potential which would prevent coagulation and sedimentation.

This suspended asbestos might settle under certain environmental conditions. Although no specific data are available on settling rates of asbestos, several analytic models of the physical processes in aquatic environments have been developed in recent years. Examples include calculations of vertical eddy diffusivity within a nepheloid layer (Feely 1976), dissolution of diatoms (Loi and Lerman 1975), and suspended sediment transport (Nihoul 1977). Many of the analytic models have relied on Stoke's Law, which is an analytic solution to the problem of a sphere settling in an unbounded Newtonian fluid (Sverdrup et al., 1964). The work of Neihof and Loeb (1972, 1974) and Chase (1979) on the electrochemical characteristics of natural particulates and their settling behavior in natural water systems suggests that the Stokesian assumption may not be appropriate for charged particles. It appears to be impossible at present to describe the settling behavior of asbestos in aquatic systems more definitely than to say that asbestos will stay in suspension for quite a long time.

Although there has been little study of asbestos transport in the aquatic environment, it appears that the transport of asbestos depends upon such poorly understood geochemical mechanisms as surface chemistry, mineralogy of the fiber, and physical settling rates. Only further study of the problem will enable a fuller understanding of the asbestos minerals in the aquatic environment.

(3) Terrestrial Transport. There is presently no information available on the transport of asbestos in the natural terrestrial environment. Burilkov and Michailova (1970), in their study of soil samples in a Bulgarian tobacco-growing region with dispersed asbestos outcroppings, have discussed the health effects of farming in the region but did little study of the transport of asbestos minerals in the soils.

5.1.2 Environmental Fate

Asbestos has often been touted as an indestructible mineral; in reality, however, this is far from the case. Experiments on thermal effects and the acid leaching of asbestos have been summarized by Speil and Leineweber (1969) and Hodgson (1979) and have only a peripheral relation to the environmental behavior of asbestos; however, the following laboratory experiments are definitely germane with regard to its degradation in the environment.

Choi and Smith (1972) observed the kinetics of the dissolution of chrysotile in water over a temperature range of 5 to 45°C. A correlation was noted between the rate of dissolution of magnesium from the chrysotile and the rate of pH drift. The rate of the dissolution reaction was directly proportional to the specific surface area of the asbestos minerals. It was noted that magnesium cations may be continuously liberated from the chrysotile fibers, leaving behind an intact silica structure. This original structure could then readsorb metal cations, since it will develop a highly negative charge. In general, however, this readsorption of metal cations is not observed; the smaller the particle, the faster the magnesium is liberated from the asbestos structure. Moreover, the reaction is temperature-sensitive only in the initial stages of contact between chrysotile and water.

Hostetler and Christ (1968) determined an activity product of chrysotile in water at 25°C of $10^{-51.0}$. These results suggest that chrysotile is slowly soluble in water under conditions of continuous extraction. How applicable these results are to the ambient environment can be determined only through further experimentation. For instance, Chowdhury (1975) studied the leaching of asbestos in distilled water and at body temperature (37°C). He found that, for all practical purposes, amosite and crocidolite were inert under these conditions. Nonetheless, although he was unable to reach a chemical equilibrium after two months of leaching, a significant amount of the chrysotile had dissolved (1,000 µmol of Mg/g asbestos had been leached). He found further that under a dynamic system, after the magnesium had leached out, the silica skeleton began flaking apart, thereby eliminating the asbestos structure.

It appears that asbestos does not have an adsorptive affinity for the solids normally found in natural water systems; however, some materials, notably trace metals and organic compounds, have an affinity for asbestos minerals. The charge-dependent behavior of asbestos can be described by the concept of the zeta potential, the isoelectric point (IEP), and the zero point of charge (ZPC). (For a detailed description of these concepts, see Parks 1967.) The zeta potential is a measure in mV of the surface charge of a solid. The ZPC is the pH at which the solid surface charge from all sources is zero. The IEP is a ZPC arising from interaction of H^+, OH^-, the solid, and water alone. The ZPC of a complex oxide such as asbestos is approximately the weighted average of the IEPs of its components. Predictable shifts in ZPC occur in response to specific adsorption and to changes in cation coordination, crystallinity, hydration state, cleavage habit, surface composition, and structural charge or ion exchange capacity.

Prasad and Pooley (1973) investigated the electrokinetic properties of amphibole asbestos dust samples in comparison with quartz dust. The isoelectric-point of amosite was found at a pH of 3.1 and that of crocidolite at a pH of 3.3 (Figures 4 and 5). The zeta potential of these amphibole asbestos minerals, because of the formation of the fibers, is a function of the combined face and edge charge. The face charge will be due to the silica in the structure, while the edge charge is due to the layers of metal cations sandwiched between the layers of silica. Because of differences in fracture, when the fibers are being produced, a

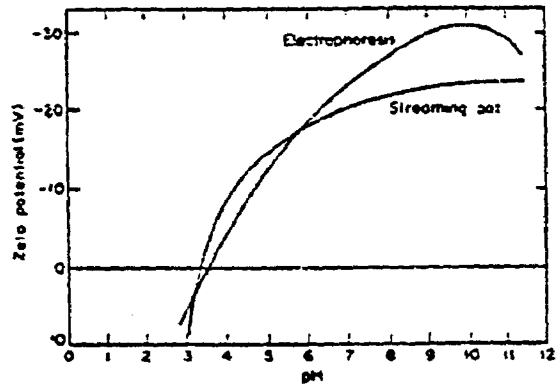

Figure 4. Variation of Zeta Potential with pH for Amosite Using the Streaming Potential and Electrophoresis Techniques

Source: Prasad and Pooley (1973)

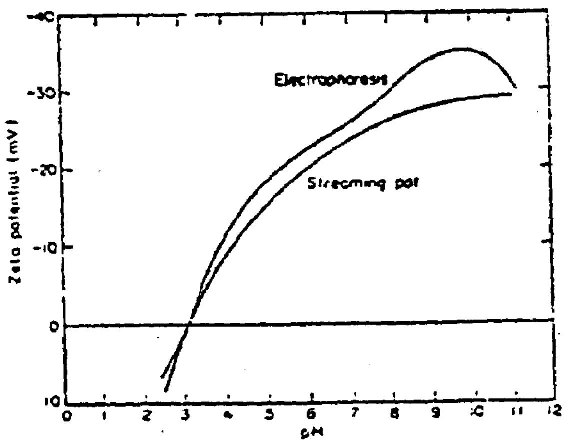

Figure 5. Variation of Zeta Potential with pH for Crocidolite Using Streaming Potential and Electrophoresis Techniques

Source: Prasad and Pooley (1973).

variation in the ratio of face to edge charges is likely. It is evident from the results that amphibole asbestos has a net negative charge, i.e., the sum of the negatively charged silica surfaces and the positively charged edges of the metal cation is negative. This net charge is very much lower than the actual value of charge per unit area on the fiber-face surface. The amphibole asbestos is, therefore, capable of adsorbing both cationic and anionic species, the former much more extensively than the latter.

Chowdhury and Kitchener (1975) found a wide variety of zeta potentials in natural and synthetic chrysotiles. Strongly positive values were found in samples containing an excess of magnesium in the form of brucite, $Mg(OH)_2$. Synthetic chrysotile and natural samples containing little or no brucite gave moderately positive zeta potentials over the pH range of 3 to 11. Weakly positive or weakly negative zeta potentials were found in chrysotiles which had undergone weathering (due to natural leaching of the brucite layer). Since the pH and the ambient concentration of Mg^{+2} ions near the surface are the main controlling factors of the chrysotile zeta potential, and since chrysotile's brucite layer is susceptible to leaching in aqueous solution, the zeta potential of chrysotile is a constantly changing value. These results explain the temporary colloidal stability of dilute suspensions of chrysotile in environmental media in the mutual coagulation of chrysotile and amphibole asbestos slurries.

This effect of the colloidal stability of the chrysotile was first described by Naumann and Presher (1968). They found that, because of the positive zeta potential of chrysotile in environmental media, low viscosity suspensions could be prepared by means of the inherent charge of the chrysotile surfaces. This charge, however, is so small in pure chrysotile that dispersion was obtained only with short fibers and low fiber concentrations (1 percent). By increasing the concentration of certain metallic salts, it was found that low viscosity suspensions could be prepared under almost any environmental condition. These observations suggest that the presence of trace metals will produce a suspension of chrysotile asbestos in water which will persist until sufficient magnesium has leached from the chrysotile structure to degrade the suspension. Furthermore, it is probable that under certain conditions asbestos will persist in the water column until its concentration becomes high enough to destroy the suspension or until leaching of the brucite layer decays the zeta potential to a point where it will become negative.

Ralston and Kitechener (1975) studied the surface chemistry of amosite asbestos. The amphibole structure of the fiber was found to be resistant, undergoing only superficial change in aqueous media under normal environmental conditions. Internal cations are neither leached nor exchanged. The surface properties of the fiber resemble those of pure silica (quartz): cationic surfactants are adsorbed strongly, while anionic surfactants are not adsorbed. Thus, the surface chemistry of amosite asbestos is controlled by its trace contaminants, while the fiber itself behaves like quartz.

In studies concerning the removal of asbestos fibers from drinking water, it was found that coagulation/flocculation methods were effective in removing asbestos fibers from water. Lawrence et al. (1975) found that coagulation with a 1 ppm cationic polyelectrolyte resulted in the removal of approximately 99 percent of the fibers and that all the remaining fibers were chrysotile. The residual of chrysotile was explained by chrysotile's positive surface charge in contrast to the negative surface charge of amphiboles, and most other volume was reduced to about 20 percent of the total volume. Further reduction in the sediment volume was then extremely slow (19 percent after 24 hours), suggesting that natural flocculation is only a powerful force at high asbestos fiber concentrations. They also found that the addition of coated diatomite (diatomite coated with aluminum hydroxide) was quite effective in increasing the flocculation of asbestos fibers. Schmitt et al. (1977) found that, after sedimentation, the addition of a positively charged cationic polyelectrolyte induced further aggregation of the particles and allowed for easy filtration.

In general, the environmental behavior of asbestos from contaminated vermiculite will be controlled by such effects as leaching, coagulation, surface chemical reactions, and transport phenomena. It is difficult at this point to determine which of these processes are most important except to say that asbestos, once introduced into the environment, will remain until it is buried in the sediment layer of the aquatic environment or bound somewhere in the terrestrial environment.

5.2 Identification of Principal Pathways of Exposure

Three routes of exposure are commonly addressed in exposure assessments: inhalation, ingestion, and dermal absorption. The following sections show that the principal route of exposure to asbestos-contaminated vermiculite is inhalation (Section 5.2.1). Subsequent sections address the possibility of ingestion of asbestos from vermiculite releases into the environment (5.2.2) and the likelihood of dermal contact leading to exposure (5.2.3).

5.2.1 Inhalation of Asbestos-contaminated Vermiculite

Airborne emissions of vermiculite constitute a minority of releases to the environment (See Section 4.0). However, the asbestos fibers in these emissions are persistent and readily transported through the ambient atmosphere. Asbestos fibers of respirable sizes (<10μm) are small and settle very slowly (Sawyer and Spooner 1978). Atmospheric transport processes therefore tend to lead to exposure via inhalation of ambient air near point sources of vermiculite discharges, as well as from nonpoint sources (e.g., agricultural and horticultural applications).

These point sources of atmospheric vermiculite discharges are numerous; they include the four mines as well as the 47 cities with exfoliation facilities. Exposure from these sources may be occupational (for those working at the sites) or ambient (for those living near the sites). Transportation and disposal of vermiculite may also result in atmospheric emissions.

The use of vermiculite-containing products may lead to inhalation exposure of industrial and commercial users and consumers. Little monitoring data is available to substantiate this (see Section 6.0). Estimates of atmospheric concentrations resulting from general environmental emissions as well as consumer and occupational use are provided in a later section of this report (Section 6.4); exposure is estimated in Section 8.1.

5.2.2 Ingestion of Asbestos-contaminated Vermiculite

Much of the vermiculite waste from mining, milling, and exfoliation is discharged to water; some of the processes, such as wet beneficiation, generate large quantities of liquid waste. These wastewaters are generally sent to settling ponds and the supernatant is recycled; thus, no discharge of asbestos-laden vermiculite to the environment is expected. If asbestos from vermiculite entered the aquatic envionment via washout, runoff, or direct discharge, the fibers would probably not enter the food chain to any appreciable extent (Callahan et al. 1979); therefore, exposure via ingestion of aquatic organisms would be insignificant. Ingestion of ambient water during such recreational activities as swimming is rarely a significant exposure (Scow et al. 1979). Use of contaminated ambient water as a potable-water source would lead to significant exposure only if the water were not treated with standard coagulation-flocculation, which removes most asbestos (Lawrence et al. 1975).

Not all inhaled asbestos fibers are respirable; a fraction of particles entering the bronchi are cleared from the respiratory system and are subsequently ingested (Timbrell 1965). The exact dimensions of respirable particles are not known, but particles greater than 10 μm are generally too large to be retained in the lungs (Stern 1976). Since the fiber size distribution of asbestos in vermiculite is not known, the ingestion exposure from airborne particulates cannot be determined. Particles larger than the respirable fibers settle more quickly and would not be as widely transported from a point source; the geographic range of exposure would be limited to the immediate area. The greatest exposure via ingestion of nonrespired fibers would therefore be expected to occur in areas with high fiber concentrations.

Vermiculite products are not used in food processing, and uptake of fibers by plants to which vermiculite fertilizers have been applied would not be expected. Movement of chemicals across root cell membranes is an active transport process involving elemental units (Ray 1972); fibers cannot diffuse or be transported in this manner. In summary, ingestion is probably not an important route of exposure to asbestos in vermiculite.

5.2.3 Dermal Absorption of Asbestos-Contaminated Vermiculite

The processing and use of vermiculite may involve extensive dermal contact, such as with the use of plant growth media. However, asbestos fibers would probably not penetrate intact skin surfaces. Dermal exposure would occur only if the skin were broken and fibers entered the body directly.

6. MONITORING DATA AND ESTIMATES OF ENVIRONMENTAL CONCENTRATIONS

The priority review of asbestos-contaminated vermiculite (USEPA 1980a) identified a number of data gaps that could be filled only by monitoring the data. As a result, the EPA-OTS Field Studies Branch initiated a study of asbestos fibers in bulk vermiculite samples and in mining and milling operations (MRI 1982). The monitoring project team initially planned to address exfoliation plants as well; priority shifts during the course of the project precluded this phase of the study, although two exfoliation plants located with beneficiation plants were sampled.

Midwest Research Institute (MRI) coordinated the efforts of Ontario Research Foundation and IIT Research Institute, who were responsible for sample analyses. The results of this monitoring study are summarized in this section. The reader is referred to the MRI (1982) report, "Collection, Analysis, and Characterization of Vermiculite Samples for Fiber Content and Asbestos Contamination," for further details on experimental protocol, analysis, and results.

