Revised Draft Report

Nonoccupational Asbestos Exposure

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1. INTRODUCTION

In January 1986, the Office of Toxic Substances (OTS) proposed a rule that banned the use of asbestos in certain products and phased out the use of asbestos in all other products. The public comment period for this rule closed on June 30, 1986, and public hearings were held July 15-25, 1986. OTS is now charged with updating previous work, based on recent literature references and data obtained during the review process. This report presents updated information on certain nonoccupational exposures to asbestos.

1.1 Background

Asbestos is a fibrous silicate mineral valued for its noncombustible, nonconductive, chemically inert properties. It has been used in a wide variety of products including building components, insulation, plastics, textiles, pipe, friction products, and filters. Exposure to asbestos has been linked with lung cancer, mesothelioma, and asbestosis.

In 1984, Versar prepared an asbestos exposure assessment under Task 49 of EPA Contract 68-01-6271. Along with other information, this exposure assessment was used in preparing the 1986 proposed rule. Based on more recent information, however, certain aspects of this report need to be updated. The more recent information includes (1) testimony given in the public hearings and in public comments, (2) the asbestos NESHAP review, (3) a survey of asbestos mining, milling, and processing companies that was conducted by ICF Corporation, and (4) recent literature references, which have been identified through a literature search.

1.2 Report Scope and Organization

The scope of this report is limited to specific nonoccupational exposures designated by the Office of Toxic Substances. The topics covered and their organization within this report are as follows:

Topic	Section No.
Airborne Asbestos from Vehicle Brakes	2
Consumer Exposure to Asbestos in Coatings, Sealants, and Paints	3
Consumer Exposure to Asbestos in Vinyl Asbestos Floor Tile	4
Consumer Exposure During Brake Repair	5
Other Potential Consumer Exposures	6

2. AIRBORNE ASBESTOS FROM VEHICLE BRAKES

Both disc and drum brakes contain asbestos fibers as friction material. When either type of brake is applied, the friction material is mechanically abraded and thermally degraded. The abrasion of the friction material often results in airborne asbestos. Because most of the 170 million vehicles registered in the U.S. in 1985 were equipped with brakes capable of emitting asbestos to the atmosphere, the quantity of asbestos emitted by each vehicle and the contribution of brakes to ambient asbestos levels are of concern. Several studies have been undertaken to identify these parameters.

The results of these studies are summarized in Table 2-1. As shown in this table, it is difficult to compare results among studies because of differences in focus, basic assumptions and reporting methods. Three of the studies with similar focuses, but different methods were Williams and Muhlbaier (1982); Jacko, DuCharme, and Somers (1973); and Cha and Carter (1982). Although these three studies use different approaches to the question of ambient asbestos levels resulting from vehicle brakes, they all publish results of their studies in enough detail to allow additional analyses. The other studies listed in Table 2-1 either contain insufficient data to allow further analysis or determine factors that do not apply to the current analysis. For these reasons, the remainder of this section will focus on the data collected for these three studies.

Two factors are common to all three studies: (1) transmission electron microscopy is used to quantify asbestos levels, and (2) the analyses performed on the data collected use vehicle registration, mileage, and use statistics which are now outdated. To the extent possible, this report will apply consistent methods and conversion factors to the published data to result in up-to-date, comparable estimates of national asbestos emissions. The arithmetic average of these values will then form the basis for estimates of asbestos emissions

Table 2-1. Results Reported in Previous Studies

Reference	Result	Comments
Williams and Muhlbaier (1982)	0.063 ng/m^3 ambient asbestos concentration from braking	Assumes only passenger cars contribute. Calculated by analogy with airborne lead.
	4,700 kg/yr	Airborne asbestos emissions of 2.6 ug/km, with 1.14 x 10^8 passenger cars, each averaging 1.6 x 10^4 km/yr (1977 figures). Raw data from dynamometer tests.
	19 ng/m^3 toll booth asbestos concentration	By analogy with the General Motors Sulfate Dispersion Experiment.
Jacko, DuCharme, and Somers (1975)	5,060 lb/yr airborne asbestos from clutch and braking	Includes asbestos from disc and drum brakes and clutches for passenger cars, trucks, and miscellaneous vehicles. Raw data from vehicle tests.
Chu and Carter (1982)	0.25 ng/m^3 ambient asbestos concentration from automobiles	Uses dispersion model for St. Louis, MO, with emissions estimated by combining measured results for disc brakes from representative braking cycles with estimated values for drum brakes. Accounts for automobiles only.
Bingham et al. (1983)	3.7 to 25 ng/m^3	Ambient asbestos concentration resulting from automotive friction products. Theoretical basis.
Anderson et al. (1973)	0.02%	Asbestos content of emissions. Dynamometer tests.
Ziskind et al. (1982)	31,000 to 42,000 fibers/m^3	Chrysotile asbestos concentrations measured beside a Century City, California, highway.
Rohl et al. (1976)	2-15% asbestos in brake drum dusts	Asbestos content of dust blown out of brake during maintenance.
	2.6-16.0 fibers/m^3	Range of means 3 to 20 feet from maintenance operation (blowing dust out of brake drums with compressed air).
Williams and Muhlbaier (1980)	0.08 ng/m^3 ambient asbestos concentration from braking	Assumes only passenger cars contribute. Calculated by analogy with airborne lead.
	4,900 kg/yr total asbestos emissions from braking	0.03% of the total brake emission is asbestos.

from 24 United States cities. The city-wide emissions will be used, in conjunction with ambient air dispersion modeling, to estimate the asbestos concentration in these cities resulting from vehicular brakes. Finally, an average national ambient asbestos concentration from vehicle brakes is estimated by two methods.

2.1 National Asbestos Emissions

In order to use the data compiled in the three studies mentioned previously, background information on the studies must be known. The methods used in each of the three studies will be outlined in this section, followed by a detailed discussion of the manipulations performed on these data to derive comparable asbestos emissions estimates. Table 2-2 summarizes pertinent data from each of the three studies, along with comparable emissions estimates based on these data. These estimates result from equating emissions from trucks, buses, and motorcycles with those from cars, and, therefore, misrepresent total asbestos emissions. To avoid this problem, emission factors were used to scale automobile emissions up or down in order to reflect emissions from trucks, buses, and motorcycles. The results of these manipulations are presented in Table 2-3; bases for these manipulations are summarized in Table 2-4. A more detailed discussion of Tables 2-2, 2-3, and 2-4 follows the descriptions of the studies conducted by Williams and Muhlbaier; Jacko, DuCharme, and Somers; and Cha and Carter.

Williams and Muhlbaier (1982) performed dynamometer tests on new and used disc and drum brakes. They collected airborne, sedimentary, and entrained particles, and analyzed samples for asbestos content. These measurements allowed the researchers to determine directly such factors as the mass of particulates emitted, the percentage of particulates that remain airborne, and the asbestos content of airborne emissions. The experiment was repeated for different initial velocities and deceleration rates. By averaging the driving cycles and the emissions, they estimated

Table 2-2 Airborne Asbestos Emissions from Vehicles

Study (date)	Type of test	Brake type	Average particulate emission (mg/brake/stop)	Average percentage of particulates airborne (%)	Airborne particulate emissions Range (mg/brake/stop)	Airborne particulate emissions Average (mg/brake/stop)	Asbestos content of airborne particulates (%) Range	Asbestos content of airborne particulates (%) Mean	Airborne asbestos emission (ug/veh/stop)	Airborne asbestos emission (ug/veh/km)	Airborne asbestos emission (kg/yr)[a]
Williams and Muhlbaier (1982)	Dynamometer	Disc	3.3	55	-	-	-	0.030	2.2	2.64	7,000
		Disc	--	--	0.70-12.0	1.6[b]	0.00095-0.18	0.027	1.55	1.86	4,900
		Drum	--	--	0.75-2.8	1.1[b]	0.0020-0.19	0.031			
Jacko, DuCharme, and Somers (1973)	Vehicle	Disc	--	--	0.082-1.27[c]	0.39	0.052-0.290	0.159	1.59	1.91	5,000
		Drum	--	--	0.004-0.181[c]	0.06	0.079-0.493	0.216			
		Disc	--	--	0.082-0.364[d]	0.091[e]	0.052-0.290	0.159	0.72	0.86	2,300
		Drum	--	--	0.042-0.181[d]	0.099[e]	0.079-0.493	0.216			
Cha and Carter (1982)	Dynamometer	Disc	2.43	31	--	--	0.00005-0.14	0.017	0.43[f]	1.30[g]	3,400

[a]Conversion factors used in calculating consistent units (except as noted) are: 1.2 stops/km (2.0 stops/mile) (Jacko, Ducharme and Somers 1973), 1.64×10^8 autos, trucks and buses registered in U.S. in 1983 (USDOC 1985a), avg. of 10,000 miles traveled per vehicle (USDOC 1985a), 2 drum and 2 disc brakes, mean (or average) values.

[b]Median values.

[c]Results for seven different driving cycles (e.g., city driving, severe stopping) are included.

[d]Severity weighting factors are available for only five of the seven driving cycles, therefore, only those five are included in this range.

[e]Average value weighted by severity of braking mode. These values are assumed to be more accurate than the non-weighted averages; therefore, they are used in the remainder of this report.

[f]Includes contribution from two drum brakes. The values for the drum brakes were estimated by applying the ratio of airborne particulate emissions from drum and disc brakes found by Williams and Muhlbaier (1982) (1.1/1.6) to the airborne asbestos emissions from disc brakes estimated in the current study.

[g]Assumes 5.05 stops per mile (3.03 stops/km), measured by author during this test (inner-city driving).

Table 2-3. Airborne Asbestos Emissions by Vehicle Type

Data source	Brake type	Average airborne particulate emissions (mg/brake/stop)	Mean asbestos content of airborne particulates (%)	Airborne asbestos emissions (ug/veh/km)[a,b]						Total airborne asbestos emissions from vehicular brakes (kg/yr)[b]						
				cars	buses	Light truck	Med truck	Heavy truck	Motor-cycle	car	bus	Light truck	Med truck	Heavy truck	Motor-cycle	total
Williams and Muhlbaier (1982)	disc	1.6[c]	0.027	1.86	10.66	4.1	10.66	28.7	0.93	3,900	120	2,300	270	3,500	18	10,000
	drum	1.1[c]	0.031													
Jacko, DuCharme & Somers (1973)	disc	0.091[d]	0.159	0.86	6.68	2.57	6.68	17.99	0.43	1,800	75	1,400	170	2,200	8.3	5,600
	drum	0.099[d]	0.216													
Cha and Carter[f] (1982)	disc	0.746[e]	0.017	1.30	6.87	2.63	6.87	18.5	0.654	2,700	76	1,500	180	2,300	13	6,800
	drum	0.513[e,g]	0.017													

[a]Except as noted, assumes 1.2 stops/km.
[b]Emissions estimates were based on data in Table 2-4.
[c]Median values.
[d]Average values weighted by severity of braking mode. These values were assumed to be more accurate than the non-weighted averages, and are, therefore, the values used in the remainder of this report.
[e]These values are reported as they appear in the reference, they are not consistent with those derived from values noted in Table 2-2.
[f]Cha and Carter (1982) report average of 5.05 stops/mile (3.03 stops/km).
[g]Estimated by applying the ratio of airborne particulates emitted by disc brakes to that emitted by drum brakes determined by Williams and Muhlbaier (1982).

Example calculation, for light trucks. $[1.1\times10^{-3}$g/(drum brake) x (stop)] x (1.2 stops/km) x (2 drum brakes/axle) x (0.00031) x (5/light truck/axle) x (1×10^{6}ug/g) = 4.1 ug/veh/km. Note: Although the correct units for airborne asbestos emissions are ug/(vehicle x km), they are reported as ug/veh/km to be consistent with convention. The unitless emission factor (2.5 for light trucks) is based on the relative weights of friction material in truck and bus brakes as compared to that in car brakes (Jacko, DuCharme & Somers 1973). The product of this factor times the number of axles per vehicle results in the emission factor (in $(veh/axle)^{-1}$) given in Table 2-4 and the original reference (Jacko, DuCharme and Somers 1973) for each vehicle class.