OSHA has monitored fiber levels in the O.M. Scott and Sons Co. lawn and garden products plant in Marysville, OH. These data are summarized within this section.

The monitoring data have been supplemented by estimates of environmental concentration. Computer modeling was performed by the General Software Corp. under the direction of the modeling team of EPA's Chemical Fate Branch. Estimates of levels encountered during consumer use of vermiculite products were based upon monitoring, materials balance, and product use data.

6.1 Monitoring of Mining and Milling Facilities (MRI 1982)

Monitoring data on vermiculite have been gathered by Midwest Research Institute (MRI) under an EPA contract. Sample analyses were conducted for MRI by Ontario Research Foundation (ORF) and IIT Research Institute (IITRI).

The original scope of the study included two phases. The first phase was the collection and analysis of air and bulk samples associated with vermiculite ore and beneficiated vermiculite at U.S. ports of entry and from the four U.S. vermiculite mines. The second phase included a similar effort for a representative number of exfoliation plants.

Because of priority shifts within EPA, the second phase was not undertaken and the scope of the first phase was reduced. Sampling trips were made to the W.R. Grace mine and milling facilities, near Libby, Montana, during October 21 through 26, 1980; and to both the Grace and

Patterson mines and processing (including exfoliation) facilities near Enoree, S.C., during November 3 through 6, 1980. Both air samples and bulk samples were collected at each location. Air sampling was of two types, personal and stationary.

Air samples were analyzed only by phase contract optical microscopy, and the originally planned electron microscopic analysis was omitted. Bulk samples considered to be representative of each mine were selected as "priority" samples for immediate analysis. This set, comprising seven samples, included the head feed for the ore processing mill and, where size grades were produced, the smallest and mid-size grades. Samples were analyzed by various techniques including electron microscopy for fiber content, with emphasis on asbestiform minerals. The analysis was done by two independent laboratories. It was considered possible that fibers could be bound between the vermiculite plates and released by exfoliation. Therefore, analyses were conducted both on the samples as received and after laboratory exfoliation to see if additional fibers are released by exfoliation. Laboratory exfoliation differs from commercial exfoliation in that under the conditions of commercial exfoliation, much of the fines and heavies are removed from the vermiculite. The laboratory exfoliation is done under conditions that produce no sample fractionation. Thus, much of the asbestos would be removed from the vermiculite during commercial exfoliation, but none would be removed during laboratory exfoliation.

Density-separated fractions from the bulk samples were analyzed by optical microscopy (OM) and x-ray diffraction (XRD) analysis. Isopropanol-suspended fractions of bulk samples of nonexfoliated vermiculite and water-suspended fractions of exfoliated bulk samples of vermiculite were analyzed by transmission electron microscopy (TEM). The results of the OM and XRD analyses are summarized in Table 8.

A difference in the interpretation of the analytical protocol resulted in a variation in the counting procedure. The requirement to count 100 fibers was interpreted by ORF to mean 100 asbestiform fibers, while IITRI counted 100 particles, defined as fibers by having an aspect ratio of ≥3:1. To check teh significance of this counting variation, two samples with different fiber characteristics were selected for each laboratory to repeat the analysis using the alternate procedure. These samples included grade 5 samples from Libby, Montana, and from Enoree, South Carolina. Table 9 is a summary of the TEM analysis of the selected samples and includes the number of fibers and their concentration in parts per million as determined by the two laboratories.

The results suggest that there are more asbestiform fibers associated with the smaller size grades of vermiculite than with the larger grades. Both dust samples collected at Libby were found to have a very high

Table 8. Summary of Optical Microscopy/XRD Analysis Results

Sample[a]	Fibrous phases: Estimated mass, %	Fibrous phases: Mineral types	Nonfibrous amphiboles: Estimated mass, %	Nonfibrous amphiboles: Mineral types
Libby Grace				
Grade 1, 270-I	4-6	Trem-actin	1-3	Trem-actin
Grade 2, 276-I	4-7	Trem-actin	3-5	Trem-actin
Grade 3, 259-I	2-4	Trem-actin	< 1	Trem-actin
Grade 4, 282-I	0.3-1	Trem-actin	1-3	Trem-actin
Grade 5, 264-I	2-4	Trem-actin	2-5	Trem-actin
Grade 5 (1-day), 267-I	2-5	Trem-actin	4-8	Trem-actin
			< 1	Anthophyllite
Head feed, 291-I	21-26	Trem-actin	6-9	Trem-actin
Extract, 294-I	1-4	Trem-actin	1-3	Trem-actin
Baghouse mill, 297-I	8-12	Trem-actin	2-6	Trem-actin
Screen plant, 288-I	2-5	Trem-actin	1-4	Trem-actin
S.C. Grace				
Grade 3, 430-I	< 1[b]	Mixed	2-4	Trem-actin
		Anthophyllite	< 1	Anthophyllite
		Trem-actin		
Grade 4, 433-I	< 1[b]	Mixed	1-3	Anthophyllite
		Anthophyllite	1-4	Trem-actin
		Trem-actin		
Grade 5, 427-I	< 1[b]	Mixed	4-6	Anthophyllite
		Anthophyllite	2-4	Trem-actin
		Trem-actin		
Mill feed (+100 mesh), 436-I	< 1	Mixed	1-3	Anthophyllite
		Anthophyllite	6-9	Trem-actin
		Trem-actin		
Grade 3, expanded, 439-I	< 1[b]	Mixed	< 1	Anthophyllite
		Anthophyllite	< 1	Trem-actin
		Trem-actin		
Grade 4, expanded, 442-I	< 1[b]	Mixed	< 1	Anthophyllite
		Anthophyllite	0.5-1	Trem-actin
		Trem-actin		
S.C. Patterson				
Ungraded, 573-I	< 1	Mixed	4-8	Anthophyllite
		Trem-actin	8-12	Trem-actin
		Anthophyllite		

a With the exception of Sample No. 267-I, all results are for composite samples.

b Fiber bundles were mixed phase materials--both anthophyllite and tremolite-actinolite were present.

Source: MRI 1982.

Table 9. Summary of Electron Microscopy Analysis

Sample[a]	Priority sample[b]	Analysis, exfoliated[c] no	Analysis, exfoliated[c] yes	Asbestiform fibers, all lengths: Amphibole Fibers/g x 10^6	Amphibole Mass (ppm)	Chrysotile Fibers/g x 10^6	Chrysotile Mass (ppm)
Libby Grace							
Grade 1							
270-I			X	31.6	78	0.9	3.5×10^{-3}
Grade 2							
276-I			X	23.4	48.5	0	0
Grade 3	P						
259-I		X		38.9	210	0.9	0.01
259-0		X		25	59	< 2.1	-
259-I			X	42.0	250	0.4	6.1×10^{-3}
259-0			X	59	240	< 1	-
Grade 4							
282-0		X		1	1		
282-I			X	65	460	0	0
282-0			X	1.8	17	< 0.4	-
Grade 5	P						
264-I		X		118	840	-	-
264-0		X		100	600	< 1.4	-
264-I(0)		X		127	1,200	-	-
264-0(I)		X		98	570	-	-
264-I			X	142	2,600	-	-
264-0			X	160	1,800	< 1.6	-
264-I(0)			X	119	350	-	-
264-0(I)			X	110	2,600	< 1.6	-
Head feed	P						
291-I		X		62.5	670	1.4	0.13
291-0		X		130	690	1.2	< 1
291-I			X	73.8	590	-	-
Extractor							
294-I			X	55.0	420	0.7	3.4×10^{-3}
Mill dust							
297-0		X		100	4,600	-	-
297-I			X	777	35,000	-	-
Screening dust							
288-0		X		300	3,000	< 1.6	-
288-I			X	1,800	41,000	-	-

(continued)

Source: MRI 1982.

Table 9. (continued)

Sample[a]	Priority[b] sample	Analysis,[c] exfoliated no	yes	Asbestiform fibers, all lengths: Amphibole Fibers/g x 10^6	Amphibole Mass (ppm)	Chrysotile Fibers/g x 10^6	Chrysotile Mass (ppm)
S.C. Grace							
Grade 3	P						
430-I		X		1.0	0.55	0.1	5×10^{-4}
430-O		X		2.7	< 1	< 0.3	-
430-I			X	3.1	3.7	-	-
430-O			X	2.4	1	< 0.5	-
Grade 4							
433-I		X		1.6	6.5	-	-
433-O		X		2.7	35	< 0.3	-
433-I			X	3.1	1.4	-	-
433-O			X	2.7	2	< 0.3	-
Grade 5	P						
427-I		X		0.6	1.5	-	-
427-O		X		17	37	2.6	-
427-I(O)		X		3.0	4.8	0.07	1×10^{-4}
427-O(I)		X		31	130	2.6	< 1
427-I			X	3.5	4.1	-	-
427-O			X	2.9	120	< 0.3	-
427-I(O)			X	3.2	7.3	-	-
427-O(I)			X	2.4	9	0.9	< 1
Head feed	P						
436-I		X		0.3	0.49	-	-
436-O		X		12	22	0.3	< 1
436-I			X	1.3	0.81	-	-
Grade 3 exfoliated							
439-I				11.7	-	-	-
S.C. Patterson beneficiated							
Ungraded	P						
573-I		X		0.03	3.7×10^{-4}	0.03	1.4×10^{-4}
573-O		X		1.7	27	< 0.3	-
573-I			X	0.5	3	0.2	5.3×10^{-3}
573-O			X	1.1	4	< 0.3	-

a The "I" and "O" following the sample number indicate the analyzing laboratory, IITRI and ORF, respectively. The "(I)" and "(O)" indicate the counting procedure, e.g., 264-I(O) are the results from IITRI using the ORF procedure.

b Seven samples were designated as priority samples for complete analysis at the time the program was reduced in scope.

c Analysis was conducted on the samples as received and following laboratory exfoliation, which unlike commercial exfoliation, does not cause sample fractionation.

amphibole content and indicate that considerable asbestos is removed from the vermiculite during beneficiation. The South Carolina vermiculite appears to contain substantially fewer asbestiform fibers than does that from Libby, Montana. The laboratory-exfoliated vermiculite samples do not appear to contain significantly more asbestiform fibers than did the same samples analyzed before laboratory exfoliation.

Table 10 is a summary of the phase contrast results of the air samples. Only one of the analyzed air samples exceeded 2.0 fibers/cc. However, the rainy weather conditions at the time of sampling for all three locations might have resulted in lower than normal fiber counts.

MRI concluded that the IITRI and ORF results were in general agreement within the expected range of variability of the methodology. However, it can be seen from Table 9 that their results often differ by as much as an order of magnitude. These data are included in the summary of monitoring data seen in Table 11.

6.2 Monitoring of Exfoliation and Product Formulation

OSHA has monitored fiber levels at the O.M. Scott plant in Marysville, OH. The data are summarized in Table 11. Note that information is lacking on analytical methods.

The following kinds of samples have been collected:

- Area samples. Samples have been taken in the expander (exfoliation) areas and in other parts of the building. Results are expressed as total fiber counts; fibers have not been confirmed as asbestos.
- Personnel samples taken during the performance of various activities (Table 11). These fibers are presumed to be asbestos.
- Bulk vermiculite samples from different suppliers and from waste generation (Table 12).

6.3 Monitoring of Ambient Air Near Mines and Mills

The MRI monitoring study (MRI 1982) included some area sampling in the vicinity of mines and mills (Table 10, stationary samples). A maximum of 0.5 f/cc was recorded in Libby about 4.5 km downwind of the mine. A concentration of 0.03 f/cc was recorded at the W.R. Grace mine in Enoree; 0.05 f/cc was reported 100 m downwind of the mill. Levels reached 0.02 f/cc within 50 m of the Patterson site in Enoree*.

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*Distance from source was not reported in MRI (1982); data is from personal communication between Gaylord Atkinson, MRI and John Doria, Versar, Inc.

Table 10. Results of Phase Contrast Analysis of Air Samples Collected at Three Sites

Sample	Sample vol. (ℓ)	Fibers / cc ORF	Fibers / cc IITRI
LIBBY, GRACE			
106 Field blank[a]	-	<0.02	0.04
133 Field blank[a]	-	0.03	0.05
Personnel samples			
131 Front loader, mine	303	0.02	0.04
148 Pit haul driver, mine	297	<0.01	0.01
138 Mine analyst, mine	294	1.5	1.9
141 Bottom operator, mill	276	1.2	0.4
130 No. 2 operator, mill	285	3.1	9.7
139 Dozer operator, mine	270	0.02	0.2
101 Shuttle truck, between screening and sizing plant	385	0.1	0.2
Stationary samples			
104 Screening plant, DW	390	0.08	0.5
111 Screening plant, DW	368	0.1	0.02
108 Trailer court	169	0.03	ND[b]
136 No. 5 substation	111	0.03	0.02
SOUTH CAROLINA, GRACE			
312 Field blank[a]	-	<0.02	0.04
346 Field blank[a]	-	<0.02	0.02
Mine personnel samples			
310 Truck driver	257	<0.01	0.3
301 Dragline operator	240	<0.01	ND[b]
Mine stationary samples			
307 Mine (N) crosswind	291	<0.01	0.02
323 Mine (E) downwind	154	0.01	0.02
338 Mine (W) upwind	264	0.03	0.01

Table 10. (continued)

Sample	Sample vol. (ℓ)	Fibers / cc	
		ORF	IITRI
Mill and exfoliation personnel samples			
340 Mill monitor	340	0.03	0.03
321 Mill lab technician	478	0.07	0.2
347 No. 4 bagger, exfoliation	314	0.06	0.1
330 No. 3 bagger, exfoliation	285	0.1	0.05
Mill stationary samples			
328 Mill (ENE) downwind	287	0.05	0.04
335 Mill (N) crosswind	80	0.04	ND[b]
300 Screening plant floor	354	0.06	0.14
SOUTH CAROLINA, PATTERSON			
505 Field blank[a]	-	<0.02	<0.01
533 Field blank[a]	-	<0.02	0.02
Beneficiating and expanding Personnel samples			
508 Payload operator	255	<0.01	0.04
520 Plant foreman	252	0.01	0.3
542 Bagger/forklift	249	<0.01	0.1
Stationary samples			
513 (NE) downwind	188	<0.01	ND[b]
506 Control off-site	274	<0.01	ND[b]
515 (SE) crosswind	299	0.01	0.01
528 (SW) upwind	147	0.02	ND[b]

[a]Values for blanks were calculated assuming a 100-liter sample.
[b]ND: No fibers detected (100 grids).
ORF = Ontario Research Foundation.
IITRI = IIT Research Institute.
Source: MRI 1981.

Table 11. Summary of Monitoring Data for Asbestos-containing Vermiculite

Population	Sampling and analytical methods	Number of observations	ORF[a]	IITRI[b]	Asbestos fiber concentration, f/cc MIN	MEAN	MAX	Comments
I. OCCUPATIONAL								
A. Miners and millers of vermiculite								
• Grace mine and mill at Libby (MRI 1982)	PS, OM	1	0.02	0.04				Front loader, mine
		1	<0.01	0.01				Pit haul driver, mine
		1	1.5	1.9				Mine analyst, mine
		1	1.2	0.4				Bottom operator, mill
		1	3.1	9.7				No. 2 operator, mill Dozer
		1	0.02	0.2				operator, mine
		1	0.1	0.2				Shuttle truck, between plants
• Grace mine at Enoree (MRI 1982)	PS, OM	1	<0.01	0.3				Truck driver
		1	<0.01	ND				Dragline operator
• Grace mill at Enoree (MRI 1982)	PS, OM	1	0.03	0.03				Mill monitor
		1	0.07	0.2				Mill lab technician
• Patterson mill (see I.C.)								
B. Importers and exporters of vermiculite								
C. Exfoliators of vermiculite								
• Grace facility at Enoree (MRI 1982)	PS, OM	1	0.06	0.1				No. 4 bagger
		1	0.1	0.05				No. 3 bagger
• Patterson facility (beneficiation, exfoliation) at Enoree (MRI 1982)	PS, OM	1	<0.01	0.04				Payload operator
		1	0.01	0.3				Plant foreman
		1	<0.01	0.1				Bagger/forklift

Table 11. (continued)

• O.M. Scott, OSHA personnel (OSHA 1979)	PS	10	ND	0.21	Screens and mills
		11	ND	0.35	Screens and mills, blender
		22	ND	0.21	Cleaning dryer
		12	ND	0.19	Paddle mixer, dryer
		9	ND	0.096	Control operator
		6	ND	0.044	Feeder operator
		12	ND	0.30	Process operator, expander area
		24	0	1.1	Track unloading area
		24	0	0.036	Packaging
		4	ND	ND	Dumping, reblend, and sweeping
• O.M. Scott, OSHA area (OSHA 1979)	AS	2		ND	Ironized control room
		1		ND	Warehouse: receiving area
		1		ND	Warehouse: mid-aisle
		2		ND	Polyform track area
D. Users of unexfoliated vermiculite					
1. Steel workers					
2. Manufacturers of gypsum wallboard					
(a) Wholesale/retail traders of wallboard					
(b) Installers of wallboard					
E. Users of exfoliated vermiculite					
1. Producers of lightweight aggregates					
(a) Users of plasters, concretes, and aggregates containing vermiculite					

Table 11. (continued)

(b) Wholesale/retail traders of lightweight aggregates

2. Producers of vermiculite insulation

(a) Users of vermiculite insulation for loose fill, block fill, and packing.

(b) Wholesale, retail traders of vermiculite insulation

3. Producers of agricultural and horticultural products containing vermiculite

• O.M. Scott (see 1.C.)

(a) Users of agricultural and horticultural products containing vermiculite

(1) Users of pesticides and fertilizers

(1) Users of horticultural media

(2) Users of cattle feed

(3) Users of hatchery and poultry litter

(b) Wholesale/retail traders of agricultural and horticultural products containing vermiculite

Table 11. (continued)

4. Producers of minor vermiculite-containing products

    (a) Producers of vermiculite filters for pollution control and similar uses

        (1) Users of vermiculite filters in waste-water treatment

        (2) Users of vermiculite for nuclear waste disposal

        (3) Users of vermiculite filters for air purification

    (b) Producers of oil well drilling muds

        (1) Well drillers

    (c) Producers of artificial dust and fireplace ashes from vermiculite

        (1) Motion picture industry workers

    (d) Producers of refractories and firebricks

        (1) Users of refractories and firebricks

        (2) Miscellaneous users of vermiculite products

Table 11. (continued)

(3) Miscellaneous wholesaler/ retailers of vermiculite products						
5. Transporters of vermiculite						
(a) Truck drivers	PS,	1	<0.01	0.3		See I.A.
(b) Ship and dock workers	OM					
(c) Rail workers						
(d) Warehousemen	AS				0	See I.C.
II. TRANSPORTATION AND STORAGE SPILLS						
III. CONSUMERS						
A. Homeowners insulating attics						
B. Users of lawn and garden fertilizers						
C. Users of houseplant potting soil						
D. Users of kitty litter						
E. Users of vermiculite in barbecue grills						
IV. DISPOSAL						
V. FOOD						
VI. DRINKING WATER						

Table 11. (continued)

VII. AMBIENT ENVIRONMENT					
A. Air					
1. Concentrations around mines and mills (MRI 1982)	OM	13	<0.01 0.1	ND- 0.5	Within 5 km of source
B. Water					
C. Soil					

[a]ORF = Ontario Research Foundation analysis of split sample.

[b]IITRI = IIT Research Institute analysis of split sample.

ND = Not detected.

OM = Optical (phase contrast) microscopy.

PS = Personnel sample.

AS = Area sample.

Table 12. Asbestos in Bulk Samples from O.M. Scott and Sons Co.

Source	Analytical method	No. of observations	Asbestos detected
Libby (unexfoliated)	unknown	2	none
Libby (exfoliated)	unknown	2	none
S. Africa (unexfoliated)	unknown	1	none
S. Africa (exfoliated)	unknown	1	none
Cyclone waste	unknown	2	none
Dryer waste	unknown	4	none
Central vacuum waste	unknown	1	none

Source: OSHA, 1979.

6.4 Estimates of Environmental Concentrations of Asbestos from Vermiculite

Because the primary exposure pathway for asbestos released by the mining processing, use, distribution, and disposal of vermiculite is via inhalation, atmospheric concentrations of asbestos are central to the development of an integrated exposure estimate. Two basic types of emissions can result in exposure: (1) releases during exfoliation, and (2) releases during the use of vermiculite-containing products. Estimates of atmospheric concentrations resulting from these emissions are discussed in Sections 6.4.1 and 6.4.2. Atmospheric modeling in Section 6.4.1 was performed by Scott Reingrover of General Software Corporation and Bill Wood, Joan Lefler, Loren Hall, and Annett Nold of the Chemical Fate Branch of EPA/EED. No effort is made to differentiate concentrations for different fiber sizes of asbestos, despite the fact that fiber size may affect risk, because the assumptions and available data underlying these estimates are too crude to support this type of analysis.

6.4.1 Releases from Exfoliation Plants*

The releases from the model exfoliation plant described in the regulatory options document (GCA 1980) were used to represent source strength at exfoliation plants. Emissions were assumed to occur uniformly over a year. The model plant rates were cited without a particle size breakdown. The asbestos fibers of respirable size are of concern, and these are much smaller than the vermiculite particles of large enough sizefor the commercial grades. It was assumed that the releases escaping the baghouse provide an estimate of the quantity of respirable particles. The basis for the assumption is that the baghouse would tend to trap larger particles.

Emissions from the baghouse were cited as 0.58 kg/hr (0.16 g/sec) of vermiculite and 0.026 kg/hr (0.01 g/sec) of asbestos. Other engineering data were not documented, but the effluent from the exfoliation furnace to the baghouse was estimated to be 5,200 ft^3/min (2.45 m^3/sec), escaping the baghouse at 300°C. The work year for the plant was 6,000 hours. Exposure estimates were made assuming emissions of 0.01 g/sec continuously for a year. This assumption of continuous emissions does not take into account the 6,000-hour work year; modeling results may therefore be overestimates by more than 50 percent, and should thus be considered worst-case averages.

The Atmospheric Transport and Diffusion Model (ATM) (Culkowske and Patterson 1976) was used to provide estimates of annual average fiber concentrations surrounding the model exfoliation plant. Input parameters for the ATM simulation are presented in Table 13. Meteorologic conditions

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*Portions of this section were provided by Annett Nold, EPA/EED/CFB (1981).

were based on wind rose data for a weather station in St. Louis, Missouri. Deposition processes, including washout, were included. Two simpler models were also used to bracket exposure levels. The results are summarized in Table 14. Worst-case concentrations, which would exist for short time spans (approximately an hour), were also estimated using a simple Gaussian plume model, PTMAX (Williamson 1973, Turner 1969). The worst-case results are on the order of 1 to 10 $\mu g/m^3$ (see Table 14). The annual averages provided by ATM are of greater utility for estimating cumulative exposure. The ATM generates annual averages for sectors surrounding the source using wind rose data. As a rule of thumb, the annual averages near the source tend to be two orders of magnitude less than the worst cases found by PTMAX, and this was roughly true in this study. The position and magnitude of the maximum concentration are sensitive to wind speed and direction and atmospheric stability. For the St. Louis wind rose, the maximum moves around the geographic area rather than remaining localized, so that averages are much lower than the maximum. Sensitivity with respect to source height and temperature was tested with additional trials of PTMAX and ATM; near-source concentrations from ATM vary over almost an order of magnitude but concentrations more than a kilometer away are much more stable.

The National Oceanographic and Atmospheric Administration's Atmospheric Turbulence and Diffusion Laboratory box model (ATDL) provides a simple representation of annual average pollutant concentrations near a point or area source. The model is based on centering the source in an area defined by the programmer; in this case, a box 20 km by 20 km wide and 150 m high was chosen. These dimensions approximate the distance within which fibers from the exfoliation plant may contribute significantly to background. Emissions of 0.01 g/sec asbestos into a wind velocity of 5.5 m/sec were used; this represents age meteorological data for St. Louis. Results (Table 14) are within the range predicted by ATM.

Figure 6 is a reproduction of the ATM printout for this facility; data are generated for each of the 10 distances from the source and the 16 wind directions. Population data are included for each of the wind rose sectors; these data are retrieved via a computerized interface with SECPOP, a file of Bureau of Census data. Figure 7 summarizes the averages and extremes of the concentrations estimated by ATM, and illustrates the rapid decline in levels as distance from the source increases.

It is assumed that the St. Louis meteorological data and the model plant emissions will produce estimates of the environmental concentrations seen around all exfoliation plants. For the purposes of this exposure assessment, the St. Louis ATM data will be applied to the other 46 cities with exfoliation plants, although it is recognized that emission rates and wind patterns will vary from location to location.

Table 14. Modeling Estimates of Ambient Asbestos Fiber Concentrations Surrounding a Vermiculite Exfoliation Plant[a]

Asbestos release rate, g/sec	Short-term worst-case asbestos concentration, ug/m^3 (PTMAX)	Area annual average concentration, (20 km box) ug/m^3 (ATDL box model)	Wind-rose sector annual average (10 km radius) ug/m^3 (ATM)
0.01	1.0 to 10.0	5.0×10^{-4}	1.0×10^{-4} to 4.0×10^{-2}

[a]Values range over several orders of magnitude due to varying wind dispersion patterns.

Source: Annett Nold, EPA/EED/CFB (1981).

[illegible] STUDY - ASBESTOS1 - NOV 1981
POLLUTANT : ASBESTOS   SOURCE : BRUDA CO. - ST. LOUIS,MO   EMISSION TYPE : BAGHOUSE
WEIGHTED TEMPLAN VALUES WITHIN INDIVIDUAL SECTOR SEGMENTS : ANNUAL AVERAGE CONCENTRATION (UG/M3)
POPULATION (PERSONS)
& POPULATION EXPOSURE (UG/YR)
& POPULATION EXPOSURE = ANNUAL AVERAGE CONCENTRATION * POPULATION * ANNUAL BREATHING RATE(22M3/DAY * 365 DAYS/YR)