Table 2-4 Input Data for Emissions Estimates

Vehicle class	Number[a]	Comment (source)	Average distance travelled[b] (km/yr)	Comment (source)	Brake configuration[c]	Emission factor[d] $(veh/axle)^{-1}$	Comment (source)
Passenger cars	132,108,164	1985 Registration figures (B. Baker*)	15,815	1985 Registration figures (B. Baker*)	2 Disc, 2 Drum	1	(Jacko, Ducharme, & Somers 1973)
Light truck	34,817,214	89.3% of the total number of trucks registered in 1982 fall into the "light" category (USDOC 1985b). The total number of trucks registered in 1985 was 38,989,042 (B. Baker*).	16,052	1984 Figures (USDOT 1986)	Drum	5	(Jacko, Ducharme, & Somers 1973)
Medium truck	1,364,616	3.5% of the total number of trucks registered in 1982 fall into the "medium" category (USDOC 1985b). The total number of trucks registered in 1985 was 38,989,042 (B. Baker*).	18,889	1985 Figures (B. Baker*)	Drum	13	(Jacko, Ducharme, & Somers 1973)
Heavy truck	2,768,222	7.1% of the total number of trucks registered in 1982 fall into the "heavy" category (USDOC 1985b). The total number of trucks registered in 1985 was 38,989,042 (B. Baker*).	44,210	1982 Figures. Weighted average of values given for light-heavy and heavy-heavy trucks (USDOC 1985b)	Drum	35	(Jacko, Ducharme, & Somers 1973)

Table 2-4 (continued)

Vehicle class	Number[a]	Comment (source)	Average distance travelled[b] (km/yr)	Comment (source)	Brake configuration[c]	Emission factor[d] (veh/axle)$^{-1}$	Comment (source)
Bus	593,527	1985 Registration figures (B. Baker*)	18,794	1985 Registration figures (B. Baker*)	Drum	13	(Jacko, Ducharme, & Somers 1973)
Motorcycle	5,444,404	1985 registration figures (B. Baker*)	3,547	1985 Registration figures (B. Baker*)	1 Disc, 1 Drum	1	Brake configuration for majority of motorcycles (Bloom**)

* Personal communication between C. Lewis (Versar Inc.) and B. Baker (Motor Vehicle Manufacturers Association (313) 872-4311). January 16, 1987.

**Personal communication between C. Lewis (Versar Inc.) and M. Bloom (Service Manager, Crossroads Cycle (703) 820-3711) January 16, 1987.

[a] In order to use the most up-to-date figures available, 1985 data were used for car, bus, motorcycle, and truck (total) vehicle classes. The number of trucks in each type category (light, medium, and heavy) was determined by using, as apportionment factors, the most up-to-date registration figures available for the truck categories of interest (1982 data).

[b] Data for average distance travelled by different vehicle classes were available from several sources. For cars, light and medium trucks, buses, and motorcycles, the values reported by different sources varied by less than 6 percent. For these classes (cars, medium trucks, buses, and motorcycles), the 1985 registration data were used when possible. Registration data for 1985 were not available for light or heavy trucks. For light trucks, data from three sources varied by three percent; 1984 USDOT data were used. For the category of heavy trucks, average mileage figures varied from 27,435 mi/yr (USDOC 1985b) to 61,031 miles/yr (USDOT 1986). The lower value is an average for light-heavy and heavy-heavy trucks weighted by the number of registrations in each class. In this category, truck classes were well-defined by the USDOC, and fit our 3-category classification, therefore, USDOC data were used.

[c] For light, medium, and heavy trucks, and buses, only the type of brake is of concern. It is assumed that, for these vehicle types, there are two brakes per axle, and the emission factor is applied to the per axle emissions.

[d] This factor is based on the relative weight of friction material in vehicle brakes and the average number of axles per vehicle within each vehicle class. The factors were given in Jacko, DuCharme, and Somers (1973) as shown, except that no units were assigned. The units were added for clarity

that 2.6 ug of asbestos is emitted to the air for each kilometer traveled by a typical car. Information is available in the published reports to refine this value. For instance, data are available on the differences in emissions between disc and drum brakes. Applying this differentiation, with the assumption that the vehicle has two disc and two drum brakes, decreases the estimated emissions to 1.9 ug/km. Additional analyses performed by the researchers employed 1977 vehicle registration and use statistics to estimate nationwide emissions. Updated statistics can be used to produce more realistic values. Results of this type of manipulation are presented in Table 2-2.

Jacko, DuCharme, and Somers (1973) designed, built, and installed collection devices on the disc and drum brakes and clutch assembly of an average automobile. The test car was then driven through predetermined cycles that were planned to test both normal and abusive brake wear. The emissions from each driving cycle were collected and analyzed for asbestos fibers with a transmission electron microscope. Therefore, knowledge of the mass of particulates emitted to the air, deposited on the ground, or entrained in the brake assembly for each driving cycle, as well as the asbestos content of these particulates, could be measured directly. These data, combined with information on the duration (in miles) of each driving cycle allowed calculation of the average airborne asbestos emissions for each type of driving.

The first entry noted for this study on Table 2-2 shows the range of airborne emissions and asbestos contents for all seven of the driving cycles. The airborne asbestos emissions determined from the arithmetic averages of the values in these ranges are artificially high because equal weight was given to all driving cycles.

The average values noted in the next entry eliminated this problem by weighting the different cycles by the severity factors described by the authors. Severity factors were only available for five of the seven

driving cycles; therefore, only the results from these five are used in this analysis. Using weighted averages to estimate the airborne asbestos emissions lowers the estimated value by more than a factor of two over the unweighted estimates.

Cha and Carter (1982) based their dynamometer studies of asbestos emissions from brakes on statistically determined representative braking cycles (RBCs). They then collected and directly measured the mass of the airborne particulates and analyzed the asbestos content with a transmission electron microscope. The authors then weighted the resulting figures by the frequency of occurrence of a particular RBC as determined by their statistical evaluation. As shown in Table 2-2, these weighted averages were used to estimate the airborne asbestos emissions. The analysis presented in the referenced report seemed to lack consistency, and is, therefore, not noted in this report. One assumption used by Cha and Carter is, however, incorporated into the emission estimates given in Table 2-2, i.e., that the ratio of airborne particulate emissions from disc brakes to that from drum brakes that was determined by Williams and Muhlbaier (1982) was also valid in the current study. Although Cha and Carter only tested disc brakes, this ratio allowed them to estimate values for drum brakes and calculate a per-vehicle figure consistent with the other reports.

The assumptions used in compiling Table 2-2 are: (1) each vehicle has four brakes, two disc and two drum, (2) average braking cycles include 1.2 stops/km (Jacko, DuCharme, and Somers 1973), (3) asbestos is emitted from brakes on automobiles, trucks, and buses, (4) there were 164 million vehicles in those categories in the U.S. in 1983 (USDOC 1985a), and (5) each vehicle averaged 10,000 miles of travel in 1983 (USDOC 1985a). It should be stressed that the emission estimates provided in Table 2-2 result from averaging the miles traveled by all vehicles, and by equating the emissions from trucks and buses with those

from cars. In addition, not all vehicle classes have two disc and two drum brakes, many have drum brakes only. Therefore, these assumptions misrepresent total asbestos emissions.

A better estimate of asbestos emissions resulting from vehicular brakes can be obtained by estimating and summing the individual contributions from automobiles, light, medium, and heavy trucks, buses, and motorcycles. Estimates of this type, based on data found in the three referenced studies, are provided in Table 2-3. The relative contributions from each vehicle type are determined, as in the method described for Jacko, DuCharme, and Somers (1973), by applying emission factors for each vehicle class to the estimated per axle automotive emissions. Although this method is based on imperfect emission factors, it should provide a more realistic estimate of asbestos emissions than those presented in Table 2-2.

In Table 2-3, whenever possible, the individual totals for cars, buses, and motorcycles are based on 1985 vehicle registrations and average distance travelled as shown in Table 2-4*. The total number of trucks in each weight category was determined by applying a distribution ratio derived from 1982 data (USDOC 1985b) to the 1985 number of trucks registered in the U.S.* The average distance traveled each year by trucks in the light and medium weight categories was taken from census data (USDOC 1985b), while that for the heavy weight category was obtained by weighting the average distance traveled by light-heavy and heavy-heavy (DOC classification) trucks, by the number of trucks reported in those categories (USDOC 1985b).

The estimated total airborne asbestos emissions for all vehicle types range from 5.6 to 10 metric tons per year.

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* Personal communication between C. Lewis (Versar, Inc.) and B. Baker (Motor Vehicle Manufacturers' Association (313) 872-4311) January 16, 1987.

2.2 Asbestos Emissions from 24 Cities

The portion of the national airborne asbestos emissions from vehicular brakes (shown in Table 2-3) originating in each of 24 United States cities was estimated with the aid of the National Emissions Data System (NEDS), average mileage figures, and census data. The method used for this estimation is described in the following section.

Twenty-four cities were chosen to represent small, medium, and large cities in all parts of the country. The 24 cities are identified in Table 2-5. As shown by this table, the cities studied range from 35 thousand people in Elmira, New York, to 3 million people in Los Angeles, California.

Once the cities were identified, it was necessary to determine the proper portion of the national emissions to be assigned to each city. For this effort, NEDS was used to provide data on the amount of fuel used by different vehicle classes within each county of concern in 1983. NEDS is maintained by EPAs Office of Air Quality Planning and Standards in Research Triangle Park, North Carolina. Data from NEDS are available as publications, complete printouts, and magnetic tape files. Additional data on the use of NEDS is available in "NEDS National Emissions Data System Information" (USEPA 1980).

The NEDS data were combined with 1983 average mileage data for each vehicle class to estimate the vehicle miles travelled by each vehicle class within the counties. In some cases, such as Denver, Colorado, and Napa, California, the city of concern corresponded to the county for which NEDS data were available. In other cases, however, the city of concern was within a larger county. In these cases, the vehicle mile data derived from NEDS for the county was decreased by a factor determined by population ratio between the city and the county.

Table 2-5. Cities for Which Concentrations Were Estimated

City	County	Population within city limits[a]
Large[b]		
Baltimore, MD	Baltimore	786,775
Chattanooga, TN	Hamilton	169,565
Denver, CO	Denver	492,365
Detroit, MI	Wayne	1,203,339
Houston, TX	Harris	1,595,138
Los Angeles, CA	Los Angeles	2,966,850
Miami, FL	Dade	346,865
Rochester, NY	Monroe	241,741
St. Louis, MO	St. Louis	453,085
Wichita, KS	Sedgewick	279,272
Medium[b]		
Boise, ID	Ada	102,451
Charleston, WV	Kanawha	63,968
Duluth, MN	St. Louis	92,811
Eugene, OR	Lane	105,625
Lincoln, NE	Lancaster	171,932
Montgomery, AL	Montgomery	176,387
Odessa, TX	Ector	90,027
Portland, ME	Cumberland	61,572
Small[b]		
Elmira, NY	Chemung	35,327
Napa, CA	Napa	50,879
Ocala, FL	Marion	37,170
Pine Bluff, AR	Jefferson	56,636
Rochester, MN	Olmstead	57,890
Santa Fe, NM	Santa Fe	48,953

[a]1983 figures (USDOC 1983).
[b]The city size classifications were based on the size of the entire standard metropolitan statistical area as reported in USDOC (1983).

Additional problems were encountered in that NEDS data classified vehicles into four distinct categories according to fuel consumption: (1) light duty gasoline vehicles, (2) light duty diesel vehicles, (3) heavy duty gasoline vehicles, and (4) heavy duty diesel vehicles. These categories did not correspond with those for which mileage estimates were available or with those chosen for the asbestos emissions estimates. Therefore, the amount of fuel (both gasoline and diesel) used by light vehicles was determined, and this total number was apportioned between cars and trucks based on the vehicle registration ratio. The resulting four categories, (1) cars, (2) light trucks, (3) heavy gasoline vehicles, and (4) heavy diesel vehicles, corresponded to those for which mileage figures were available. For the purpose of determining asbestos emissions, however, the distinction between gasoline- and diesel-powered heavy duty vehicles was not necessary because of the small number of heavy duty gasoline vehicles. Therefore, the vehicle mile data for the two categories was summed to provide a total value for heavy duty trucks. The three remaining categories - cars, light duty trucks, and heavy duty trucks - correspond to those categories for which asbestos emissions from brakes were highest (see Table 2-3). Therefore, the vehicle miles traveled by each vehicle class within each area of concern were determined.

This value was divided by the total vehicle miles travelled nationally and the resulting ratio was applied to the national asbestos vehicle emissions values (see Table 2-3) to estimate that portion of the national emissions that was contributed by each city of concern. The results of these manipulations are shown in Table 2-6. Each step of the calculation is detailed in Appendix A.

For comparison purposes, an alternate method was also used to estimate emissions within the city of Baltimore. In this alternate method, data available from the Regional Planning Council were used in conjunction with data obtained by the Maryland Air Management

Table 2-6. Estimated Car, Light Truck, Heavy Truck, and Combined Emissions for 24 Cities

City	Cars (g/sec)	Light trucks (g/sec)	Heavy trucks (g/sec)	Combined (g/sec)
Large				
Baltimore, MD	3.93×10^{-4}	1.85×10^{-4}	7.14×10^{-4}	1.29×10^{-3}
Chattanooga, TN	6.41×10^{-5}	3.02×10^{-5}	1.94×10^{-4}	2.88×10^{-4}
Denver, CO	2.81×10^{-4}	1.32×10^{-4}	4.75×10^{-4}	8.87×10^{-4}
Detroit, MI	3.36×10^{-4}	1.58×10^{-4}	5.98×10^{-4}	1.09×10^{-3}
Houston, TX	7.49×10^{-4}	3.52×10^{-4}	1.63×10^{-3}	2.73×10^{-3}
Los Angeles, CA	2.70×10^{-3}	1.27×10^{-3}	3.93×10^{-3}	7.90×10^{-3}
Miami, FL	1.29×10^{-4}	6.04×10^{-5}	1.64×10^{-4}	3.53×10^{-4}
Rochester, NY	8.25×10^{-5}	3.88×10^{-5}	8.27×10^{-5}	2.04×10^{-4}
St. Louis, MO	1.23×10^{-4}	5.80×10^{-5}	3.84×10^{-4}	5.65×10^{-4}
Wichita, KS	1.12×10^{-4}	5.24×10^{-5}	2.55×10^{-4}	2.43×10^{-4}
Baltimore, MD[a]	1.50×10^{-4}	3.77×10^{-5}	5.68×10^{-5}	2.43×10^{-4}
Medium				
Boise, ID	4.18×10^{-5}	1.96×10^{-5}	8.95×10^{-5}	1.51×10^{-4}
Charleston, WV	2.90×10^{-5}	1.36×10^{-5}	1.24×10^{-4}	1.67×10^{-4}
Duluth, MN	7.04×10^{-5}	3.31×10^{-5}	9.85×10^{-5}	2.02×10^{-4}
Eugene, OR	6.29×10^{-5}	2.96×10^{-5}	1.33×10^{-4}	2.25×10^{-4}
Lincoln, NE	5.81×10^{-5}	2.73×10^{-5}	1.16×10^{-4}	2.01×10^{-4}
Montgomery, AL	5.70×10^{-5}	2.68×10^{-5}	1.53×10^{-4}	2.37×10^{-4}
Odessa, TX	3.99×10^{-5}	1.88×10^{-5}	1.48×10^{-4}	2.06×10^{-4}
Portland, ME	4.76×10^{-5}	2.24×10^{-5}	9.14×10^{-5}	1.61×10^{-4}
Small				
Elmira, NY	1.80×10^{-5}	8.44×10^{-6}	1.83×10^{-5}	4.47×10^{-5}
Napa, CA	2.81×10^{-5}	1.32×10^{-5}	2.32×10^{-5}	6.45×10^{-5}
Ocala, FL	5.22×10^{-5}	2.45×10^{-5}	5.52×10^{-5}	1.32×10^{-4}
Pine Bluff, AR	2.63×10^{-5}	1.24×10^{-5}	4.69×10^{-5}	8.56×10^{-5}
Rochester, MN	3.23×10^{-5}	1.52×10^{-5}	4.14×10^{-5}	8.89×10^{-5}
Santa Fe, NM	3.42×10^{-5}	1.61×10^{-5}	3.64×10^{-5}	8.68×10^{-5}

[a]For this entry, emissions were determined by an alternate method. See text for an explanation of this method.

Administration from EPA's MOBIL3 model (USEPA 1984) to determine vehicle miles travelled within set area source grids. These grids were chosen according to population density and the shape of the city of Baltimore, and they correlate reasonably well with the outline of the city. These grids are illustrated in Figure 2-1. Emissions were then determined for the area source grids by applying emission factors based on the per-vehicle kilometer emissions values given in Table 2-3. This method of evaluating emissions takes driving patterns and speed into consideration.

2.3 Ambient Asbestos Concentrations Resulting from Vehicle Brakes

The ambient concentrations of asbestos in the air of each city were modeled based on specific meteorological conditions of each city. Because the ambient concentration is linear with respect to emissions, modeling was performed for each city based on an emission rate of 1 g/sec. The actual concentration was then determined by scaling this figure according to the emissions estimated for each city. This method allowed for flexibility in the emissions figures without requiring additional computer modeling. For instance, emissions from Baltimore were estimated by an alternate method as described in the previous section, and combined with the model results to derive a comparable concentration estimate.

The computer model used in this task was the Graphical Exposure Modeling System (GEMS) BOXMOD model. This model is accessed through the GEMS Atmospheric Modeling System (GAMS) (GSC 1986) maintained by EPA's Office of Toxic Substances. The BOXMOD model characterizes each city as a square surface from which pollutants are emitted into a box extending above the surface. The size of the square was estimated by assuming that the surface area covered by the city was configured in a perfect square. Ambient air pollutant concentrations in the box are a function of the amount of pollutants and the dispersive conditions within the box. The BOXMOD model assumes no transport of pollutants into the box and a uniform pollutant emission rate from the surface.

Solid line represents the actual outline of Baltimore City.

Broken line represents the area modeled by the alternate method.

Figure 2-1. Modeled area of Baltimore City.

For the purpose of this study, the model was run in a Gaussian mode whereby pollutant concentrations within the box are assumed to be normally distributed with highest concentrations occurring at the surface and decreasing rapidly with height. Summary meteorological data from the weather station nearest the particular city under study were used to simulate local dispersion conditions. Loss of pollutant-mass within the urban area because of dry deposition was negligible because of the small diameter of the asbestos fibers (virtually all fibers are less than 5 um, with 83 percent less than 0.375 um (Rohl et al. 1976)). Precipitation scavenging was close to zero with no loss attributable to chemical removal processes.

Ambient concentrations estimated by these methods are presented in Table 2-7. Ambient concentrations from brakes on all vehicle types range from 0.005 ng/m^3 in Lincoln, Nebraska, to a high of 0.258 ng/m^3 in Los Angeles, California.

The air concentration calculated for Baltimore by the alternate method is only 19 percent of the value estimated for Baltimore by the method used for the rest of the cities. This variance is caused by the difference in the estimated emissions. Because this alternate method is based on data generated by the State of Maryland specifically for Baltimore, it cannot be readily applied to other cities. If, however, analogous data were available and the alternate method applied, it would not be realistic to expect the resulting concentration estimates to vary in any consistent way with the concentrations estimated in this report. The variance would be expected to be random because there is no reason to expect that NEDS data would vary in any systematic way when compared to hypothetical state-generated data.

Estimated asbestos concentrations resulting from vehicular brakes for each of the 24 cities are illustrated in Figures 2-2, 2-3, and 2-4. Each figure depicts the ambient asbestos concentration for the cities within

Table 2-7. Estimated Annual Asbestos Concentrations from Vehicle Brakes in 24 American Cities

City	Cars (ng/m^3)	Light trucks (ng/m^3)	Heavy trucks (ng/m^3)	Combined vehicle brakes[a] (ng/m^3)
Large				
Baltimore, MD	0.064	0.030	0.116	0.209
Chattanooga, TN	0.007	0.003	0.022	0.033
Denver, CO	0.031	0.014	0.052	0.098
Detroit, MI	0.024	0.011	0.043	0.079
Houston, TX	0.017	0.008	0.036	0.061
Los Angeles, CA	0.088	0.041	0.128	0.258
Miami, FL	0.044	0.021	0.056	0.121
Rochester, NY	0.021	0.010	0.021	0.051
St. Louis, MO	0.020	0.009	0.062	0.092
Wichita, KS	0.011	0.005	0.025	0.041
Baltimore, MD[b]	0.024	0.006	0.009	0.039
Medium				
Boise, ID	0.009	0.004	0.019	0.031
Charleston, WV	0.018	0.008	0.077	0.104
Duluth, MN	0.010	0.005	0.014	0.029
Eugene, OR	0.022	0.010	0.047	0.078
Lincoln, NE	0.001	0.001	0.003	0.005
Montgomery, AL	0.006	0.003	0.017	0.026
Odessa, TX	0.014	0.007	0.052	0.072
Portland, ME	0.019	0.009	0.036	0.064
Small				
Elmira, NY	0.033	0.015	0.034	0.082
Napa, CA	0.018	0.008	0.015	0.041
Ocala, FL	0.025	0.012	0.026	0.063
Pine Bluff, AR	0.014	0.007	0.025	0.046
Rochester, MN	0.012	0.006	0.016	0.034
Santa Fe, NM	0.012	0.005	0.012	0.029

[a]This column represents the sum of the estimated concentrations from each category (cars, light trucks, and heavy trucks). The numbers in this column may not exactly total because of rounding.

[b]For this entry, emissions were determined by an alternate method. See text for an explanation of this method.