DISTANCES (KM) :		0.0- 0.5	0.5- 1.0	1.0- 2.0	2.0- 3.0	3.0- 4.0	4.0- 5.0	5.0-10.0	10.0-15.0	15.0-25.0	25.0-50.0
SECTOR	WIND-ANGLE										
N	0.0	3.140E-02	1.390E-02	6.251E-03	3.623E-03	1.825E-03	1.232E-03	6.038E-04	2.317E-04	1.036E-04	3.683E-05
		0	2142	4169	4852	16887	9559	39509	53133	31602	29169
		0.000E+00	2.03?E+05	2.083E+05	1.170E+05	1.595E+05	9.454E+04	1.916E+05	9.884E+04	2.576E+04	8.640E+03
NNE	22.5	1.317E-02	5.37?E-03	2.135E-03	1.03?E-03	6.293E-04	4.259E-04	2.073E-04	7.767E-05	3.391E-05	1.178E-05
		0	0	3600	6938	11054	13199	13102	15193	10115	84219
		0.000E+00	0.000E+00	5.879E+04	5.785E+04	5.580E+04	6.171E+04	2.181E+04	9.479E+03	2.704E+03	7.931E+03
NE	45.0	1.889E-02	5.843E-03	2.550E-03	1.349E-03	8.415E-04	5.791E-04	2.826E-04	1.052E-04	4.507E-05	1.493E-05
		0	2136	5082	7447	12179	12949	19681	32240	24908	23819
		0.000E+00	1.011E+05	1.041E+05	8.064E+04	8.230E+04	5.999E+04	4.431E+04	2.724E+04	9.014E+03	2.853E+03
ENE	67.5	2.032E-02	7.977E-03	3.808E-03	2.027E-03	1.262E-03	8.041E-04	4.224E-04	1.665E-04	6.660E-05	2.181E-05
		0	0	2023	7056	13604	11187	10088	2913	15602	16980
		0.000E+00	0.000E+00	6.130E+04	1.149E+05	1.379E+05	7.702E+04	3.421E+04	3.660E+03	8.343E+03	2.974E+03
E	90.0	2.049E-02	1.0??E-02	6.156E-03	3.3??E-03	2.074E-03	1.477E-03	6.911E-04	2.510E-04	1.045E-04	3.340E-05
		0	320	0	2545	1251	8934	20212	34330	28182	17029
		0.000E+00	3.723E+04	0.000E+00	6.865E+04	2.083E+04	1.020E+05	1.122E+05	6.919E+04	2.365E+04	4.579E+03
ESE	112.5	2.653E-02	1.32?E-02	5.199E-03	2.443E-03	1.440E-03	9.939E-04	4.819E-04	1.804E-04	7.074E-05	2.702E-05
		0	0	1703	2516	2057	9135	15927	23055	55713	49867
		0.000E+00	0.000E+00	7.109E+04	4.9??E+04	2.444E+04	7.283E+04	6.167E+04	3.340E+04	3.522E+04	1.082E+04
SE	135.0	1.924E-02	9.2??E-03	3.424E-03	1.490E-03	8.676E-04	5.733E-04	2.763E-04	1.048E-04	6.694E-05	1.678E-05
		0	257	1804	7042	8822	10640	8116	12226	5815	10988
		0.000E+00	1.9??E+04	4.706E+04	8.457E+04	6.140E+04	4.897E+04	1.800E+04	1.029E+04	1.899E+03	1.668E+03
SSE	157.5	1.213E-02	5.974E-03	2.244E-03	9.900E-04	5.763E-04	3.810E-04	1.847E-04	7.066E-05	3.175E-05	1.126E-05
		0	0	1374	5153	11366	13282	17584	5923	3762	10266
		0.000E+00	0.000E+00	2.476E+04	4.095E+04	5.259E+04	4.070E+04	2.604E+04	3.364E+03	9.590E+02	9.268E+02
S	180.0	1.749E-02	8.600E-03	3.309E-03	1.551E-03	9.263E-04	6.199E-04	2.978E-04	1.093E-04	4.662E-05	1.577E-05
		0	364	3993	8152	7933	9659	46148	6851	2932	3214
		0.000E+00	2.514E+04	1.061E+05	1.016E+05	5.901E+04	4.808E+04	1.103E+05	6.013E+03	1.098E+03	4.071E+02
SSW	202.5	1.234E-02	5.565E-03	2.370E-03	1.252E-03	7.802E-04	5.322E-04	2.565E-04	9.171E-05	3.787E-05	1.175E-05
		55	1123	1165	1685	4239	4461	36275	33151	42764	36001
		5.310E+03	5.019E+04	2.217E+04	1.695E+04	2.656E+04	2.701E+04	7.472E+04	2.442E+04	1.300E+04	3.356E+03
SW	225.0	1.129E-02	4.694E-03	1.905E-03	9.951E-04	6.197E-04	4.234E-04	2.048E-04	7.318E-05	3.095E-05	9.529E-06
		0	0	2169	2402	2454	12304	75714	3751	21609	29443
		0.000E+00	0.000E+00	3.320E+04	1.920E+04	1.221E+04	4.183E+04	1.243E+05	2.204E+03	5.195E+03	2.253E+03
WSW	247.5	1.220E-02	5.571E-03	2.233E-03	1.164E-03	7.350E-04	4.995E-04	2.381E-04	8.293E-05	3.313E-05	1.019E-05
		0	1137	2510	187	3387	4353	45595	72744	37980	16118
		0.000E+00	5.087E+04	4.599E+04	1.779E+03	1.999E+04	1.745E+04	8.719E+04	4.844E+04	1.010E+04	1.319E+03
W	270.0	2.261E-02	1.106E-02	4.754E-03	2.665E-03	1.541E-03	1.054E-03	5.083E-04	1.842E-04	7.648E-05	2.410E-05
		0	413	0	0	1955	5517	32450	12846	30298	23834
		0.000E+00	3.66?E+04	0.000E+00	0.000E+00	2.420E+04	4.671E+04	1.325E+05	1.903E+04	1.861E+04	4.613E+03
WNW	292.5	1.950E-02	1.013E-02	4.839E-03	2.755E-03	1.756E-03	1.211E-03	5.882E-04	2.111E-04	8.630E-05	2.646E-05
		0	0	1211	0	3956	6334	38959	31493	48676	37027
		0.000E+00	0.000E+00	4.706E+04	0.000E+00	5.580E+04	6.159E+04	1.840E+05	5.343E+04	3.373E+04	7.866E+03
NW	315.0	2.299E-02	1.178E-02	4.872E-03	2.389E-03	1.450E-03	9.792E-04	4.774E-04	1.799E-04	7.851E-05	2.651E-05
		0	0	4286	6042	9535	14092	32769	56776	49902	42586
		0.000E+00	0.000E+00	1.677E+05	1.167E+05	1.110E+05	1.108E+05	1.256E+05	8.200E+04	3.146E+04	9.066E+03
NNW	337.5	2.284E-02	1.181E-02	4.783E-03	2.173E-03	1.288E-03	8.608E-04	4.193E-04	1.637E-04	7.233E-05	2.557E-05
		0	2212	3387	6744	9236	16953	58862	65515	107940	5141
		0.000E+00	2.097E+05	1.249E+05	1.177E+05	9.547E+04	1.172E+05	1.711E+05	8.881E+04	6.269E+04	[illegible]

Figure 6. ATM-SECPOP Annual Average Concentration Estimates for Wind Rose Sectors of St. Louis, MO

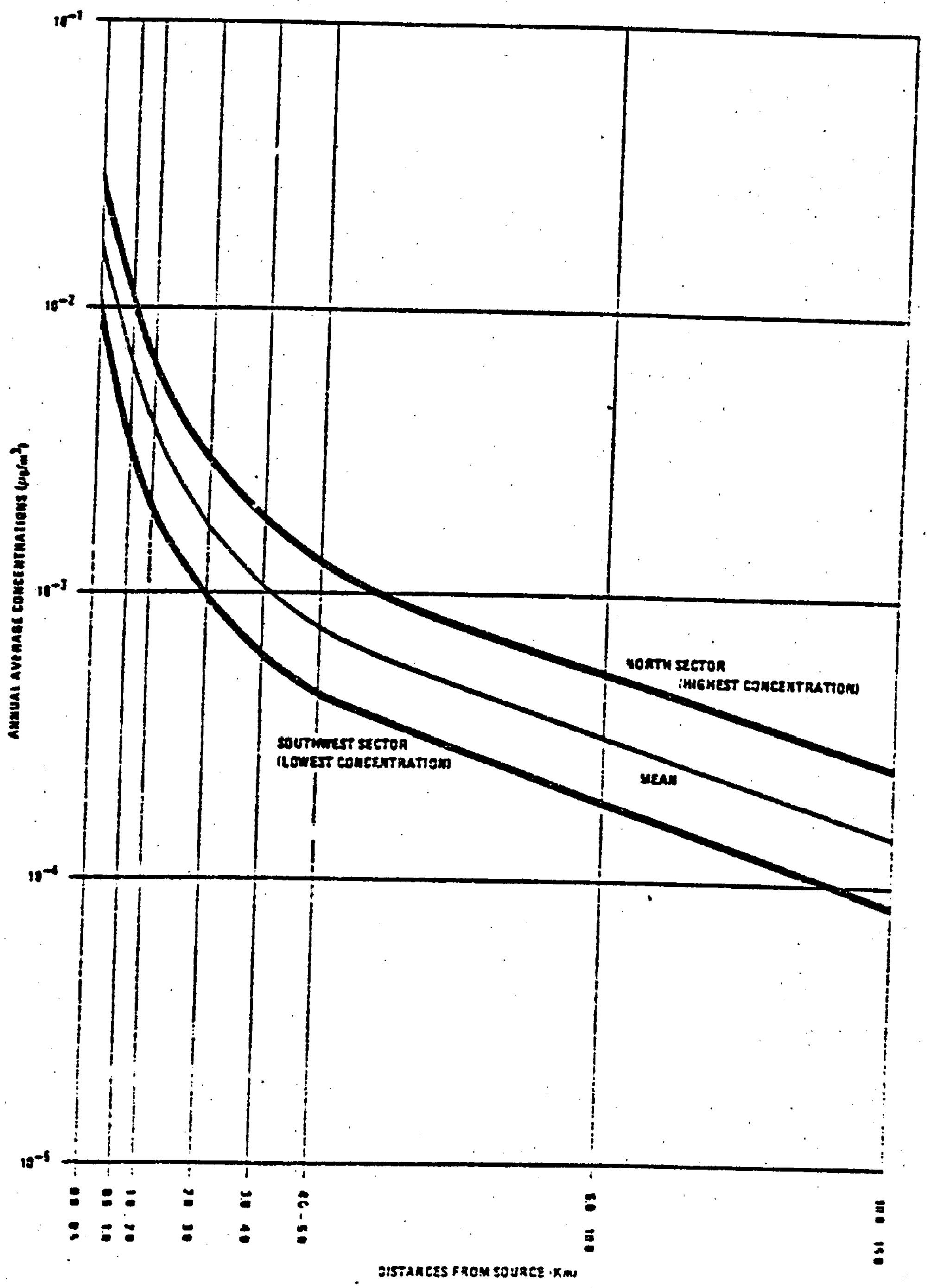

Figure 7. Atmospheric Transport Model (ATM) Annual Average Asbestos Concentrations

6.4.2 Releases from Use of Products Containing Vermiculite

Asbestos concentrations to which consumers may be exposed were estimated for three applications of vermiculite; these include loose-fill insulation in attics, a component of garden fertilizers, and a component of lawn fertilizers and herbicides. These uses were identified as having the most significant consumer exposure potential. Vermiculite's use as an aggregate results largely in occupational exposure during application of plasters and concretes. Once in place, the vermiculite is contained within a matrix and will not release asbestos fibers.

(1) Vermiculite Loose-fill Attic Insulation. The calculations of asbestos concentrations generated by homeowner installation of vermiculite insulation in attics were based on engineering assumptions, monitoring data, materials balance information, and experimentally-determined release rates. It was assumed that the rate of vermiculite application would be constant over an eight-hour period (the duration cited by JRB (1982)). No air exchange was factored in, and it was assumed that all fibers released would remain airborne.

The materials balance data furnished by JRB (1982) indicate that 510 kg of vermiculite are used in an average attic, which would have a volume of 158 m^3. It is assumed that 1 percent of the bulk vermiculite (of the grades used in insulation) is asbestos. This assumption is based on the data in MRI (1982), although few samples of exfoliated vermiculite were analyzed. Some exfoliated vermiculites will contain less than 1 percent asbestos. One percent is used as a reasonable worst case.

The release of dust into the air was estimated by simulating the pouring and spreading action involved in installation. Horticultural-grade vermiculite was obtained; it is assumed that it is roughly equivalent to that used for insulation. The vermiculite was weighed on an electronic balance accurate to 0.1 g, poured, then reweighed. The amount lost was the dust that did not settle immediately after pouring, and made up 0.0425 percent of the total mass.

If 510 kg of vermiculite are applied evenly over eight hours, the hourly rate is 510/8, or 63.75 kg. The hourly asbestos release to the atmosphere is calculated by multiplying the release rate, percent asbestos, and the application rate.

$$0.000425 \times 0.01 \times 63.75 \text{ kg} = 0.00027 \text{ kg}$$

In a 158 m^3 attic volume, the concentration after one hour would be 0.00027 kg/158 m^3 or 1,700 $\mu g/m^3$. If no fibers settled in the eight-hour period of application, the concentration of asbestos in the attic would reach 13,600 $\mu g/m^3$ (see Figure 8).

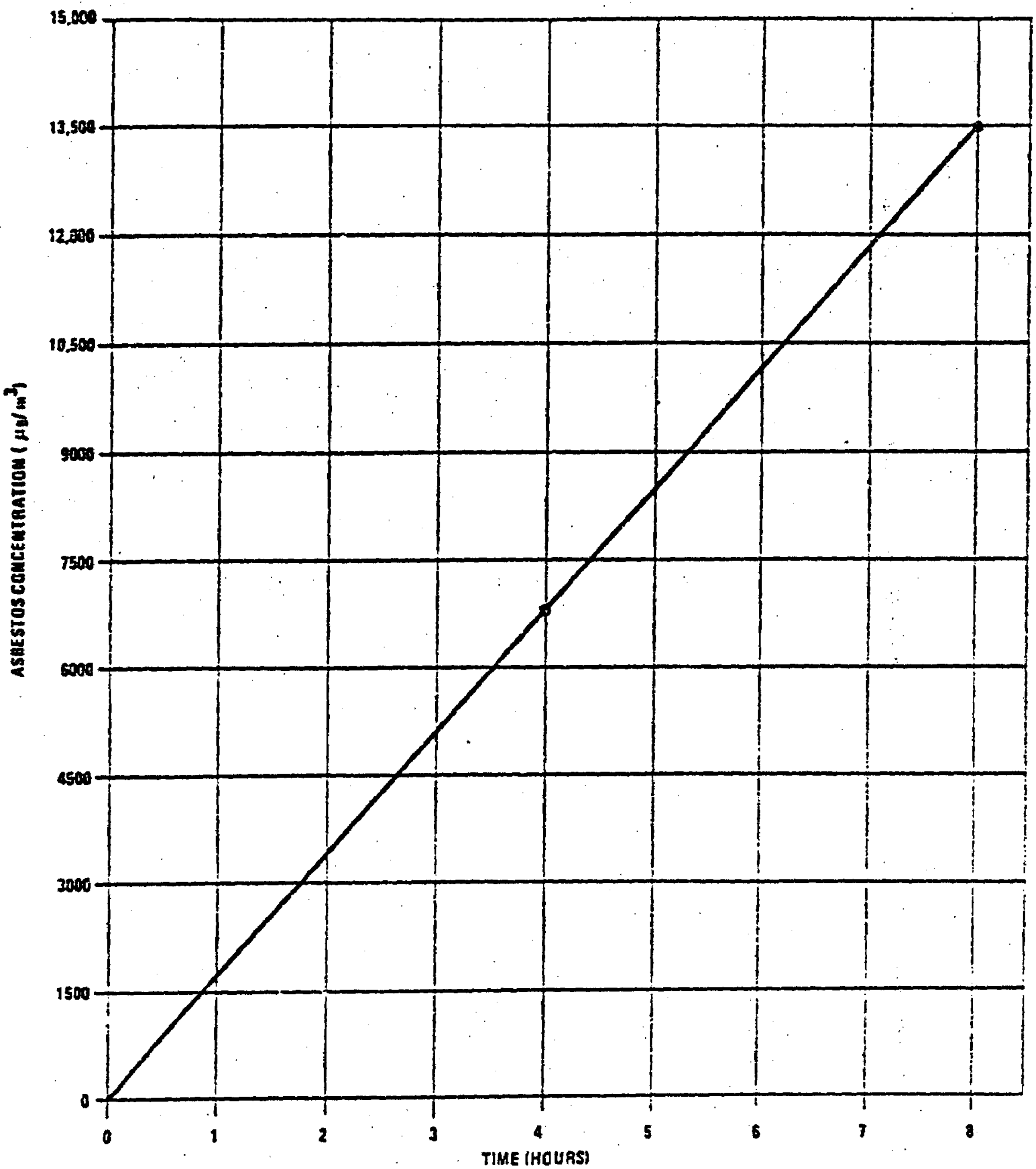

Figure 8. Estimated Asbestos Concentrations During Installation of Loose-Fill Vermiculite Attic Insulation

The assumptions involved in this calculation make it a worst-case estimate; it is probable that some of the dust will settle out, and ventilation in the attic will remove some of the dust. The lack of particle size data prevents use of settling velocity data (such as that shown in Figure 2).

(2) Vermiculite-carrier Garden Fertilizers. Atmospheric concentrations of asbestos resulting from the use of vermiculite-based fertilizer in gardens were estimated, based on product information, monitoring data, engineering assumptions, and experimental results.

A dust release rate of 0.0643 percent was obtained by weighing a bag of garden fertilizer before and after pouring; some air movement was simulated during the experiment. It was assumed that the dust composition was identical to the product formulation given on the package; therefore, about 20 percent of the dust was vermiculite, of which one percent is asbestos fibers.

The 10 lb. bag of fertilizer is designed to treat 600 ft^2, which is assumed to be the area of an average garden. Release of dust is continuous over the area, and all fibers are assumed to remain suspended in the air.