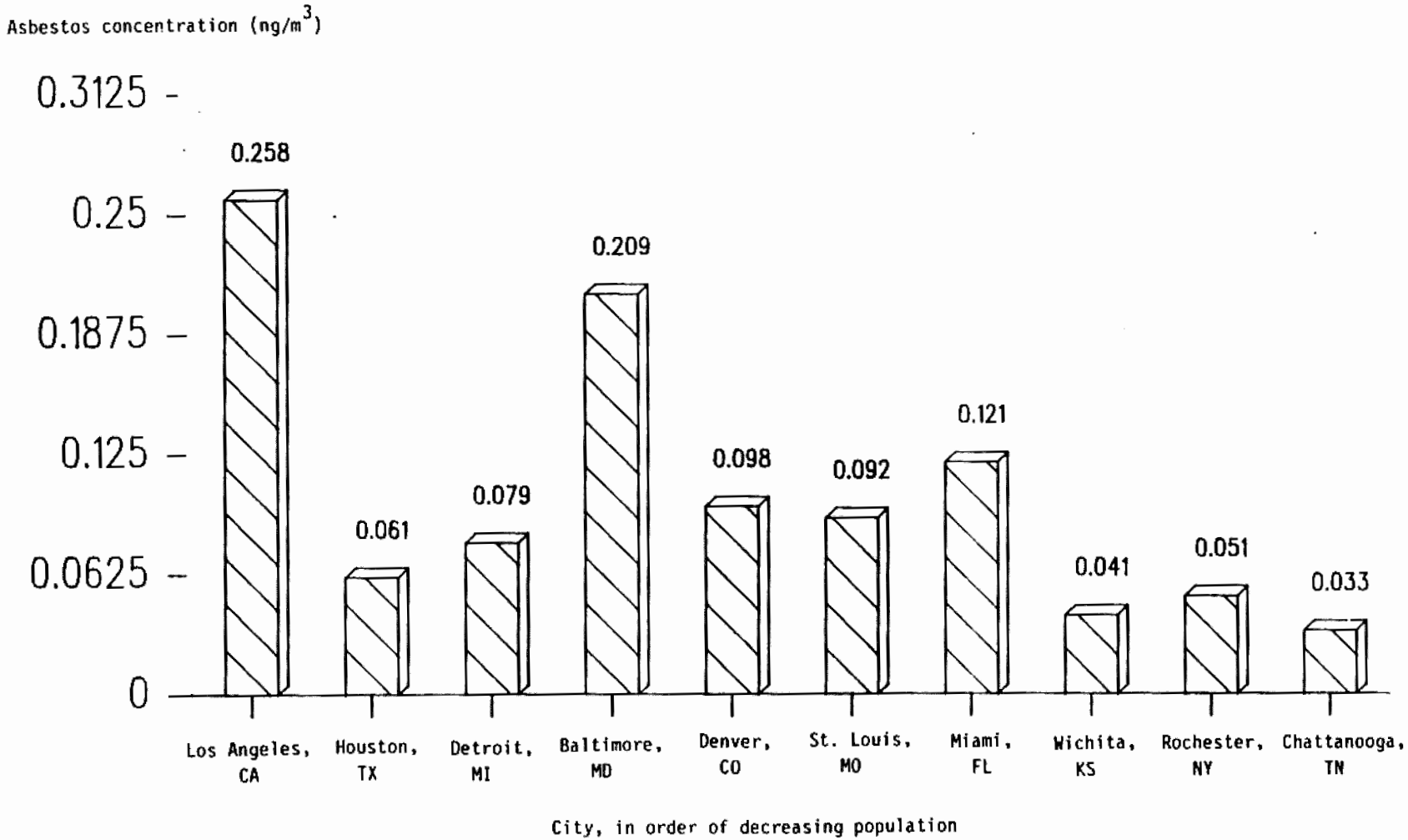

Figure 2-2. Estimated asbestos concentration in the air of 10 large cities resulting from vehicular brakes.

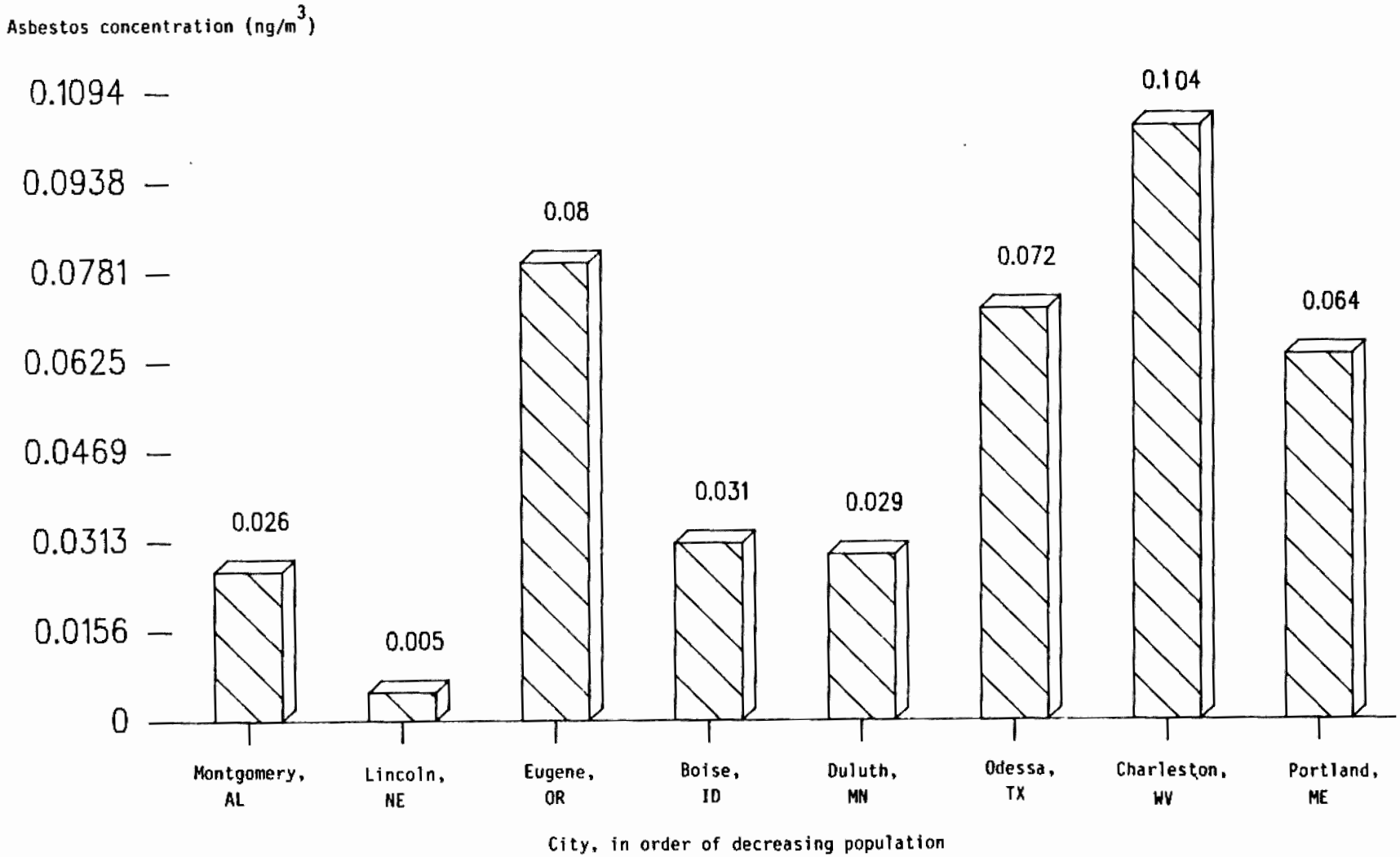

Figure 2-3. Estimated asbestos concentrations in the air of 8 medium-sized cities resulting from vehicular brakes.

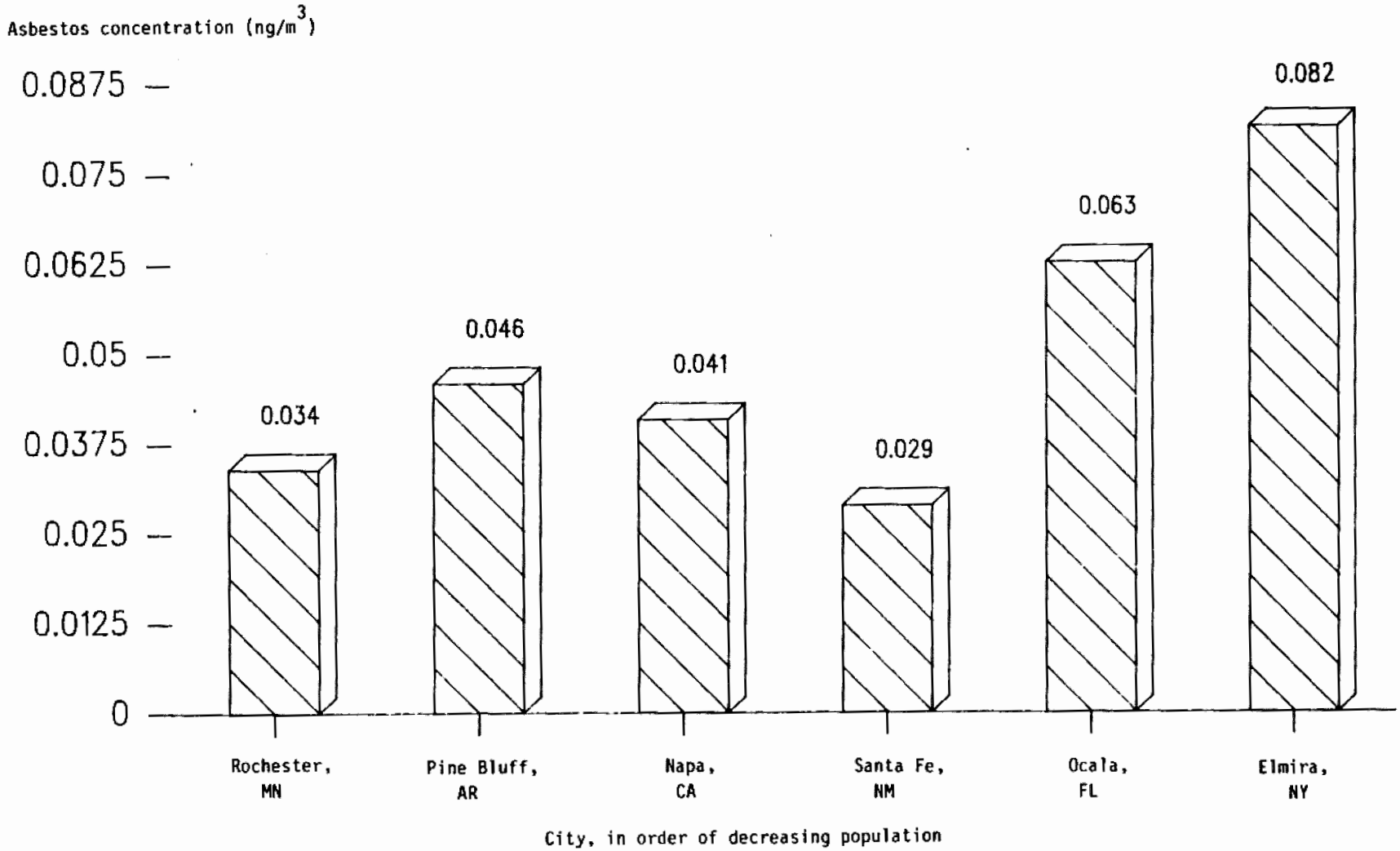

Figure 2-4. Estimated asbestos concentration in the air of 6 small cities resulting from vehicular brakes.

each size classification, in order of decreasing population. A general trend can be seen loosely correlating city size with asbestos concentration from vehicular brakes between large and small cities. However, a definite conclusion concerning the effect of population as a measure of ambient asbestos concentrations within a size category is not supported.

Figure 2-5 illustrates the relative contributions of each vehicle class to the total ambient concentration from vehicle brakes. The quantities shown in this figure were determined by averaging the asbestos concentrations from each vehicle class over all the cities studied. Figure 2-5 shows that, with more severe braking and higher asbestos emissions for each vehicle, the total contribution from heavy trucks is much higher than that from cars or light trucks. This distribution exists in spite of the fewer vehicle miles travelled in the cities by heavy trucks.

2.4 Average National Ambient Asbestos Concentration from Vehicle Brakes

This section details two methods for estimating national ambient asbestos concentrations from vehicle brakes. Both of these methods use dispersion modeling described in Section 2.3 for 24 U.S. cities. The first method provides bracketed worst- and best-case estimates of 0.087 ng/m^3 and 0.039 ng/m^3, respectively. The second method provides a best estimate of 0.057 ng/m^3.

2.4.1 Method 1: Population

Quick estimates of worst- and best-case national asbestos concentrations can be derived based on population. For both the worst and best cases, the cities for which modeling was conducted were grouped into six categories, according to their 1980 populations (USDOC 1983) and average ambient asbestos concentrations in each population category were obtained (Appendix A). For the worst-case estimate, it was assumed that rural areas with populations below 25,000 have the same ambient asbestos

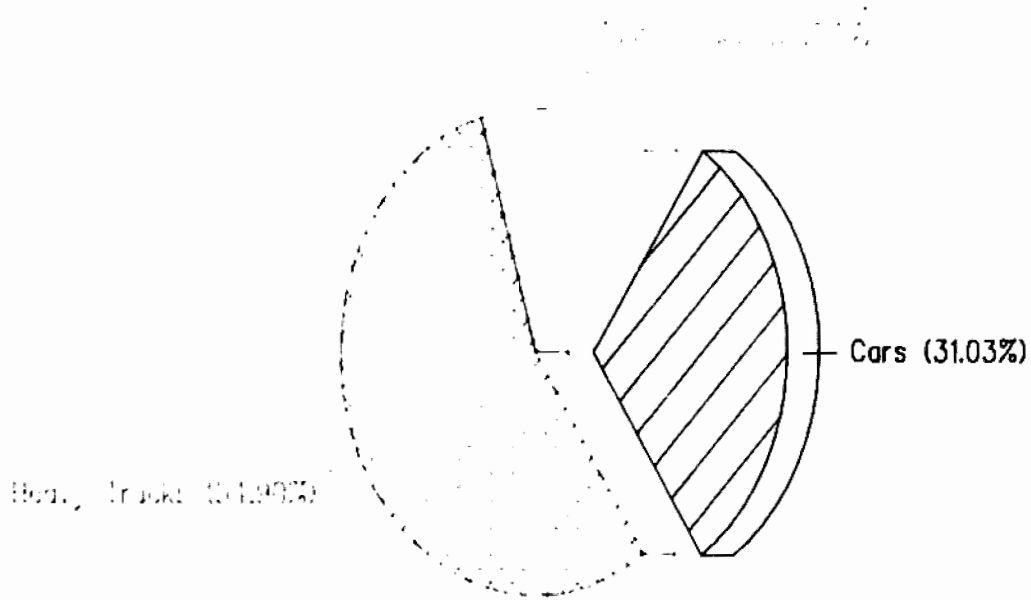

Figure 2-5. Average relative contribution to the total average asbestos concentration.

concentrations as do cities and towns with populations above 25,000. Conversely, for the best-case estimates, it was assumed that the rural areas with populations below 25,000 had no ambient asbestos from vehicle braking; therefore, the entire national average concentration was contributed by areas with more than 25,000 people.

For the worst-case estimate, the average concentrations were then weighted by the number of people in each category (in 1980) (USDOC 1985a). The weighting factor was derived by dividing the number of people in each category by the total number of people in the categories considered. This method, detailed in Table 2-8, results in a worst-case estimate of 0.0872 ng/m^3, by assuming that towns and rural areas of less than 25,000 population have the same average asbestos concentrations as those with greater than 25,000 population. In other words, the weighted average concentration estimated for the cities or towns with more than 25,000 people is assumed to hold for the rest of the country.

In reality, the rural areas have relatively less asbestos released to the atmosphere from vehicle brakes than do urban areas; therefore, a corresponding best-case value can be derived by assuming that the rural areas have no asbestos released from brakes. Because 55.5 percent of the population lives in areas with fewer than 25,000 people (USDOC 1985a), the worst-case asbestos level would be lowered by 44.5 percent, to 0.039 ng/m^3 as a best-case value.

The major advantage to this method is that it provides a bracketed estimate of national concentration. However, this method has three distinct disadvantages. First it relies heavily on the choice and number of cities within each population category. Because the cities were not chosen specifically for this type of categorization, they do not represent a statistically accurate sampling. In fact, for the 500,000 to 1,000,000 category, only one city is used to represent the entire category. This fact could shift the weighted averages significantly. Second, this method relies on the correlation between city population and

Table 2-8. Worksheet for Estimating National Ambient Asbestos Levels by a Population Correlation

Area size (population)	Total U.S. population in each category[a] (in thousands)	Area (city)	Concentration[b] (ng/m^3)	Percent of national population in cities >25,000 within each group	Weighted average concentration (ng/m^3)
>1,000,000	17,530	Detroit	0.079	17.4	0.023
		Houston	0.061		
		Los Angeles	0.258		
		Average	0.133		
500,000-1,000,000	10,834	Baltimore	0.209	10.8	0.023
250,000-500,000	12,158	Denver	0.098	12.1	0.011
		Miami	0.121		
		St. Louis	0.092		
		Wichita	0.041		
		Average	0.088		
100,000-250,000	17,015	Chattanooga	0.033	16.9	0.006
		Rochester, NY	0.051		
		Boise	0.031		
		Eugene	0.080		
		Lincoln	0.005		
		Montgomery	0.026		
		Average	0.038		
50,000-100,000	19,786	Charleston	0.104	19.6	0.011
		Duluth	0.029		
		Odessa	0.072		
		Portland	0.064		
		Pine Bluff	0.046		
		Rochester, MN	0.034		
		Napa	0.041		
		Average	0.056		
25,000-50,000	23,436	Elmira	0.082	23.2	0.013
		Ocala	0.063		
		Santa Fe	0.029		
		Average	0.058		
Total	100,759[c]			100	0.087

[a]USDOC (1985a).
[b]Versar (1987).
[c]This is the subpopulation total for areas with more than 25,000 people; the population in areas with less than than 25,000 people is 125,787,000. These figures are based on a total population of 226,546,000 persons in 1980 (USDOC 1985a)

ambient asbestos concentration from vehicle brakes. Although the data presented in this report show a general trend of decreasing concentration with city size, a definite correlation is not supported. Third, the national concentration is scaled up from city concentrations that were derived by scaling down national emissions. This indirect route in itself introduces uncertainty into the resulting estimate.

2.4.2 Method 2: National Emissions

The alternate method is based on ambient air modeling of 24 cities, in conjunction with the overall national asbestos emissions given in Table 2-3. This method has the advantage of using the emission rate as it was initially estimated (on a national level) rather than scaling a national estimate down to the city level (as in Section 2.2) and then scaling it back up to the national level.

Because the modeling was initially conducted for a unit emission rate of 1 g/sec, the final concentration figure for each city can be adjusted for estimated emission rates. The concentration based on unity emissions averaged over all the 24 cities modeled is 0.325 ug/m^3. Because the concentrations were modeled based on an area source of a given size, the average concentration over all 24 cities has to be scaled up to a national level. This scaling can be accomplished by multiplying the average concentration by the ratio of land area covered by the 24 cities to that within the contiguous U.S. as follows:

$$(0.325\ ug/m^3) \times (5{,}779\ km^2 \text{ in the 24 cities}^a)/(7{,}813{,}112\ km^2 \text{ in the U.S.}^b) \times (10^3\ ng/ug) = 0.240\ ng/m^3.$$

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[a] See Table A-1.
[b] Source: USDOC (1985a).

This figure, when multiplied by the average national asbestos emission rate for all vehicle classes of 0.237* g/sec yields an estimated national ambient asbestos concentration from vehicle brakes of 0.057 ng/m^3. As would be expected, this value falls within the range predicted by the previous method.

Although this value is based on modeling conducted for cities with populations over 25,000, it does not exclude the rural area of the country from consideration because national emissions estimates are used. The 24-city limitation only affects the modeling results, which are based on land area and meteorological conditions. The land area restriction has been accounted for by our scaling factors. Although the cities chosen for modeling were not selected to provide an accurate cross-section of meteorological conditions, a wide variety of conditions are accounted for. This method could be refined to account for differences in meteorology types, if data were available that showed the national land area covered by a given meteorology type, and classified the cities that were modeled by meteorology type; however, these data are not available.

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* Derived from averaging the total national emissions from all vehicle classes over all three studies, as shown in Table 2-3. This figure does not equal the combined national emissions shown in Appendix A because the Appendix A emissions are for three vehicle classes only: cars, light trucks, and heavy trucks. The total used here also includes buses, medium trucks, and motorcycles.

3. CONSUMER EXPOSURE TO ASBESTOS IN COATINGS, SEALANTS, AND PAINTS

The number of asbestos-containing coatings, sealants, and paints that are available to consumers has decreased dramatically since the mid-1970s. For example, spackle, dry wall joint compounds, caulking compounds, and paints are no longer manufactured with asbestos with the intent of selling directly to consumers (Anderson et al. 1982, Versar 1984). However, consumers can still legally purchase some of these products. The list of coatings, sealants, and paint products that still may contain asbestos is presented in Table 3-1. Not all of the products in these categories, however, are likely to contain asbestos.

Table 3-2 summarizes consumer exposure to asbestos in the six coatings and sealants product categories that still may contain asbestos. A brief discussion on the potential exposure to asbestos from each of these products is given below.

3.1 Roof Coatings

These are petroleum-based products that are composed of 5 to 30 percent asbestos. The asbestos is added to improve the strength, thermal resistance, and waterproofing properties of the coating (Anderson et al. 1982). According to product labels, roof coatings can be used on metal, composition, slate, and asphalt roofs. They are recommended for the general repair of leaks (in the roof itself and around chimneys, skylights, and gutters), although roof coatings may be applied as a protective seal over an entire roof, depending on the composition of the roof.

Essentially all exposure to asbestos in roof coatings is expected to occur when it is applied. Roof coatings are generally sprayed on, although they may be applied with a brush. Estimates of the consumer population that does roofing work vary widely, from 841,000 to 11,193,000 people (see Table 3-2). However, since not all consumers doing roof repair will be using roof coatings (e.g., shingle replacement) and not

Table 3-1. Coatings, Sealants, and Paints that May Contain Asbestos and be Used by Consumers

Product	Source
Roof coating	1,2
Waterproof coating	1
Corrosion resistant coating	1
Driveway sealant	2
Epoxy adhesive	2
Glazing compound	2

[1]Anderson et al. (1982).
[2]Tzanetos (1987).

Table 3-2. Consumer Exposure to Asbestos in Coatings, Sealants, and Paints

Subpopulation	Asbestos concentration (f/cm^3)	Fiber type	Breathing rate (m^3/hr)	Hr/yr	Frequency (years)	Number of persons exposed (thousands)[d]
Roof coatings	0.0 to 0.6[a]	Chrysotile	1.3	4[b]	3-5[c]	841 - 11,193[e]
Waterproof coatings	NA	Chrysotile	1.3	NA	NA	NA
Corrosion resistant coatings	NA	Chrysotile	1.3	NA	NA	NA
Driveway sealant	NA	NA	1.3	NA	NA	NA
Epoxy adhesive	NA	NA	1.3	0.011[f]	1/12[f]	27,770[g]
Glazing compound	NA	NA	1.3	NA	NA	NA

NA - not available.
[a]Spray application (Anderson et al. 1982).
[b]Versar estimate.
[c]Home Pro Systems, Inc. (1985). This corresponds to the time suggested to refinish metal roofs. It is also assumed to be the time interval when other types of roofs will need some type of repair.
[d]Unless otherwise stated, these data were reported as the number of households that participate in do-it-yourselfer activities (e.g., roofing repair). It was assumed that only one person would be directly exposed from each household.
[e]DIY Consumer Purchase Profile (Farnsworth and McKittrick 1984) reported 11,193,000 households do roof repair. The 1983 Consumer Attitude Survey, conducted by Leo J. Shapiro & Assoc. for National Home Center News (Farnsworth and McKittrick 1984), had the lowest estimate; it reported 0.9 percent of all U.S. households do roof repair. The total number of U.S. households was 93,519,000 in 1983 (Bureau of Census 1985), which implies that 841,000 households do roof repair. The 1983 Hardware Age Consumer DIY Study, conducted by Chilton Research Services (Farnsworth and McKittrick 1984), has a mid-range estimate. They estimated that 2 percent of the U.S. population is involved with roof repair. The total population in 1983 was 234,000,000 (USDOC 1985), which implies that 4,680,000 people did roof repairs.
[f]Versar (1986b).
[g]Versar (1985).

all roof coatings are likely to contain asbestos, the lower end of this range is more reasonable.