Treatment of a 600 ft^2 garden with a 10 lb. (4540 g) bag of fertilizer will result in the release of 0.0058 g of asbestos fibers:

$$.000643 \text{ (dust release factor)} \times 4540\text{g} \times .20 \text{ (percent vermiculite)} \times 0.01 \text{ (percent asbestos)} = 0.0058\text{g}$$

If this asbestos fiber concentration is contained within the immediate area of application, the volume of air affected may be estimated as

$$600 \text{ ft}^2 \times 6 \text{ ft or } 3600 \text{ ft}^3 \text{ } (102 \text{ m}^3);$$

this simple box model provides a worst-case approximation of short-term concentrations.

The concentration of asbestos fibers released from garden fertilizer use is therefore:

$$0.0058 \text{ g} \div 102 \text{ m}^3, \text{ or } 57 \text{ ug/m}^3.$$

This concentration is the accumulation of all the fibers released during application and is the maximum that might be expected. A concentration of 28 ug/m^3 would be expected after half the fertilizer is applied; a linear function such as that seen in Figure 8 is assumed in this model as well.

(3) Vermiculite-carrier Lawn Fertilizers and Herbicides. The release rate (0.0643 percent) obtained for garden fertilizers was also used in this approximation. Other factors remain the same, with the exception of product-specific information:

- 15 percent of the product is vermiculite, approximated from package information and patent formulation data (U.S. Patent No. 3,083,089)
- 7.6 kg treats 465 m^2, from package information.

It was estimated that the average lot size is one-quarter acre (1010m^2). The asbestos released from lawn fertilizer application can be estimated:

$$0.000643 \text{ (dust release rate)} \times \frac{7600\text{g product}}{465 \text{ m}^2} \times 1010 \text{ m}^2 \times 0.15 \text{ (percent vermiculite)} \times 0.01 \text{ (percent asbestos)} = 15{,}900 \ \mu\text{g}$$

A box model (1.8 m by 1010 m^2, or 1818 m^3) is used to calculate the asbestos concentration after all fertilizer is applied:

$$\frac{15{,}900 \text{ mg}}{1{,}818 \text{ m}^3} = 8.7 \ \mu\text{g/m}^3 \text{ asbestos}$$

The concentration after one half the fertilizer had been applied would be 4.4 $\mu g/m^3$.

This type of simple model assumes that mixing is homogeneous and instantaneous within the box; although this is not a valid assumption, it serves the purpose of estimating worst-case exposure.

7. EXPOSED POPULATIONS

The following section presents the best available data concerning the number of persons exposed to asbestos-contaminated vermiculite. In many cases, the data apply to the total numbers of producers and users of vermiculite; no attempt is made to estimate the proportion using the asbestos-contaminated mineral. Section 7.1 lists the occupationally-exposed populations, Section 7.2 deals with consumers of vermiculite products, and Section 7.3 estimates the population exposed to asbestos via ambient air near vermiculite emission point sources.

7.1 Occupational Populations

7.1.1 Miners and Millers

There are four active vermiculite mines in the U.S.: W.R. Grace in Libby, Montana; Grace in Enoree, South Carolina; the Patterson Vermiculite Co., also in Enoree; and Virginia Vermiculite in Louisa County, Virginia. The Grace mine in Libby produced 181,000 kkg of vermiculite in 1979 (JRB 1982). Ore is mined by bench quarrying using power shovels and ammonium nitrate blasting. After mining, it is hauled by trucks to a nearby primary processing plant and then to the mill (JRB 1982). The Libby mine employs 250 persons (EIS 1980). The Grace mine at Enoree produced 119,000 kkg in 1979 (JRB 1982). Ore is mined from several open pits, exploited with little or no blasting. It is then hauled by trucks on public roads to a central concentrating mill (JRB 1982). Based on operations at the Libby mine, it is assumed that the Grace mine at Enoree employs 200 persons. The Patterson Vermiculite Company mined 5,000 kkg in 1979 (JRB 1982). The ore is mined from open pits and hauled by trucks to the mill two miles away (JRB 1982). Patterson has between 20 and 49 employees (EIS 1980). The Virginia Vermiculite mine began operations in 1979, mining 9,000 kkg (JRB 1982). Further data are unavailable. Using figures for Patterson as a guide, it is assumed that the Virginia mine employs between 20 and 49 persons.

The total number of employees involved in vermiculite mining and milling is between 490 and 548. Over half of these workers are expected to be non-operating support personnel (Hunsicker and Sittenfield 1973); therefore, these figures are an upper limit for exposure.

7.1.2 Exfoliators

There are 52 vermiculite exfoliation plants in 32 states (JRB 1982). Employment figures for these plants (see Table 15) represent an upper limit for possible vermiculite exposure. Populations may be overestimated for the following reasons: (1) figures include clerical personnel who may not be directly exposed and (2) non-vermiculite

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Table 15. Location, Employment, and Products of U.S. Exfoliation Plants

Name	Location	Number of employees	Product
Brouk Co.	St. Louis, MO		
Cleveland Builders Supply Co.	Cleveland, OH		gypsum
Diversified Insulation Inc.	Minneapolis, MN		insulation
J.P. Austin Assoc., Inc.	Beaver Falls, PA		
W.R. Grace Co., Construction Products Div.	Irondale, AL		
W.R. Grace Co., Construction Products Div.	Phoenix, AZ		
W.R. Grace Co., Construction Products Div.	North Little Rock, AK	35	exfoliated vermiculite
W.R. Grace Co., Construction Products Div.	Newark, CA		
W.R. Grace Co., Construction Products Div.	Santa Ana, CA	200	concrete products
W.R. Grace Co., Construction Products Div.	Denver, Co		crude petroleum; oil and gas exploration; exfoliated vermiculite
W.R. Grace Co., Construction Products Div.	Pompano Beach, FL	25	chemicals
W.R. Grace Co., Construction Products Div.	Jacksonville, FL	36	exfoliated vermiculite
W.R. Grace Co., Construction Products Div.	Tampa, FL	75	fertilizers

Table 15. (Continued)

Name	Location	Number of employees	Product
W.R. Grace Co., Construction Products Div.	W. Chicago, IL	30	exfoliated vermiculite
W.R. Grace Co., Construction Products Div.	Newport, KY	20	insulation
W.R. Grace Co., Construction Products Div.	New Orleans, LA	100	construction materials
W.R. Grace Co., Construction Products Div.	Beltsville, MD	20	
W.R. Grace Co., Construction Products Div.	Easthampton, MA	20	building paper and board mills
W.R. Grace Co., Construction Products Div.	Dearborn, MI	39	insulation
W.R. Grace Co., Construction Products Div.	Minneapolis, MN	35	exfoliated vermiculite; also concrete products (50 employees)
W.R. Grace Co., Construction Products Div.	St. Louis, MO		polishes and sanitary products
W.R. Grace Co., Construction Products Div.	Omaha, NB	20	insulation; also home improvements (22 employees)
W.R. Grace Co., Construction Products Div.	Trenton, NJ	55	exfoliated vermiculite
W.R. Grace Co., Construction Products Div.	Weedsport, NY	50	insulation
W.R. Grace Co., Construction Products Div.	High Point, NC	35	exfoliated vermiculite

Table 15. (Continued)

Name	Location	Number of employees	Product
W.R. Grace Co., Construction Products Div.	Oklahoma City, OK		equipment rental and leasing; crude petroleum, oil and gas exploration, oil field and other machines
W.R. Grace Co., Construction Products Div.	Portland, OR		
W.R. Grace Co., Construction Products Div.	New Castle, PA	45	plastic products
W.R. Grace Co., Construction Products Div.	Kearney, SC		
W.R. Grace Co., Construction Products Div.	Travelers Rest, SC		
W.R. Grace Co., Construction Products Div.	Enoree, SC	133	exfoliated vermiculite
W.R. Grace Co., Construction Products Div.	Nashville, TN	20	insulation; also fertilizers (105 employees)
W.R. Grace Co., Construction Products Div.	San Antonio, TX		
W.R. Grace Co., Construction Products Div.	Dallas, TX		soap and detergents
W.R. Grace Co., Construction Products Div.	Milwaukee, WI	21	chocolate and cocoa, exfoliated vermiculite
International Vermiculite Co.	Girard, IL	20 - 49	mineral wool
Koos Inc.	Kenosha, WI	100 - 249	agricultural chemicals

Table 15. (Continued)

Name	Location	Number of employees	Product
Mica Pellets, Inc.	De Kalb, IL	20 - 49	
Robinson Insulating Co.	Great Falls, MT		insulation
Robinson Insulating Co.	Minot, ND		insulation
Schundler Co.	Metuchen, NJ	20 - 49	concrete block and brick
O.M. Scott	Marysville, OH	1,000 - 2,499	fertilizers
Strong-Lite Products	Pine Bluff, AK		
Verlite Co.	Tampa, FL		
Vermiculite of Hawaii, Inc.	Honolulu, HI		
Vermiculite Intermountain, Inc.	Salt Lake City, UT		
Vermiculite Products, Inc.	Houston, TX		
A.B. Dick	Denver, CO		
Diversified Insulation	Wellsville, KS	50 - 99	building paper and board mills
Lite Weight Products	Kansas City, KS		
Patterson Vermiculite Co.	Enoree, SC	a	
Virginia Vermiculite	Louisa Co., VA	a	

[a] Probably included in mining population figures (see Table 11).

Sources: EIS 1980.
JRB 1982.
OSHA 1979.

containing products may also be manufactured at the plant; these products are listed in the table when they are known. Persons involved in manufacture of such products may not be exposed to vermiculite.

A typical exfoliation plant has three men in operations and two men for other work per furnace for each shift (Hunsicker and Sittenfield 1979). However, not all employees exposed to vermiculite at these plants are involved in exfoliation. The cost of transporting exfoliated vermiculite prohibits locating exfoliation plants great distances from locations of further processing or end use. Therefore, about one third of all exfoliated vermiculite is formulated into a final product at the exfoliation plant. The other two-thirds is bagged or shipped in bulk for subsequent reformulation, rebagging, or use as is by the consumer (see Table 16). Consequently, workers at the same plant may be exposed to vermiculite by exfoliation, formulation, bagging, loading, or combinations of these operations.

Some exfoliation occurs at mine sites. W.R. Grace in Enoree is estimated to exfoliate 5,000 kkg per year at a plant near the mine (JRB 1982); 133 workers are involved in exfoliation there (Table 15). Patterson exfoliates all its vermiculite at its mill; they ship no unexfoliated vermiculite. The number of employees listed for the mine probably includes exfoliators. Virginia Vermiculite is estimated to exfoliate 2,000 kkg at the mine site (JRB 1982); the number of employees involved is unknown. No vermiculite is exfoliated at the Grace mine in Libby (JRB 1982).

Employment figures are not available for some exfoliation plants listed in Table 15. Based on an average of 120 employees per plant, calculated from known employment, the total number of workers in exfoliating plants (excluding the Patterson and Virginia mines) is between 1,694 and 1,979.

7.1.3 Other Occupationally Exposed Populations

Table 17 summarizes the populations exposed to vermiculite. Few data are available on the extent of vermiculite use within each industry. Therefore, the percentage of workers in each industry actually exposed to vermiculite is often impossible to determine. Table 17 does include some exposure data derived from the National Occupational Health Survey. In using Table 17, note that exposure resulting from manufacture or formulation of vermiculite-containing products at the exfoliating plant is included under the heading "Exfoliation" and is not differentiated from exposure resulting from exfoliation per se.

The uses of exfoliated vermiculite are numerous, but 98 percent of consumption falls into three major categories: lightweight aggregates,

Table 16. Estimates for Vermiculite Transportation from Exfoliation Plant

	Exfoliated vermiculite (percent of total)		
End use	Bag	Bulk	Use at plant
Aggregates	24		12
Insulation	31		
Agricultural chemical carrier	1	3	13
Growing media	7		7
Other uses	1		1
TOTAL	64	3	33

Source: JRB 1982.

Table 17. Summary of Estimated Population Exposure to Vermiculite[a]

Population	Number of establishments	Total number of persons	Number of persons exposed	Comments
I. OCCUPATIONAL				
A. Mines and millers of vermiculite	4	490 - 548		EIS 1980 & Versar estimate
B. Importors and exporters of vermiculite				
C. Exfoliators of vermiculite	50	1,694 - 1,979		EIS 1980 & Versar estimate
D. Users of unexfoliated vermiculite				
1. Steel workers				
• Furnacemen, smeltermen, and pourers	27		76	NOHS 1980
• Metal molders	19		863	NOHS 1980
• All iron and steel foundry workers		195,000		NOHS 1980
2. Manufacturers of gypsum wallboard				
• See I.C.				
(a) Wholesale/retail traders of wallboard				
(b) Installers of wallboard				
• See I.E. 1.(a)				
E. Users of exfoliated vermiculite				
1. Producers of lightweight aggregates				
• See I.C.				
(a) Users of plasters, concretes, and aggregates containing vermiculite				
• Construction laborers	622		10,753	NOHS 1980
• Cement and concrete finishers	40		440	NOHS 1980
• Brick and stone masons	184		3,000	NOHS 1980

Table 17. (continued)

Population	Number of establishments	Total number of persons	Number of persons exposed	Comments
• Plasterers	382		4,242	NOHS 1980
• Drywall installers	352		16,204	NOHS 1980
(b) Wholesale/retail traders of lightweight aggregates				
• Building material suppliers	40,600	294,000		Bureau of Census 1980
2. Producers of vermiculite insulation				
• See I.C.				
(a) Users of vermiculite insulation for loose fill, block fill, and packing				
• Construction laborers (See I.E.1.(a))				
• Insulation workers	72		298	NOHS 1980
• Shippers and receivers				
(b) Wholesale/retail traders of vermiculite insulation				
• Building material suppliers (See I.E.1(b))				
3. Producers of agricultural and horticultural products containing vermiculite				
• Pesticide and fertilizer formulators		44,000		Bureau of Census 1980
• Premixed soil formulators				
• Cattle feed formulators				
• Hatchery and poultry litter formulators				
(a) Users of agricultural/horticultural products				

Table 17. (continued)

Population	Number of establishments.	Total number of persons	Number of persons exposed	Comments
containing vermiculite				
(1) Users of pesticides and fertilizers				
• Nurserymen		> 3,400		Amer. Assoc. Nurserymen* 1981
• Greenhouse employees				
• Gardeners and groundskeepers	18		666	NOHS 1980
• Landscape contractors				
• Agricultural workers: family		299,000		Bureau of Census 1980
• Agricultural workers: wage laborers	78		470	NOHS 1980
(2) Users of horticultural media				
• See I.E.3.(a)(1)				
• Florists	29,400	88,000		Bureau of Census 1980
(3) Users of cattle feed				
(4) Users of hatchery and poultry litter				
(b) Wholesale/retail traders of agricultural/horticultural products containing vermiculite				
• Hardware stores	26,500	112,800		Bureau of Census 1980
• Lawn and garden stores	15,500	27,000		Bureau of Census 1980
• Drug stores	44,400	440,000		Bureau of Census 1980
• Food stores		2,000,000		Bureau of Census 1980
• Feed/farm suppliers				Bureau of Census 1980
• General merchandise retailers		2,200,000		Bureau of Census 1980