Once the coating has dried, essentially no releases are expected during normal use. This is because the asbestos should be securely bound to the petroleum-based product.

3.2 Waterproof/Corrosion Resistant Coatings

Both waterproof and corrosion resistant coatings are petroleum-based products. They are discussed together because of similar application practices and exposure potential.

According to product labels, both types of coatings are usually applied with a brush to a well-defined small area. Corrosion resistant coating will be applied outdoors, while waterproof coatings may be applied outdoors or indoors (e.g., basements, garages). Since these coatings are not likely to be severely agitated during application (like the spraying of roof coatings), the asbestos fibers in these products are expected to remain bound in the tacky petroleum base. After the petroleum base solidifies, essentially no asbestos releases are expected to occur during normal use.

3.3 Driveway Sealants/Epoxy Adhesives/Glazing Compounds

Tzanetos (1987) indicates that driveway sealants, epoxy adhesives, and glazing compounds contain asbestos, although this could not be confirmed from an independent shelf survey. Assuming that they do contain asbestos, however, exposure is expected to be limited by the wetted and viscous consistency of these products.

Driveway sealant is a petroleum-based product that is used to cover asphalt driveways to give the driveway a smooth and consistent appearance and to prevent moisture from seeping into the asphalt, which may cause damage as it freezes and thaws. Sealers also help prevent damage from oxidation, ultraviolet sunlight, and gas and oil spills. The sealant is applied from a standing position with a long-handled 36-inch squeegee.

Epoxy adhesives are usually two-part systems comprising a resin and a hardener which must be mixed by the consumer in equal parts. Epoxies are suitable for bonding almost any two materials together including wood, metals, ceramics, tiles, rigid plastics, pottery, and drywall. Epoxy adhesives will generally be used indoors for small repairs.

Glazing compound is a putty-like substance used to seal glass into wood windows. It is usually applied with a putty knife on the outdoor surface of the window. After the glazing compound has cured, it is painted for appearance and to prevent water from seeping under the glazing compound and contacting the wood frame.

No exposure data could be found to quantify asbestos releases from these products during application.

4. CONSUMER EXPOSURE TO ASBESTOS IN VINYL ASBESTOS FLOOR TILE

In 1976, the sales of floor materials represented about 15 percent of the total U.S. market for asbestos (Sebastien 1982). It is assumed that vinyl asbestos floor tile contains approximately 10 percent asbestos (Jenkins 1985), although it may contain as much as 20 percent (Dolan 1985). Consumer exposure to asbestos in the floor tiles can result from two mechanisms: (1) the removal of the floor tile by the consumer and (2) normal wearing of the tile that frees asbestos fibers. Inhalation exposure assessments for these two mechanisms follow and the results are presented in Table 4-1.

4.1 Removal of the Floor Tile by the Consumer

The physical requirements of sanding, scraping, or chipping asbestos floor tiles can result in significant concentrations of fibers in the air. Concentrations as high as 26,109 ng/m^3 have been reported for a single sample collected over 2 1/2 hours of post-removal air monitoring (Jenkins 1985). It is expected that the consumer would only remove floor tile containing asbestos once in his lifetime and would take four to eight hours to complete the task (Anderson et al. 1982). Because of the light activity involved in removing the tiles, an average adult inhalation rate of 1.3 m^3/hr is assumed (Versar 1986a).

4.2 Floor Tile Wear

Normal wear of vinyl floor tiles containing asbestos can result in asbestos air concentrations as high as 50 ng/m^3 (Dufour 1984). For the two following inhalation exposure estimates, concentrations of 25 ng/m^3 and 50 ng/m^3 were used for best estimate and worst case scenarios, respectively. It is assumed that the duration of each exposure event averages 8 hours/day over 350 days/year. For an average adult, an inhalation rate of 1.1 m^3/hr was used to reflect the breathing rate of a typical office worker. Based on these conditions, the inhalation exposure to asbestos was estimated.

Table 4-1. Inhalation Exposure to Asbestos from Vinyl Tile

Scenario	Best estimate	Worst case	Source
Removal of the tile by the consumer			
Asbestos concentration	26,109 ng/m^3 [a]	26,109 ng/m^3 [a]	Jenkins (1985)
Duration of exposure	4 hours	8 hours	Anderson et al. (1982)
Number of exposures	1 exposure/lifetime	1 exposure/lifetime	Versar estimate
Inhalation rate	1.3 m^3/hr	1.3 m^3/hr	Versar (1986a)
Asbestos in air resulting from floor tile wear			
Asbestos concentration	25 ng/m^3 [b]	50 ng/m^3 [b]	Dufour (1984)
Duration of exposure	8 hours/day	8 hours/day	Versar estimate[c]
Number of exposures	250 day/year,	250 day/year,	Versar estimate[c]
	40 years/lifetime	40 years/lifetime	Versar estimate[c]
Inhalation rate	1.1 m^3/hr	1.1 m^3/hr	Versar (1986a)

[a] Fiber type is chrysotile and 49.66 percent of the fibers were greater than 5 um.
[b] The mean fiber length was 0.63 um with a standard deviation of 0.20; all asbestos was chrysotile.
[c] This assumption is based on a typical office worker.

5. CONSUMER EXPOSURE DURING BRAKE REPAIR

This section discusses consumer exposure to asbestos that occurs during do-it-yourself (DIY) brake repair. It is organized into three sections: (1) exposed population, (2) consumer vs. occupational exposure, and (3) exposure calculation.

5.1 Exposed Population

Although exposure to consumers during do-it-yourself brake repair has not been carefully analyzed, a surprisingly large population installs its own brakes. According to SMRB (1982), 13,186,000 consumers are estimated to install brakes in cars or small trucks (9,132,000 people who actually purchased the brakes plus 4,054,000 people who are members of the purchaser's household). This survey was based on a time frame of one year (1981), and thus it only presents a partial population of consumers who install their own brakes. In reality, brakes in cars and small trucks are estimated to require repair (replacement) approximately once every three years (this assumes that brakes are typically changed when vehicles travel between 25,000 and 30,000 miles*; USDOC (1985) estimates that the average car travels between 9,830 and 9,976 miles per year). Therefore, the population cited in this survey would not be expected to purchase or install brakes in the two subsequent years (1982 and 1983); however, it can be assumed that two more populations, each of which is equal in size to the 1981 estimate, would install brakes in both 1982 and 1983. In 1984, the same consumers identified in the survey would be expected to replace the brakes that they installed in 1981. Consequently, the total number of consumers who install brakes is estimated to be 39,558,000 (13,186,000 different consumers each year, for three years); their frequency of exposure is once every three years.

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* Personal communication between Clay Carpenter, Versar Inc., and Dan Turner of the American Automobile Association on January 28, 1987.

These data have been confirmed by an independent source. The 1983 home and auto DIY study, which is a survey conducted by Home and Auto Magazine, reported that 64.9 percent of the survey population performed drum brake overhauls and that 61.2 percent of the survey population performed disc brake overhauls (Farnsworth and McKittrick 1984). This survey was designed to estimate how many people routinely did a certain event (e.g., install their own brakes), rather than estimating how many people did something in a given time slice (e.g., in the last year). The survey population comprised customers of automotive and home repair stores and auto department and discount store chains. The automobile do-it-yourself population is estimated to be between 60 and 65 million people.* Assuming that approximately 63 percent of this survey population does their own brake repair, this corresponds to between 37,800,000 and 40,950,000 people. Again, it is assumed that this population has a frequency of exposure of once every three years.

5.2 Consumer vs. Occupational Exposure

Consumer exposure during brake repair would differ from occupational brake repair because of three important factors: (1) consumers do not have a standard place to perform auto repairs; in some cases, the repairs would occur in an enclosed garage, but in most cases they would occur outdoors, (2) consumers would not have available the professional equipment found in repair shops, (3) consumers have limited experience, and thus the time required to make repairs would be longer, and (4) consumers are unlikely to perform more than one brake job per year. More information on these factors and recommendations for developing exposure estimates follow:

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* Personal communication between Jim Konz of Versar Inc. and Richard Weinberg, editor of Home and Auto Magazine, on June 27, 1985.

1. Consumers would perform brake repair either in a garage or outdoors. According to 1983 data from the Bureau of the Census, 38,821,000 of the 54,724,000 owner-occupied housing units in the U.S. have garages or carports.* This distinction between garages and carports is important because carports are not enclosed and thus would not contain the released asbestos fibers in the consumer's work area. No data are available that differentiate between the number of garages and carports. An estimate can be made, however, based on the year the structure was built. The data and assumptions used to estimate the number of owner-occupied housing units with garages are presented in Table 5-1. It was estimated that approximately 54 percent of the owner-occupied housing has a garage available. No data could be found on the number of renter-occupied housing units that have garages or carports. However, data on garages can be estimated based on the total number of renter-occupied structures in the U.S. (29,914,000 units). The estimated number of rental units with garages is derived in Table 5-2. It was estimated that only 20 percent of renter-occupied housing will have garages, compared to 54 percent of owner-occupied housing. Of the 91,675,000 housing units in the country, 35,634,000 or 39 percent are estimated to have garages available for brake repair.

2. A typical consumer would not have access to the professional equipment used in a repair shop. This professional equipment can lower exposures (e.g., high-efficiency particulate air vacuum system) or increase brake repair exposures (e.g., compressed air). It is expected that consumers would only have the mechanical tools necessary to remove the wheel casing, brake components, etc. and equipment such as a brush or a household vacuum cleaner to remove loose brake dust.

   The removal of the worn brake pad and loose dust will result in the highest levels of exposure. Fiber air sample results for brake assembly clear-off methods have been reported in Roberts and Zumwalde (1982). For dry brush cleaning, the asbestos concentration varies from 0.61 f/cc (21-minute sampling time) to 0.81 f/cc (12-minute sampling time). It is not expected that the consumer would wet the brush before cleaning. Another source (Rodelsperger et al. 1986) reported fiber concentrations for dry brushing of 0.09 f/cc. This was based on personal sampling for 30 minutes or more and it only included fibers with lengths

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* Personal communication between Clay Carpenter, Versar Inc., and Dick Cranston, Bureau of the Census, on January 13, 1987.

Table 5-1. Estimated Number of Garages in Owner-Occupied Housing

Date structure built	Number of total units[a] (millions)	Estimated number of units with garages or carports[b] (millions)	Estimated number of units with garages[c] (millions)
April 1970 or later	14,534	10,300	5,200
1965 to March 1970	5,929	4,200	2,100
1960 to 1964	5,493	3,900	1,900
1950 to 1959	10,243	7,300	7,300
1940 to 1949	4,918	3,500	3,500
1939 or earlier	13,607	9,700	9,700
TOTAL	54,724	38,900[d]	29,700

[a]Bureau of Census (1985).

[b]This assumes an even distribution, over time, of the number of units with garages or carports.

[c]It is assumed that structures built before 1960, which are identified as having a garage or carport, actually have garages. Structures built in 1960 or later were assumed to have 50 percent carports and 50 percent garages.

[d]The actual number of housing units with garages or carports in 1983 was 38,821,000; the number in the table is higher because of rounding.