Table 17. (continued)

Population	Number of establishments	Total number of persons	Number of persons exposed	Comments
4. Producers of minor vermiculite - containing products				
(a) Producers of vermiculite filters for pollution control and similar uses				
(1) Users of vermiculite filters in wastewater treatment				
(2) Users of vermiculite for nuclear waste disposal				
● Nuclear physicians		> 1,200		American Coll. Nuclear Physicians 1981†
(3) Users of vermiculite filters for air purification				
● Uranium miners		9,000		Bureau of Census 1980
(b) Producers of oil well drilling muds				
(1) Well drillers		69,000		Bureau of Census 1980
(c) Producers of artificial dust and fireplace ashes from vermiculite				
(1) Motion picture industry workers				
(d) Producers of refractories and firebricks	25			Refractory Inst. 1981‡
(1) Users of refractories and firebricks				
● Iron and steel workers (See I.D.1.)				
● Non-ferrous foundry workers		78,000		Bureau of Census 1980
(e) Miscellaneous producers and users of vermiculite products				
(1) Manufacturers of:				
● Paint		37,000		Bureau of Census 1980

Table 17. (continued)

Population	Number of establishments	Total number of persons	Number of persons exposed	Comments
• Enamel				
• Ink				
• Plastics		145,000		Bureau of Census 1980
• Rubber		587,000		Bureau of Census 1980
• Paper				
• Fabrics				
• Plywood				
(2) Miscellaneous users of vermiculite products				
• Welders				
• Workers exposed to industrial premixes				
• Workers exposed to vermiculite sound insulation				
(3) Miscellaneous wholesalers/retailers of vermiculite products				
• See I.E.3.(b)				
• Pet stores				
5. Transporters of vermiculite				
(1) Truck drivers		1,900,000	129	Bureau of Census 1980 NOHS 1980
(2) Ship and dock workers				
(3) Rail workers				
• Freight handlers	33		108	NOHS 1980
(4) Warehousemen				

II. TRANSPORTATION AND STORAGE SPILLS

Table 17. (continued)

Population	Number of establishments	Total number of persons	Number of persons exposed	Comments
III. CONSUMERS				
A. Homeowners insulating attics	94,000	188,000	188,000	Versar estimate
B. Users of lawn and garden fertilizers		< 74,400,000		SMRB 1980
C. Users of houseplant potting soil				
• Members of Hobby Greenhouse Owners Assoc. of America		≥ 3,000		Encyclopedia of Associations (1981)
• House plant owners		> 46,600,000		SMRB 1980
D. Users of kitty litter		15,000,000 - <3,800,000		SMRB 1980
E. Users of vermiculite in barbecue grills				
IV. DISPOSAL				
V. FOOD				
VI. DRINKING WATER				
VII. AMBIENT				
A. Air				
1. Persons near mines and mills	4	4,680	4,680	Estimates based on Bureau of Census Advance Reports for 1980 population (Bureau of Census 1981)
2. Persons near exfoliation sites	51	13,147,496	13,147,496	Bureau of Census Advance Reports for 1980 population (Bureau of Census 1981)
3. Persons near users of vermiculite				

Table 17. (continued)

Population	Number of establishments	Total number of persons	Number of persons exposed	Comments
B. Water				
C. Land				

a All available and pertinent data are entered in the table; no entry indicates that no data are available.

* Personal communication between Debra Dillard of AAN and Pat Wood of Versar, November 2, 1981.

† Personal communication between Susan Thomas of ACNP and Pat Wood of Versar, November 19, 1981.

‡ Personal communication between Betty Lerch of RI and Pat Wood of Versar, November 17, 1981.

insulation, and agricultural uses (JRB 1982). About two-thirds of all vermiculite is used in the construction industry for lightweight aggregates and insulation. The following uses of vermiculite are summarized from the materials balance (JRB 1982).

(1) Lightweight aggregates (JRB 1982). Lightweight aggregates include concrete aggregates, plaster aggregates, and aggregate premixes. More than 95 percent of vermiculite concrete is batched and poured on site from vermiculite bagged and shipped from the exfoliating plant. The remaining 5 percent is batched in bulk at concrete premix plants. About 2.5 percent of the vermiculite concrete industry consists of precast products, mostly brick and block.

No data are available on the number of vermiculite concrete premixing or precasting plants. Installation of vermiculite concrete is performed by a very small number of specialty contractors.

Vermiculite can also be mixed with gypsum or Portland cement to form a plaster. This is applied by spraying or by hand troweling to metal surfaces or to walls and ceilings. The use of vermiculite plasters in walls and ceilings is decreasing.

Vermiculite plasters may be mixed at the construction site or formulated into premixes at the exfoliation plant. Plasters and premixes are used mainly for soundproofing, fireproofing, decorative finishes, and anti-condensation coatings. In addition, vermiculite premixes have industrial applications in chemical plants, oil refineries, and mines.

(2) Insulation (JRB 1982). Vermiculite for insulation is bagged and shipped directly from the exfoliation plant. Exfoliated vermiculite may be used as loose-fill or as block-fill insulation. In the first case, vermiculite is poured between the rafters in attics and leveled; this is often a consumer use. In the second case, vermiculite is poured into the cavities of concrete blocks as a wall is being constructed.

Minor uses of exfoliated vermiculite insulation are in the packing of chemicals to prevent leakage in transit, and in the disposal of radioactive waste, especially nuclear pharmaceuticals.

Unexfoliated vermiculite is used in iron and steel foundries to insulate hot ingots.

(3) Agriculture and horticulture (JRB 1982). Vermiculite is used as a carrier for agricultural chemicals and in plant growth media.

Vermiculite is probably no longer used in the U.S. as a carrier for commercial pesticides and agricultural fertilizers. However, it is still a common ingredient in lawn and garden fertilizers used by gardeners and groundskeepers, landscapers, nurserymen, and homeowners. About three-fourths of these mixtures are formulated at the exfoliating plant.

Vermiculite is also commonly used in growing media. Half of the vermiculite so used is formulated by the distributor into soil and soilless premixes; of this, 75 percent is shipped to greenhouses and the rest retailed to the consumer. The other half is bagged as is and shipped from the exfoliator to the distributor as "horticultural grade" vermiculite. It is probably not rebagged. It is used mainly as a mulch and soil conditioner, for hydroponics, and for packing bulbs and seeds for transportation. Of this horticultural grade sold, 50 percent is sold to landscapers, 30 percent to greenhouses, 15 percent to nursery and garden centers, and 5 percent to retail consumers (JRB 1982).

Vermiculite has minor agricultural uses in livestock feed, hatchery and poultry litter, and seed encapsulation. Few persons are expected to be exposed via these uses.

(4) Retail (JRB 1982). Vermiculite has a number of consumer uses, and may be offered for sale in virtually any kind of store that sells merchandise for the home. It is also used in window displays.

(5) Castable refractories and firebricks (JRB 1982). Vermiculite has refractory uses in aluminum and ferrous metal foundries as a component of molding sands and insulating cements and for other uses. Vermiculite-containing firebricks are used in high temperature furnaces and in other applications as listed in Table 17.

(6) Minor uses (JRB 1982). Unexfoliated vermiculite has a minor use as a component of fire-resistant gypsum wallboard. Small amounts of exfoliated vermiculite are used as follows:

- As a filler and extender in paint, enamel, ink, plastics, and rubber.
- As fireproofing in paper, fabrics, and plywood.
- As a filtration aid in wastewater treatment, air purification in uranium mines, and oil spill clean-up at shores and beaches.
- In oil well drilling muds.
- As an anti-splatter agent in welding.
- As artificial dust and fireplace ashes in the motion picture industry.

7.2 Consumer Populations

7.2.1 Attic Insulation

All loose-fill attic insulation is presumed to be installed by homeowners themselves (JRB 1982). However, no data are available on consumer exposure from this source. In order to estimate the number of houses containing such insulation, it will be assumed that vermiculite has been used in attics for ten years. Data from the Bureau of Mines (1973 - 1980) indicate that a total of 476,000 tons of loose-fill vermiculite insulation were produced in the nine-year period ending in 1980. By extrapolation, it may be assumed that 529,000 tons (480 million kg) have been produced in the past ten years. All loose-fill insulation is installed in attics (JRB 1982). If an average of 510 kg of vermiculite is installed per attic (JRB 1982), then about 940,000 houses currently contain loose-fill vermiculite insulation. Assuming that two persons work at installing insulation in one attic, then 188,000 persons are so exposed per year. If the average American household includes 2.73 persons (Bureau of the Census 1982), there are about 2.6 million people living in dwellings containing vermiculite attic insulation.

The above figures are based on the assumption that vermiculite insulation has been installed only during the past ten years. It is possible that the insulation has been used for a longer period of time but no confirmation was available.

7.2.2 Lawn and Garden Fertilizers

Market research (SMRB 1980) indicates that 33.8 percent of the U.S. population buys lawn and garden fertilizers each year (74.4 million persons based on 1980 population figures). The percentage of lawn fertilizers containing vermiculite is not known. Ortho and O.M. Scott are known to produce fertilizers containing vermiculite. Estech General has reported that vermiculite was removed from their Vigoro product line a few years ago (JRB 1982). Approximately 32 million households kept gardens in 1976 and 1977 (USEPA 1980b). It may be assumed that fertilizer is used in all gardens, but again it is not known what proportion of garden fertilizers contain vermiculite.

7.2.3 Houseplants

The number of Americans who own at least one houseplant is not known but probably includes the vast majority of the population. The percentage of houseplant potting soils that contain vermiculite is not known. The majority of houseplant owners probably buy plants that are already potted and keep them indefinitely without repotting. If the soil does contain vermiculite, it is probably kept fairly moist, is rarely (if ever) disturbed, and would therefore not be a significant source of potential exposure. A small fraction of houseplant owners are hobbyists who buy significant quantities of premixed soil or who mix their own soil, often using bagged horitcultural vermiculite. They would be exposed to vermiculite during mixing and repotting. Persons who cultivate succulents or who frequently root cuttings would use the most vermiculite. Market research (SMRB 1980) indicates that 46.6 million people purchase house plant food or fertilizer annually. This might be considered an upper limit for exposure to potting soils.

There are at least 3,000 owners of hobby greenhouses (Encyclopedia of Associations 1981) whose exposure to vermiculite should be comparable to that of greenhouse employees occupationally exposed.

7.2.4 Other Minor Uses

(1) Kitty Litter. Most litter box liners for house cats contain clay minerals; probably fewer than half contain vermiculite. About 15 million people own cats, 51% of whom use cat box filler (SMRB 1980). Assuming half of those consumers buy the vermiculite-containing product, the total exposed population would be about 3.8 million.

(2) Barbecue bases. Vermiculite is sold in bags to owners of home barbecue grills. The vermiculite is used to retain and reflect heat and to absorb grease and drippings. There is no data on the number of persons who barbecue outdoors. However, since barbecuing is a suburban pastime and requires a certain minimum of yard space, the barbecuing population is probably roughly comparable to the population of persons who buy lawn and garden fertilizers. This is apparently taken for granted by the distributors of the product, who usually recommend that the used, greasy vermiculite be packed around shrubs as mulch.

7.3 Populations Exposed to Asbestos-contaminated Vermiculite in the Ambient Environment

Persons living near mines, mills, and exfoliation plants are exposed to asbestos fibers emitted from baghouses and other control devices, as well as uncontrolled fiber emissions. Section 5 discussed the transport of these fibers from exfoliation sites; it was seen that the fibers were widely dispersed within the 50 km radius addressed by ATM, affecting all those living within the area.

The four American vermiculite mines are found at three sites: Libby, Montana; Enoree, South Carolina (two mines); and Louisa, Virginia. The estimated 1980 population of these three towns is 4,680 persons (Bureau of Census 1981), all of whom could experience ambient exposure to asbestos fibers from mining and milling operation emissions.

There are 52 exfoliation plants in 47 cities within the U.S. (JRB 1982). The inhabitants of these cities are exposed to various levels of asbestos fibers. St. Louis was chosen as a representative site and was used in the ATM-SECPOP model (see Section 6.4.1) estimating ambient exposure from exfoliation. In the ATM-SECPOP results, all persons within 50 km were exposed to some asbestos. For the purposes of this exposure assessment, it was not possible to count the populations within 50 km of each site accurately. Instead, 1980 Census data (Bureau of Census 1981) were obtained for most of the 47 cities. Table 18 lists these data. The total number of persons ambiently exposed to asbestos from vermiculite exfoliation is estimated to be 13,147,496. Section 8 will discuss the level to which each subpopulation within that total is exposed.

The procedure used to estimate this population is limited, and the figures obtained must be considered approximations. The limitations include:

- Data were unavailable for three sites: Beltsville MD; Kearney, SC; and Enoree, SC. Maps indicate that these are small towns. A population of 1,000 was assumed for each.

- It was not possible, within the scope and resources of this study, to determine the exfoliation plants' actual locations, to see whether nearby towns might be affected.

- It was assumed that the total reported population within a town would be exposed to some extent. ATM results indicate that fibers are dispersed to a 50 km radius, and it is unlikely that any city enumerated by the Census would exceed those bounds.

- It was assumed that asbestos is present as a contaminant in the vermiculite processed at all of the exfoliation plants. Actually, some vermiculite is not contaminated with asbestos.

It is not possible to determine the number of persons exposed to asbestos from vermiculite transport or disposal; in many cases they would be the same persons exposed via mining, milling, or exfoliation, since disposal and transport would be localized around these industrial sites.

No significant ambient exposure via water or land would be expected. Section 5, summarizing the fate and transport of asbestos fibers and exposure pathways, shows that water and land are not important sources of exposure to asbestos from vermiculite.

Table 18. Sites of Exfoliation Plants and Populations Potentially Exposed

City	1980 Population
St. Louis, MO[a]	453,085
Cleveland, OH	573,822
Minneapolis, MN[a]	370 951
Beaver Falls, PA	12,525
Irondale, AL	6,521
Phoenix, AZ	764,911
N. Little Rock, AR	64,419
Newark, CA	32,126
Santa Ana, CA	203,713
Denver, CO[a]	491,396
Pompano Beach, FL	52,618
Jacksonville, FL	540,898
Tampa, FL[a]	271,523
West Chicago, IL	12,550
Newport, KY	21,587
New Orleans, LA	557,482
Beltsville, MD	1,000[b]
Easthampton, MA (Town, Hampshire Co.)	15,580
Dearborn, MI	90 660
Omaha, NE	311,681
Trenton, NJ	92,124
Weedsport, NY (Village)	1,952
High Point, NC	64,107
Oklahoma City, OK	403,213
Portland, OR	366,383
New Castle, PA	33,621
Kearney, SC	1,000[b]
Travellers Rest, SC	3,017
Nashville, TN (Nashville-Davidson)	455,651
San Antonio, TX	785,410
Dallas, TX	904,078
Milwaukee, WI	636,212
Girard, IL	2,246
Kenosha, WI	77,685
Dekalb, IL	33,099
Enoree, SC	1,000[b]
Great Falls, MT	56,725
Minot, ND	32,343
Metuchen, NJ (Borough)	13,762
Marysville, OH	7,414
Pine Bluff, AR	56,576
Honolulu, HI	762,874
Salt Lake City, UT	163,033
Houston, TX	1,594,086
Wellsville, KS	1,363
Kansas City, KS	161,087
Louisa, VA (Town)	932
TOTAL	13,147,498

[a]Two plants operate within this city.
[b]No data were available; a population of 1,000 is assumed.

Sources: JRB 1982, Bureau of Census 1981.

8. INTEGRATED EXPOSURE ANALYSIS

This integrated exposure analysis combines the estimation of environmental concentrations with the identification of locations and habits of the exposed populations to yield exposure profiles. Section 8.1 identifies the exposed populations, addresses the pathways leading to exposure, and calculates individual exposure for subpopulations. Subsections within 8.1 deal with each exposure scenario and with a profile of "worst plausible case" exposure. Section 8.2 is a qualitative assessment of the uncertainties and limitations inherent in the exposure analysis.

8.1 Exposure Profiles and Calculations

8.1.1 Occupational Exposure

Occupational exposure occurs during the mining and beneficiation, exfoliation, transport, and use of vermiculite. The following sections deal with each major step in the flow through commerce.

(1) Miners and Millers of Vermiculite. Mining and beneficiation of vermiculite are performed at four sites employing a total of approximately 500 persons. It is estimated that half of that total are clerical, managerial, and administrative personnel not coming in frequent contact with the processes and subsequent releases (Hunsicker and Sittenfield 1979). Actual production workers (or operatives) are exposed to levels ranging from less than 0.01 to 9.7 fibers/cc (see Table 11).

Table 19 displays the inhalation exposure calculations for asbestos-contaminated vermiculite. As explained in Section 5.2, inhalation is assumed to be the only significant route of asbestos exposure from vermiculite. Mining and milling releases may lead to an exposure level of as much as 9.7 f/cc in worker subpopulations. This assumes that all fibers are respirable; it has been shown that this is not true (Timbrell 1965), but fiber size data necessary to factor in the respirable fraction of fibers were not available.

(2) Exfoliators of Vermiculite. Exfoliation of vermiculite leads to atmospheric emissions from process equipment and during handling. Uncontrolled emissions to the air within an exfoliation plant may lead to occupational exposure, while process vents to the outside lead to exposure via ambient air.

The actual number of persons exposed in the workplace to asbestos from exfoliation is not known; estimates range from 1,694 to 1,979 employees at 52 plants. Fiber levels within the exfoliation area vary between nondetectable and 0.38 f/cc.

(3) Transporters of Vermiculite. The number of persons involved in transportation of vermiculite is unknown; according to the National Occupational Hazard Survey (NOHS 1980), 129 drivers and 108 rail workers are exposed to asbestos from vermiculite transport (Table 19). It is probable that a large number of workers handling vermiculite in transport are unaccounted for.

Exposure during transport may be significant. Based upon personnel samples taken at one mine, truck drivers may be exposed to 0.3 f/cc. Rail workers are potentially exposed to high fiber counts resulting from the transfer of beneficiated vermiculite from railroad cars to exfoliation facilities. Area samples have been taken in warehouses in which workers handle the exfoliated product. No asbestos was detected, but it is likely that accidental spills occur with some regularity and can lead to exposure during cleanup operations.

(4) Commercial and Industrial Users. This population includes formulators of consumer products and users of exfoliated and unexfoliated vermiculite. Few data are available to quantify asbestos exposures within this group. Parts I.D. and I.E. of Table 19 present the available data. In some cases, product formulation data were combined with exfoliation data and the same figures were used for both worker subpopulations. This was the case for producers of lightweight aggregates, vermiculite insulation, and agricultural and horticultural products.

Table 20 lists the occupational subpopulations for which no data were available, and makes a qualitative statement of potential exposure.

8.1.2 Consumer Exposure

Consumer exposure has been calculated for three types of products: vermiculite loose-fill attic insulation, lawn care products, and garden fertilizer. The other consumer uses of vermiculite are not expected to lead to high asbestos exposure, since population and releases are small.

(1) Consumer Installation of Loose-fill Vermiculite Insulation. It has been estimated that the attics in 940,000 homes have been insulated with vermiculite in the last ten years (see Section 7.2.1). At the rate of 94,000 homes per year, and assuming that the job requires two people, approximately 188,000 consumers are exposed each year.

Asbestos concentrations in an average attic are estimated in Section 6.4. The average exposure level is 6,800 $\mu g/m^3$ for the 8-hour period, assuming that the vermiculite contains 1 percent asbestos.

Table 19. Summary of Inhalation Exposure to Asbestos in Vermiculite

Population	Number of persons exposed[a]	Exposure level[b] f/cc	Exposure level[b] µg/m³	Duration[c] (hrs/wk)	Comments
I. Occupational					
A. Miners and millers of vermiculite	~ 250	ND-9.7		43.0	Number of persons exposed estimated as one-half total employment.
B. Importers and exporters of vermiculite	unknown	unknown			
C. Exfoliators of vermiculite	1,694-1,979	NC- 0.38		41.5	
D. Users of unexfoliated vermiculite					
1. Steel workers	919	unknown			
2. Manufacturers of gypsum wallboard	unknown	unknown			
(a) Wholesale/retail traders of gypsum wallboard	unknown	unknown			
(b) Installers of wallboard	unknown	unknown			

Table 19. (continued)

Population	Number of persons exposed[a]	Exposure level[b] f/cc	Exposure level[b] µg/m^3	Duration[c] (hrs/wk)	Comments
E. Users of exfoliated vermiculite					
1. Producers of lightweight aggregates	see I.c.	ND-0.38		41.5	Assumes that aggregates produced at exfoliation site. Based upon most recent data.
(a) Users of plasters, concretes, and aggregates containing vermiculite	34,639	unknown			
(b) Wholesale/retail traders of lightweight aggregates	unknown	unknown			
2. Producers of vermiculite insulation	see I.c.	ND-0.38		41.5	Assumes that insulation produced at exfoliation site. Based upon most recent data.
(a) Users of vermiculite for loose-fill, block-fill, and packing	298		6,800	36.9	Based on projected levels encountered in attic insulation.
(b) Wholesale/retail traders of vermiculite insulation	unknown	unknown			

Table 19. (continued)

Population	Number of persons exposed[a]	Exposure level[b] f/cc	µg/m^3	Duration[c] (hrs/wk)	Comments
3. Producers of agricultural and horticultural products containing vermiculite	unknown	ND-0.38		41.8	Based on OSHA 1979 and MRI 1982.
(a) Users of agricultural/horticultural products containing vermiculite	>1,136	unknown		32.7	
(b) Wholesale/retail traders of agricultural/horticultural products containing vermiculite	unknown	unknown			
4. Producers of minor vermiculite-containing products					
(a) Producers and users of vermiculite filters for pollution control	unknown	unknown			
(b) Producers and users of oil-well drilling muds	unknown	unknown			

Table 19. (continued)

Population	Number of persons exposed[a]	Exposure level[b] f/cc	Exposure level[b] $\mu g/m^3$	Duration[c] (hrs/wk)	Comments
(c) Producers and users of artificial dust and fireplace ashes	unknown	unknown			
(d) Producers and users of refractories and firebricks	unknown	unknown			
(e) Producers and users of miscellaneous vermiculite-containing products	unknown	unknown			
5. Transporters of vermiculite					
(a) Truck drivers	129	<0.01-0.3		39.9	
(b) Ship and dock workers	unknown	unknown			
(c) Rail workers	108	unknown		39.9	
(d) Warehouseman	unknown	0		39.9	
II. Transportation and storage spills	unknown	unknown			

Table 19. (continued)

Population	Number of persons exposed[a]	Exposure level[b] f/cc	Exposure level[b] $\mu g/m^3$	Duration[c] (hrs/wk)	Comments
III. Consumers					
A. Homeowners insulating attics with loose-fill vermiculite	188,000		6,800	8	Time-weighted average concentration estimate; one-time 8-hr exposure.
B. Users of lawn and garden fertilizers					Time-weighted average concentration estimate; once yearly exposures.
(1) lawn application	<74,400,000		4.4	4	
(2) garden application	<32,000,000		28	1	
C. Users of houseplant potting soil with vermiculite	>3000	unknown			
D. Users of vermiculite-based kitty litter	<3,800,000	unknown			
E. Users of vermiculite in barbecue grills	<74,400,000	unknown			
IV. Disposal	unknown	unknown			
V. Food	unknown	unknown			
VI. Drinking water	unknown	unknown			

Table 19. (continued)

Population	Number of persons exposed[a]	Exposure level[b] f/cc	Exposure level[b] µg/m³	Duration[c] (hrs/wk)	Comments
VII. Ambient					
A. Air					
1. Persons near mines and mills	4,680	ND-0.5		168	
2. Persons near exfoliation sites	53,905		1.0×10^{-2}- 2.5×10^{-2}	168	Derived from ATM-SECPOP and Bureau of Census data.
	111,754		5.0×10^{-3}- 1.0×10^{-2}	168	
	305,022		2.5×10^{-3}- 5.0×10^{-3}	168	
	1,513,277		1.0×10^{-3}- 2.5×10^{-3}	1688	
	2,908,426		5.0×10^{-4}- 1.0×10^{-3}	168	
	3,038,386		2.5×10^{-4}- 5.0×10^{-4}	168	
	4,403,096		1.0×10^{-4}- 2.5×10^{-4}	168	
	733,630		5.0×10^{-5}- 1.0×10^{-4}	168	
3. Persons near users of vermiculite	unknown		unknown		
B. Water	unknown		unknown		
C. Land	unknown		unknown		

Footnotes for Table 19

[a]Number of persons exposed taken from Table 17 unless otherwise specified in "comments" column.

[b]No attempt was made to convert units of asbestos measurement; units are as reported in primary source. Monitoring data are from Table 11 and modeling estimates are explained in Section 6.4.

[c]Ambient exposure duration was set at 168 hours per week; data do not warrant application of mobility patterns or other refinements. Occupational exposure durations based upon average work week for industry sectors (BLS 1980).

Table 20. Occupational Subpopulations: Exposure Potential

Population	Potential for exposure
Importers and exporters of vermiculite	Exposure may be comparable to levels encountered by transportation workers.
Manufacturers and users of gypsum wallboard	Uses unexfoliated vermiculite. Fabrication steps and installation may have atmospheric emissions and resultant exposure.
Users of lightweight aggregates	Exposure may occur during dry mixing; if outdoors, fibers will be diluted.
Producers and users of minor products	Exposure is highly product-specific; high exposure with artificial dusts; low exposure expected from refractories, drilling muds, filters.
Users of block-fill insulation	Workers filling blocks may be exposed to high levels of asbestos.
Wholesale/retail traders of vermiculite products	Exposure is product-specific; most products are bagged or otherwise bound. Exposure is unlikely to be significant.

Once in place, vermiculite attic insulation would probably not lead to subsequent consumer exposure. The type of attic in which vermiculite is used is ordinarily isolated from the rest of the home and is not regularly entered.

(2) Consumer Use of Garden Fertilizer. As seen in Section 6.4, asbestos levels can be estimated to reach 57 $\mu g/m^3$ during application of garden fertilizer; a time-weighted average of 28 $\mu g/m^3$ represents the mean exposure level. It is assumed that it takes one hour to fertilize the average garden and that it is done once yearly. The vermiculite in the fertilizer is assumed to contain 1 percent asbestos.

The proportion of garden fertilizers containing vermiculite and the proportion of contaminated mineral are unknown, but it is known that 32 million households had gardens in 1976 and 1977 (USEPA 1980b). If each gardener uses asbestos-contaminated vermiculite-based fertilizer, then approximately 32 million persons are exposed to 28 $\mu g/m^3$ asbestos during fertilizer use.

(3) Consumer Use of Lawn Care Products. This worst-case exposure scenario is based upon the "box model" estimated concentrations developed in Section 6.4. Each consumer might breathe a time-weighted asbestos concentration of 4.4 $\mu g/m^3$, for four hours once yearly. The vermiculite in the product is assumed to contain 1 percent asbestos.

Approximately 74.4 million Americans buy lawn and garden fertilizers each year. Again, the percentage buying asbestos-containing vermiculite products is unknown.

8.1.3 Ambient Exposure

Ambient exposure to asbestos from vermiculite is assumed to arise from two types of point sources: mines and exfoliation plants. This exposure is via releases into ambient air; water and land are not significant exposure media (see Section 5.2).

(1) Ambient Exposure Near Mines and Mills. A total of about 4,680 persons live in the three towns with vermiculite mines. All are probably exposed to asbestos fibers from controlled and uncontrolled emissions. Monitoring data collected at points around mines and mills indicate that levels of asbestos range from undetected to 0.5 fibers/cc. A full-time resident could be exposed to this level 24 hours per day. The respirable fraction of this level has not been determined. No further data are available to characterize ambient exposure around mines and mills.

(2) Ambient Exposure Near Exfoliation Plants. The ATM-SECPOP results presented in Section 6.4 are the basis for this analysis of

exposure near exfoliation sites. Bureau of Census (1981) data were used to estimate the total population affected.

ATM-SECPOP calculates levels and counts persons within a 50 km radius of a point source. As stated in the Populations section, enumeration of populations is more accurate with a 15 km radius, so the ATM data were reduced to the 15 km level. An exposure distribution was prepared from the St. Louis ATM-SECPOP output. This exposure distribution was then applied to the total U.S. population near exfoliation facilities to yield the information presented in Table 19.

As in the previous ambient exposure example, it was assumed that exposure was continuous. A maximum exposure level of 0.025 $\mu g/m^3$ was calculated. It should be noted that St. Louis SECPOP data indicate that there were residences within 1 km of the site and that exposure to those individuals was high. Other exfoliation sites may be farther removed from residential areas, although they are given city addresses. Exposure estimates may therefore be somewhat biased toward the higher end, but these calculations present a plausible worst-case situation.

8.1.4 Other Exposure Scenarios

Some exposure to asbestos associated with vermiculite occurs through the other exposure scenarios, but it is expected to be low in comparison to the three scenarios discussed above.

Spills from transporation and storage are negligible, although there are dust losses during loading and unloading of trucks, railroad cars, and barges (JRB 1982). Exposure to the general population to asbestos from loading and unloading is probably very small because of the relatively low release rates; exposure to the transportation workers during loading and unloading is considered to be an occupational exposure and is discussed in Section 8.1.1 above.