Table 5-2. Estimated Number of Garages Associated with Renter-Occupied Housing

Units in structure	Number of total units[a] (millions)	Estimated percent with garages (%)	Estimated number with garages (millions)
1, detached	8,127	54[b]	4,400
1, attached	1,441	27[c]	400
2 to 4	7,797	13[d]	1,000
5 to 9	3,636	6[e]	200
10 to 19	3,165	0[f]	0
20 to 49	2,173	0[f]	0
50 or more	2,811	0[f]	0
Mobile home or trailer	763	0[f]	0
TOTAL	29,913		6,000

[a]Bureau of Census (1985).
[b]Assumed the same percent as owner-occupied, since the vast majority of owner-occupied units are detached.
[c]Assumed one-half of the estimated percent of garages for 1, detached.
[d]Assumed one-half of the estimated percent of garages for 1, attached.
[e]Assumed one-half of the estimated percent of garages for 2 to 4 units in structure.
[f]Assumed that essentially no garages would be associated with structures with a large number of units or with mobile homes or trailers.

greater than 5 um. Finally, a study conducted in Finland found concentrations ranging from 0.3 to 0.6 f/cc for the opening and brushing of drum brakes. This was based on four samples from two workplaces with sampling times ranging from 2 to 13 minutes (Kauppinen and Korhonen 1987).

For vacuum cleaning, Roberts and Zumwalde (1982) report concentrations varying from 0.00 f/cc to 0.07 f/cc (sample time - 2 minutes). Another study, using wet and dry shop vacuums, found asbestos concentrations ranging from 0.0 to 2.1 f/cc (sample time - 1 minute), with most concentrations 0.2 f/cc or less (Lemmons n.d.). These data, however, are not directly applicable to consumer brake repair because the typical filter in a house vacuum cleaner cannot collect the fine asbestos fibers found in brake dust (USEPA 1986). Therefore, it is likely that concentrations resulting from consumer vacuum cleaning will approach, if not surpass, those found with dry brushing. It is assumed that the peak concentrations found during brake repair from assembly clean off are 0.61 to 0.81 f/cc, with an average of 0.71 f/cc.

3. According to information reported in Bragg (1986), a full-time professional brake mechanic can perform a replacement and repair job in about 1.6 hours. It is not realistic to expect that a consumer, who does brake repair approximately once every three years, would be able to do this task as quickly. It is assumed that a consumer doing brake repairs may take up to twice as long as a professional brake mechanic or 3.2 hours.

5.3 Estimated Exposure

The only exposure pathway expected during brake repair is inhalation. Exposure is expected to vary depending on the different phases of the brake work that is being done by the consumer, and the exposure estimates were organized accordingly. Two key phases are expected: (1) the high, short duration, exposure levels that occur during cleaning of the residual brake dust and (2) lower levels of a longer duration that occur when asbestos emissions mix with the surrounding air. Both of these exposure components are discussed below.

(1) Dust Cleaning Exposure - Loose asbestos dust accumulates in the brake housing and the consumer will probably remove it by dry brushing. Exposure estimates for this operation are presented in Table 5-3. These

Table 5-3. Estimated Consumer Exposure from Brake Dust Brushing

Parameter	Data	Source
Concentration	0.71 f/cc	Roberts and Zumwalde (1982)
Fiber type	Chrysotile	Versar (1984)
Fiber size	>5 um	Roberts and Zumwalde (1982)
Breathing rate	1.3 m^3/hr	Versar (1986a)
Hours/day	0.3[a]	Versar estimate
Days per three years	~1	Versar estimate
Number of persons exposed	39,558,000	SMRB (1982)
Exposures/lifetime	10[b]	Versar estimate

[a]This corresponds to approximately 17 minutes, which is the average sampling time for dry brushing reported in Roberts and Zumwalde (1982).

[b]It is assumed exposure will occur once every three years over 30 years (ages 20 to 50); therefore, the actual lifetime exposure frequency is 10.

estimates correspond to only 9 percent (0.3 hours) of the entire exposure period. This timeframe was selected because it was the average sampling period reported in Roberts and Zumwalde (1982) for dry brushing.

(2) Low Level Exposure - A consumer doing brake repair will be exposed to low (secondary) levels of asbestos after the releases from dust cleaning mix with the surrounding air. The exposure level will be highly dependent on where the brake repair takes place. If the repair occurs in a garage, the asbestos concentrations could approach those found in a commercial brake repair shop; however, if the repair occurs outdoors, secondary levels of asbestos should approach ambient levels. It was assumed that people who had a garage available would use it for repairing brakes; all other consumers are assumed to perform this work outdoors. The population that repair brakes was assumed to be evenly distributed across the entire U.S. population with respect to garage ownership. Secondary exposure levels for brake repair in garages are expected to occur over a 2.4 hour period. This is assuming that the first one-half hour results in no asbestos releases (i.e., during the removal of the tire, mounting bolts, etc.) and that the high levels from brushing occur in the next 17 minutes (0.3 hours). Based on a total work time of 3.2 hours, this leaves 2.4 hours for secondary exposure to occur. Secondary exposure levels were estimated to be 0.035 f/cm^3 (the derivation of the estimated secondary exposure levels is presented in Appendix B). The estimated exposure to secondary levels of asbestos likely to occur outdoors during brake repair was estimated to be negligible compared to the time-weighted average (TWA) for dust cleaning. Therefore, only dust cleaning is assumed to contribute to asbestos exposure during outdoor brake repair. A summary of the estimated consumer exposures from brake repair is presented in Table 5-4.

Table 5-4. Estimated Consumer Exposure During Brake Repair[a]

Location	Concentration (f/cc)	Hours/ day	Breathing rate (m^3/hr)	Days per three years	Number of persons exposed	Exposures/ lifetime[b]
Brake repair in a garage						
Exposure from brake dusting	0.71	0.3	1.3	1	15,428,000	10
Secondary exposure	0.035	2.4	1.3	1	15,428,000	10
Brake repair outdoors						
Exposure from brake dusting	0.71	0.3	1.3	1	24,130,000	10
Secondary exposure	-0	2.4	1.3	1	24,130,000	10

[a]All asbestos is chrysotile and the fiber size is greater than 5 μm.

[b]It is assumed that exposure will occur once every three years over 30 years; therefore, the actual lifetime exposure frequency is 10.

6. OTHER CONSUMER EXPOSURES

Tzanetos (1987) presents a list of consumer products containing asbestos. The major product categories still thought to contain asbestos are listed in Table 6-1.

Some of the product categories listed in Table 6-1 have already been covered in this report. Exposure estimates for two other product categories, millboard and cement sheet, were presented in USCPSC (1986). Estimated asbestos exposures for millboard being installed with hand and power tools ranged from 0.044 to 8.0 f/cc-hr averaged over an entire house and from 0.29 to 51 f/cc-hr in a closed room where the millboard was being installed. For cement sheet, exposures were estimated assuming that the sheet was installed using of an abrasive wheel saw and a drill or a toothed saw and a drill. Exposures ranged from 2.0 to 9.6 f/cc-hr averaged over an entire house and 13 to 62 f/cc-hr in a closed room where the sheet was being installed. Populations exposed to millboard during installation were not estimated because limited information was available and because it could not be confirmed if consumers can still purchase this product.

Of the remaining product categories listed in Table 6-1, roofing felt was considered to be one of the most likely categories to result in significant consumer exposure. This is because it may release asbestos when cut and because a large number of consumers are involved in roof replacements and repairs. Additional information on the other product categories could not be found. A discussion of the potential for exposure to roofing felt follows.

Roofing felt, or tar paper, is a sheet material that is generally supplied in three-foot wide rolls. It can be used as a base material for several types of common roofs or it can be used as a layering material in built-up roofs (built-up roofs are generally composed of three to five layers of tar paper and bitumen). Roofing felt is rolled onto the

Table 6-1. Consumer Product Categories Thought to Contain Asbestos

Asbestos product category	Examples
Millboard	Wallboard, garage paneling
Beater-add gaskets	Pumps, lawn mowers
High-grade electrical paper	Electrical insulation
Roofing felt	Roofing felt
Asbestos-cement flat sheet	Ovens, safes/vaults
Asbestos-cement shingle	House siding
Braking materials	Disc brake pads, brake blocks
Asbestos cloth	Wood burning stove door seals
Asbestos thread, yarn, etc.	Wicks, mantels, stove seals
Sheet gaskets	Boilers, internal-combustion engines
Packing	Internal-combustion engines, pumps
Roof coatings	Roof coating
Non-roofing adhesives, sealants, and coatings	Driveway sealant, epoxy adhesive, glazing compound
Asbestos-reinforced plastic	Skillets, toasters, automobiles
Sealant tape	Automobiles

Source: Tzanetos (1987).

surface of the roof, cut, and nailed or stapled into place. Roofing cement is used in some cases to seal the edges or areas adjacent to ducts or vents.

No asbestos-containing roofing felt was found during a shelf survey, only fiber glass-reinforced products. Furthermore, if asbestos is contained in some roofing felt, the asbestos would be tightly held in the tar matrix, and this material is always covered with some other material. The most likely time for exposure to occur would be when roofing felt is cut to fit the roof. No data were available to estimate this exposure level.

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APPENDIX A

Determination of Ambient Asbestos Concentrations from Vehicle Brakes

NOTES TO APPENDIX A

Appendix A contains the worksheet that was developed by Versar to estimate the ambient asbestos concentration in 24 U.S. cities resulting from vehicle brakes. This worksheet was developed on a personal computer equipped with spreadsheet software.

The method used to arrive at the estimated concentrations is described, in general, in the text and, in detail, in the footnotes to each column in the worksheet. Bases for the input data listed in the table in the lower right-hand corner of the first worksheet page are discussed in these notes.

Fractions of gas used by cars and trucks: The total quantity of gas used by light-duty gasoline-powered vehicles (from NEDS) was apportioned between cars and light trucks based on the number of vehicles registered in each class as shown in Table 2-4.

Mileage: The mileage values that are used by USEPA in estimating emissions included in, and reported by, NEDS (USEPA 1980) were used here. It is expected that current figures would be higher than those used here because of recent trends toward higher mileage vehicles; however, because the reported values are still used in NEDS, they are also used in these calculations.

Total distance travelled by each group: For cars and light trucks, this value was determined by multiplying the number of vehicles in each class by the average distance traveled per vehicle per year as reported in Table 2-4. However, this method was not used for the cateogry of heavy trucks because of the large differences in the average distance travelled by heavy trucks as reported in various sources (see footnote (b) to Table 2-4). To lessen the chance of propagating any errors in this value, the

total annual distance travelled by heavy trucks was taken directly from a report by the Motor Vehicle Manufacturers Association (MVMA 1986). Note that the value taken directly from MVMA (1986) corresponds well with that which would be derived from data in Table 2-4 (1.18×10^{11} km from MVMA (1986), 1.22×10^{11} km derived from Table 2-4), indicating a good possibility that the figure reported in Table 2-4 is correct.