Disposal scenarios relevant to vermiculite include landfilling of solid wastes from mining, beneficiation, exfoliation, and processing; discarded end products may also be landfilled (JRB 1982). Releases of vermiculite and asbestos from landfills are thought to be negligible. Wastewater from mining, beneficiation, and exfoliation is recycled, and only minor amounts of vermiculite and asbestos are released from water treatment operations at permanent vermiculite concrete plants (JRB 1982). Because water is not thought to be a significant exposure medium for asbestos from vermiculite, and because the aqueous releases of vermiculite and asbestos are insignificant compared to air releases covered in the occupational, consumer, and ambient scenarios, this exposure pathway is considered to be negligible.

As discussed in Section 5.2.2, asbestos is not expected to be bioaccumulated; therefore, food is not considered to be an applicable exposure scenario.

Drinking water could contain asbestos from waterborne releases from vermiculite processing and use. Releases to water from all sources are considered to be negligible (JRB 1982). Fate processes do, however, result in some intermedia transfer of asbestos from the atmospheric and land environments to surface water. The available data are inadequate to support a quantitative estimate of exposure from ingestion of drinking water, but it is considered unlikely that this exposure route is significant compared to the occupational, consumer, or ambient exposures discussed above.

8.1.5 Integrated Worst-case Exposure Scenario

The geographic distribution of vermiculite point sources and the widespread use of some vermiculite products indicate that individual exposure may come from numerous sources. This facilitates the creation of a plausible worst-case scenario, with a summation of exposure from occupation, consumer products, and contaminated ambient air. Unfortunately, asbestos data are reported in different units that cannot be validly compared.

The "worst-case" individual's exposure sources and concentrations are listed in Table 21; no attempt is made to sum these inhalation exposures, although relative contributions from different sources are apparent.

The individual works in an exfoliation plant, and lives in the city where the plant is located. He uses vermiculate-based lawn and garden fertilizers, and has insulated his attic with loose-fill vermiculite.

8.2 Uncertainty of Analysis

Assumptions and limitations to the data are discussed in detail throughout the report. Major limitations are listed below:

- The validity of the monitoring data is unclear. Different analytical techniques used by the EPA contractors may have affected the results reported in Section 6 by as much as an order of magnitude. OSHA monitoring data cannot be adequately analyzed because information on analytical techniques is lacking.

- The results of ATM-SECPOP are based on numerous assumptions in the input data. Extrapolation of those results to all exfoliation sites provides a crude approximation of exposure. The consumer exposure models are also based on assumptions and are clearly designed to be worst-case exposure analyses.

Table 21. Worst-case Individual Exposure Level Profile

Source of exposure	Exposure level[a]
Working in an exfoliation plant 2,000 hours yearly	0.38 fibers/cc
Living in city with exfoliation plant 3,736 hours yearly	0.025 μg/m^3
Fertilizing garden once yearly for one hour	28 μg/m^3
Fertilizing lawn once yearly for four hours	4.4 μg/m^3
Insulating attic for 8 hours once in lifetime	6,800 μg/m^3

[a] Exposure levels from Table 19.

- Population data were sparse; data for all populations are estimates.

- There are no data on asbestos fiber size distributions in air contaminated with vermiculite releases. Exposure calculations are therefore based on total fibers rather than on the respirable fraction. Similarly, it was assumed throughout the exposure assessment that all vermiculite is contaminated by asbestos, although some vermiculite is not. The three consumer exposure scenarios all assumed that vermiculite is contaminated with 1 percent asbestos.

Despite these limitations, this exposure assessment provides the best data and predictions available. Further study would enhance the usefulness of the data for regulatory decisionmaking.

9. REFERENCES

Bassett WA. 1959. The origin of the vermiculite deposit at Libby, Montana. Amer. Miner. 44:282-297.

Boettcher AL. 1966. Vermiculite, hydrobiotite, and biotite in the Rainy Creek Igneous Complex near Libby, Montana. Clay Minerals. 6:283-296.

Bureau of the Census. 1980. Statistical abstract of the United States. Washington, DC: U.S. Department of Commerce.

Bureau of the Census. 1981. Advance reports, population and housing, of the 1980 Census. Washington, DC: U.S. Department of Commerce.

Bureau of the Census. 1982. Census of population. U.S. summary. General population characteristics. PC80-1-B series. Washington, DC: U.S. Department of Commerce.

Bureau of Labor Statistics. 1980. Handbook of labor statistics. Washington, DC: U.S. Department of Labor. Bulletin 2070.

Bureau of Mines. 1973-1980. Vermiculite. Preprint from the Bureau of Mines minerals yearbook. Washington, DC: U.S. Department of the Interior.

Burilkov T, Michailova L. 1970. Asbestos content of the soil and endemic pleural astestosis. Environ. Res. 3:443-451.

Callahan MA, Slimak MW, Gabel NW, et al. 1979. Water-related environmental fate of 129 priority pollutants. Chapter 7. Asbestos. Washington, DC: U.S. Environmental Protection Agency.

Chase RRP. 1979. Settling behavior of natural aquatic particulates. Limnol. Oceanog. 24(3):417-426.

Chatfield EJ, Lewis GM. 1979. Examination of vermiculite for the presence of asbestos fibers. Mississauga, Ontario: Ontario Research Foundation. Report number 22056-2.

Choi I, Smith RW. 1972. Kinetic study of dissolution of asbestos fibers in waters. J. Colloid Interface Sci. 40(2):253-262.

Chowdhury S. 1975. Kinetics of leaching of asbestos minerals at body temperatures. J. Appl. Chem. Biotechnol. 25:347-353.

Chowdhury S, Kitchener JA. 1975. The zeta potentials of natural and synthetic chrysotile. Internat. J. Mineral Processing. 2:277-285.

Cook PM. 1973. Distribution of taconite tailings in Lake Superior water and public water supplies. Duluth, Minnesota. USEPA National Water Quality Laboratory. Second progress report, July 1973.

Culkowski WM, Patterson MR. 1976. A comprehensive atmospheric transport and diffusion model. Oak Ridge, Tennessee: Oak Ridge National Laboratory. ORNL/NSF/EATC-17.

Deer WA, Howie RA, Zussman J. 1962. Rockforming Minerals Vol. 3. Sheet Silicates. pp. 246-257.

Dement JM, Harris RL. 1979. Estimate of pulmonary and gastrointestinal deposition for occupational fiber exposures. Washington, DC: U.S. Department of Health, Education and Welfare (NIOSH) Publication No. 79-135.

EIS. 1980. Economic Information Service. Computer printout: employment in vermiculite industry.

Encyclopedia of Associations. 1981. Detroit, Michigan: Gale Research Co.

Feely RA. 1976. Evidence for aggregate formation in a nepheloid layer and its possible role in the sedimentation of particulate matter. Marine Geol. 20:7-13.

GCA. 1980. Vermiculite regulatory options analysis. Bedford, MA: GCA Technology Division.

Gooch EO. 1957. Vermiculite. Virginia Minerals 3(1):1-6.

Gruner JW. 1934. The structures of vermiculite and their collapse by dehydration. Amer. Miner. 19:557-575.

Haagen-Smit AJ, Wayne LG. 1976. Atmospheric reactions and scavenging processes. In: Stern AC, ed. Air pollutants, their transformation, and transport. New York: Academic Press.

Harwood CF, Ase PK. 1977. Field testing of emission controls for asbestos manufacturing waste piles. IITRI, Cincinnati, Ohio: U.S. Environmental Protection Agency.

Harwood CF, Blaszak TP. 1974. Characterization and control of asbestos emissions from open sources. IITRI. Washington, DC: U.S. Environmental Protection Agency. PB 238-923.

Hewson EW. 1976. Meteorological measurements. In: Stern Ac, ed. Air pollutants, their transformation, and transport. New York: Academic Press.

Hodgson AA. 1979. Chemistry and physics of asbestos. In: Michaelo L, Chissick SS. Asbestos. Vol. 1 - properties, applications, and hazards. New York: John Wiley and Sons.

Hostetler PB, Christ CL. 1968. Studies in the system $MgO-SiO_2-CO_2-H_2O(I)$: The activity product constant of chrysotile. Geochim. Cosmochim. Acta. 32:485-497.

Hunsicker S, Sittenfield M. 1979. Occupational hazards of vermiculite. Philadelphia, PA: Calculon. EPA Contract No. 68-01-3899.

Hunter CE. 1950. Vermiculite of the Southeastern states. In: Sayder FG, ed. Symposium on mineral resources of the Southern United States. Knoxville, Tennessee: The University of Tennessee Press.

JRB. 1982. Interim draft final. Level II materials balance - vermiculite. Washington, DC: U.S. Environmental Protection Agency.

Kramer JR. 1976. Fibrous cummingtonite in Lake Superior. Can. Mineral. 14:91-98.

Kreston P, Berggren G. 1978. The thermal decomposition of vermiculite. Thermochimica Acta. 23:171-182.

Lawrence J, Tosine HM, Zimmerman HW. 1975. Removal of asbestos fibers from potable water by coagulation and filtration. Water Res. 9:397-400.

Lawrence J, Zimmerman HW. 1977. Asbestos in water: mining and processing effluent treatment. J. Water Poll. Control Fed. 49:156-160.

Lol D, Lerman A. 1975. Size spectra of biogenic particles in ocean water and sediments. J. Geophys. Res. 80: 423-430.

McCormick RA, Holzworth GC. 1976. Air pollution climatology. In: Stern AC, ed. Air pollutants, their transformation, and transport. New York: Academic Press.

Mifsud A, Forness V, Rausell-Colon JA. 1977. Natural alteration of vermiculite to chrysotile. Amer. Miner. 62:1225-1231.

MRI. 1982. Collection, analysis, and characterization of vermiculite samples for fiber content and asbestos contamination. Final report. Washington, DC: U.S. Environmental Protection Agency. Contract No. 68-01-5915.

Myers JB. 1960. Vermiculite. In: Industrial Minerals and Rocks, 3rd ed. New York: AIME.

Naumann AW, Presher WH. 1968. Colloidal suspensions of chrysotile asbestos surface charge enhancement. J. Colloid Interface Sci. 27(1):133-140.

Neihof RA, Loeb GI. 1972. The surface charge of particulate matter in seawater. Limnol. Oceanogr. 17:7-16.

Neihof RA, Loeb GI. 1974. Dissolved organic matter in seawater and the electric charge of immersed surfaces. J. Mar. Res. 32:5-12.

Nihoul JC. 1977. Turbulent boundary layer bearing silt in suspension. Phys. Fluids. 20:5197-5202.

NOHS. 1980. National Occupational Hazard Survey. Computer printout. Vermiculite exposure: projected numbers by occupation. Washington, DC: National Institute for Occupational Safety and Health.

OSHA. 1979. Occupational Safety and Health Administration. Industrial Hygiene Survey: O.M. Scott and Sons. Report C6635-180.

Parks GA. 1967. Aqueous surface chemistry of oxides and complex oxide minerals. In: Stumm W, ed. Equilibrium concepts in natural water systems. Advances in chemistry series 67. Washington, DC: American Chemical Society.

PEDCO Environmental Specialists Inc. 1973. Investigation of fugitive dust sources, emissions and control. Washington, DC: U.S. Environmental Protection Agency.

Petrov VP. 1962. Perlite and vermiculite (geology, exploration, and production technology). New Dehli and Washington, DC: Indian National Scientific Documentation Centre and U.S. Department of Interior, Geological Survey.

Prasad NA, Pooley FD. 1973. Characteristics of amphibole asbestos dust surfaces in aqueous media with reference to quartz. J. Appl. Chem. Biotechnol. 23:675-687.

Ralston J, Kitchener JA. 1975. The surface chemistry of amosite asbestos, and amphibole silicate. J. Colloid Interface Sci. 50(2):242-246.

Ray PM. 1972. The living plant. New York: Holt, Rinehart and Winston Inc.

Sawyer RN, Spooner CM. 1978. Sprayed asbestos-containing materials in buildings - a guidance document. Washington, DC: U.S. Environmental Protection Agency. EPA-450/2-78-014.

Schmitt RP, Linsten DC, Shannon TF. 1977. Decontaminating Lake Superior of asbestos fibers. Environ. Sci. Technol. 11(5):462-465.

Scow K, Wechsler AE, Stevens J, Wood M, Callahan MA. 1979. Identification and evaluation of waterborne routes of exposure from other than food and drinking water. Washington, DC: U.S. Environmental Protection Agency.

Sebastien P, Billon MA, Dufour G, Gaudichet A, Bonnaud G. 1979. Levels of asbestos air pollution in some environmental situations. In: Selikoff IJ, Hammond EC, eds. Health hazards of asbestos exposure. Annals of the New York Academy of Science. 330:401-415.

Smith GR, Carpenter LM, Stanley RL, Mueller PK. 1973. Determination of the concentration of asbestos fibers in ambient air near an asbestos processing plant. Berkeley, CA: Air and Industry Hygiene Laboratory.

SMRB. 1980. Simmon Market Research Bureau Inc. The 1980 study of media and markets. New York: Simmons Market Research Bureau, Inc.

Speil S, Leineweber JP. 1969. Asbestos minerals in modern technology. Environ. Res. 2:166-208.

Stern AC, ed. 1976. Air pollution, Vol. 1. New York: Academic Press.

Sverdrup HV, Johnson WM, Fleming RH. 1964. The oceans, their physics, chemistry and general biology. Englewood Cliffs, New Jersey: Prentice-Hall.

Timbrell V. 1965. The inhalation of fibrous dust. Annals N.Y. Acad. Sci. 255-273.

Turner DB. 1969. Workbook of atmospheric dispersion estimates. Cincinnati. OH: U.S. Department of Health, Education, and Welfare, Public Health Service. PHS pub. no. 999-AP-26.

USEPA. 1974. U.S. Environmental Protection Agency. Background information on national emission standards for hazardous pollutants - proposed amendments to standards for asbestos and mercury. Washington, DC: EPA-450/2-74-009a.

USEPA. 1980a. U.S. Environmental Protection Agency. Priority review level 1 - asbestos-contaminated vermiculite. Washington, DC: U.S. Environmental Protection Agency.

USEPA. 1980b. U.S. Environmental Protection Agency. Dietary consumption distributions of selected food groups for the U.S. population. Washington, DC: U.S. Environmental Protection Agency. EPA 560/11-80-012.

Wanta RC, Lowry WP. 1976. The meteorological setting for dispersal of air pollutants. In: Stern AC, ed. Air pollutants, their transformation and transport. New York: Academic Press.

Whelpdale DM, Munn RE. 1976. Global sources, sinks, and transport of air pollutants. In: Stern AC, ed. Air pollutants, their transformation and transport. New York: Academic Press.

Williamson SJ. 1973. Fundamentals of air pollution. Addision-Wesley.