Average national emissions: Total airborne asbestos emissions from vehicular brakes (in kg/yr) for cars, light trucks, and heavy trucks from 3 studies are reported in Table 2-3. These values were averaged over the three studies, and the average value converted to units of g/sec. The average values that were used in this worksheet were based on actual values obtained before any rounding took place (values reported in Table 2-3 have been rounded to two significant figures). The averages that were used are:

Cars:	2,800 kg/yr
Light trucks:	1,753 kg/yr
Heavy trucks:	2,655 kg/yr

For example, for light trucks:

$$(1753 \text{ kg/yr}) \times (10^3 \text{ g/kg}) \times (1 \text{ yr}/365 \text{ days}) \times (1 \text{ day}/24 \text{ hr}) \times (1 \text{ hr}/3600 \text{ s}) = 0.05559 \text{ g/s}.$$

Table A-1. Ambient Asbestos Levels Resulting from Vehicular Brakes - Worksheet

Column Designator (1)			A	B	C	D	E	F	G	H	I	J
	AREA	COUNTY	SOURCE LAND AREA (km2)(2)	SOURCE DIMEN (km)(2)	CITY POP (2)	COUNTY POP(3)	GAS USED BY LIGHT GAS VEHICLES (GAL)(4)	GAS USED BY CARS (GAL)(5)	GAS USED BY LT. TRUCKS (GAL)(6)	GAS USED BY HEAVY GAS TRUCKS (GAL)(4)	FUEL USED BY HEAVY DIESEL TRUCKS (GAL)(4)	MILES BY CARS (MILES)(7)
Large												
	1 Baltimore, MD	Baltimore Co	208	14	786775	786775	4.3140E+08	3.4124E+08	9.0163E+07	3.4266E+07	7.8568E+07	5.75E+09
	2 Chattanooga, TN	Hamilton	320	18	169565	259049	1.0755E+08	8.5071E+07	2.2478E+07	9.9340E+06	3.6185E+07	1.43E+09
	3 Denver, CO	Denver	286	17	492365	492365	3.0798E+08	2.4361E+08	6.4368E+07	2.2471E+07	5.2494E+07	4.10E+09
	4 Detroit, MI	Wayne	351	19	1203339	2282598	6.9371E+08	5.5347E+08	1.4624E+08	6.1052E+07	1.1919E+08	9.33E+09
	5 Houston, TX	Harris	1440	38	1595138	2315809	1.1936E+09	9.4410E+08	2.4945E+08	1.0153E+08	2.7045E+08	1.59E+10
	6 Los Angeles, CA	Los Angeles	1204	35	2966850	2966850	2.9652E+09	2.3455E+09	6.1973E+08	2.1746E+08	4.0787E+08	3.95E+10
	7 Miami, FL	Dade	88.8	9.4	346865	1608159	6.5408E+08	5.1737E+08	1.3670E+08	4.9208E+07	7.3235E+07	8.72E+09
	8 Rochester, NY	Monroe	88.5	9.4	241741	606070	2.2693E+08	1.7955E+08	4.7441E+07	1.4006E+07	1.9391E+07	3.03E+09
	9 St. Louis, MO	St. Louis	159	13	453085	453085	1.3543E+08	1.0713E+08	2.8305E+07	8.1510E+06	5.0935E+07	1.81E+09
	10 Wichita, KS	Sedgewick	262	16	279272	305752	1.3400E+08	1.0599E+08	2.8005E+07	7.9440E+06	3.5412E+07	1.79E+09
Medium												
	11 Boise, ID	Ada	102	10	102451	134848	6.0371E+07	4.7753E+07	1.2618E+07	5.6780E+06	1.2955E+07	8.05E+08
	12 Charleston, WV	Kanawha	72.5	8.5	63968	151451	7.5334E+07	5.9583E+07	1.5745E+07	2.8232E+07	2.0380E+07	1.00E+09
	13 Duluth, MN	St. Louis	174	13	92811	102434	8.5284E+07	6.7460E+07	1.7824E+07	6.2250E+06	1.1112E+07	1.14E+09
	14 Eugene, OR	Lane	84	9.2	105625	182495	1.1924E+08	9.4322E+07	2.4922E+07	6.8540E+06	2.8742E+07	1.53E+09
	15 Lincoln, NE	Lancaster	155	12	171932	173550	6.4390E+07	5.0932E+07	1.3458E+07	5.6300E+06	1.2758E+07	8.58E+08
	16 Montgomery, AL	Montgomery	332	18	176387	177607	6.3037E+07	4.9862E+07	1.3175E+07	3.9030E+06	1.4790E+07	8.40E+08
	17 Odessa, TX	Ector	76	8.7	90027	100957	4.9121E+07	3.8855E+07	1.0266E+07	8.7500E+06	1.7565E+07	6.55E+08
	18 Portland, ME	Cumberland	60.6	7.8	61572	107099	9.0943E+07	7.1936E+07	1.9007E+07	5.7940E+06	1.9058E+07	1.21E+09
Small												
	19 Elmira, NY	Chemung	18.4	4.3	35327	68227	3.8059E+07	3.0105E+07	7.9543E+06	2.3320E+06	3.2910E+06	5.07E+08
	20 Napa, CA	Napa	41.7	6.5	50879	59227	3.5845E+07	2.8353E+07	7.4916E+06	1.9010E+06	2.4640E+06	4.78E+08
	21 Ocala, FL	Marion	69.6	8.3	37170	50860	7.8346E+07	6.1972E+07	1.6374E+07	4.4850E+06	7.5840E+06	1.04E+09
	22 Pine Bluff, AR	Jefferson	55.9	7.5	56636	62817	3.1997E+07	2.5310E+07	6.6874E+06	2.7840E+06	5.4910E+06	4.26E+08
	23 Rochester, MN	Olmstead	49	7	57890	60473	3.6985E+07	2.9255E+07	7.7299E+06	2.6190E+06	4.3080E+06	4.93E+08
	24 Santa Fe, NM	Santa Fe	81.5	9	48953	52042	3.9860E+07	3.1529E+07	8.3307E+06	1.7160E+06	4.3780E+06	5.31E+08
	Baltimore, MD*	na	208	14	786775	786775						

* For this entry, the emissions were determined by an alternate method. See Section 2.2 for an explanation of the method.

(1) The column designator is used to identify the columns within the equations used for this determination.

(2) USDOC. 1983.

(3) USDOC. 1984.

(4) NEDS.

(5) E = 0.791

(6) E = 0.209

(7) F = 16.85 miles/gal

AREA SOURCE EMISSIONS DATA USED THROUGHOUT THIS WORKSHEET

FRACTION OF GAS USED BY CARS:	0.791
FRACTION OF GAS USED BY TRUCKS:	0.209
MILEAGE (USEPA 1980)	
CARS (MPG):	16.85
LIGHT TRUCKS (MPG):	12.81
HEAVY GAS TRUCKS (MPG):	4.83
HEAVY DIESEL TRUCKS (MPG):	5.78

TOTAL DISTANCE TRAVELED BY EACH GROUP, NATIONALLY	
CARS(KM) (FROM TABLE 2-4):	2.09E+12
LT TRUCKS(KM) (FROM TABLE 2-4):	5.53E+11
HEAVY TRUCKS(KM) (MVMA 1986):	1.18E+11
ALL(KM):	2.77E+12
AVERAGE NATIONAL EMISSIONS (G/SEC)	
CAR:	0.08877
LT TRUCK:	0.05553
HEAVY TRUCK:	0.08420
ALL:	0.22858

Table A-1. (Continued)

Column Designator (1)	K	L	M	N	O	P	Q	R	S	T
AREA	MILES BY LT. TRUCKS (MILES)(8)	MILES BY HEAVY GAS TRUCKS (MILES)(9)	MILES BY HEAVY DIESEL TRUCKS (MILES)(10)	TOTAL MILES (MILES)(11)	TOTAL DISTANCE (KM)(12)	EST AREA EMISS. CARS (g/sec)(13)	EST AREA EMISS LT. TRUCKS (g/s)(14)	EST AREA EMISS HEAVY TKS (g/s)(15)	EST AREA EMISS ALL(g/s)(16)	CONC BASED ON UNITY EMISS (ug/m3)(17)
Large										
1 Baltimore, MD	1.15E+09	1.68E+08	4.54E+08	7.53E+09	1.21E+10	3.93E-04	1.85E-04	7.14E-04	1.29E-03	1.62E-01
2 Chattanooga, TN	2.88E+08	4.86E+07	2.09E+08	1.30E+09	2.08E+09	6.41E-05	3.02E-05	1.94E-04	2.88E-04	1.15E-01
3 Denver, CO	8.25E+08	1.10E+08	3.03E+08	5.34E+09	8.60E+09	2.81E-04	1.32E-04	4.75E-04	8.87E-04	1.10E-01
4 Detroit, MI	1.87E+09	2.99E+08	6.89E+08	6.42E+09	1.03E+10	3.36E-04	1.58E-04	5.98E-04	1.09E-03	7.28E-02
5 Houston, TX	3.20E+09	4.96E+08	1.56E+09	1.46E+10	2.35E+10	7.49E-04	3.52E-04	1.63E-03	2.73E-03	2.23E-02
6 Los Angeles, CA	7.94E+09	1.06E+09	2.36E+09	5.09E+10	8.19E+10	2.70E-03	1.27E-03	3.93E-03	7.90E-03	3.27E-02
7 Miami, FL	1.75E+09	2.41E+08	4.23E+08	2.40E+09	3.86E+09	1.29E-04	6.04E-05	1.64E-04	3.53E-04	3.43E-01
8 Rochester, NY	6.08E+08	6.85E+07	1.12E+08	1.52E+09	2.45E+09	8.25E-05	3.88E-05	8.27E-05	2.04E-04	2.52E-01
9 St. Louis, MO	3.63E+08	3.99E+07	2.94E+08	2.50E+09	4.03E+09	1.23E-04	5.80E-05	3.84E-04	5.65E-04	1.62E-01
10 Wichita, KS	3.59E+08	3.88E+07	2.05E+08	2.18E+09	3.51E+09	1.12E-04	5.24E-05	2.55E-04	4.19E-04	9.74E-02
Medium										
11 Boise, ID	1.62E+08	2.78E+07	7.49E+07	8.12E+08	1.31E+09	4.18E-05	1.96E-05	8.95E-05	1.51E-04	2.08E-01
12 Charleston, WV	2.02E+08	1.38E+08	1.18E+08	6.17E+08	9.93E+08	2.90E-05	1.36E-05	1.24E-04	1.67E-04	6.25E-01
13 Duluth, MN	2.28E+08	3.04E+07	6.42E+07	1.32E+09	2.13E+09	7.04E-05	3.31E-05	9.85E-05	2.02E-04	1.43E-01
14 Eugene, OR	3.19E+08	3.35E+07	1.66E+08	1.22E+09	1.96E+09	6.29E-05	2.96E-05	1.33E-04	2.25E-04	3.55E-01
15 Lincoln, NE	1.72E+08	2.78E+07	7.37E+07	1.12E+09	1.80E+09	5.81E-05	2.73E-05	1.16E-04	2.01E-04	2.41E-02
16 Montgomery, AL	1.69E+08	4.84E+07	8.55E+07	1.14E+09	1.83E+09	5.70E-05	2.68E-05	1.53E-04	2.37E-04	1.11E-01
17 Odessa, TX	1.32E+08	4.28E+07	1.02E+08	8.30E+08	1.34E+09	3.99E-05	1.88E-05	1.48E-04	2.06E-04	3.51E-01
18 Portland, ME	2.43E+08	2.83E+07	1.10E+08	9.16E+08	1.47E+09	4.76E-05	2.24E-05	9.14E-05	1.61E-04	3.97E-01
Small										
19 Elmira, NY	1.02E+08	1.17E+07	1.90E+07	3.31E+08	5.33E+08	1.80E-05	8.44E-06	1.83E-05	4.47E-05	1.84E+00
20 Napa, CA	9.60E+07	9.30E+06	1.42E+07	5.13E+08	8.26E+08	2.81E-05	1.32E-05	2.32E-05	6.45E-05	6.34E-01
21 Ocala, FL	2.10E+08	2.19E+07	4.38E+07	9.65E+08	1.55E+09	5.22E-05	2.45E-05	5.52E-05	1.32E-04	4.78E-01
22 Pine Bluff, AR	8.57E+07	1.36E+07	3.17E+07	5.03E+08	8.09E+08	2.63E-05	1.24E-05	4.69E-05	8.56E-05	5.42E-01
23 Rochester, MN	9.90E+07	1.28E+07	2.49E+07	6.03E+08	9.70E+08	3.23E-05	1.52E-05	4.14E-05	8.89E-05	3.84E-01
24 Santa Fe, NM	1.07E+08	8.39E+06	2.53E+07	6.32E+08	1.02E+09	3.42E-05	1.61E-05	3.64E-05	8.66E-05	3.41E-01
Baltimore, MD*						1.50E-04	3.77E-05	5.68E-05	2.43E-04	1.62E-01

* For this entry, the emissions were determined by an alternate method. See Section 2.2 for an explanation of the method.

(8) G = 12.81 miles/gal

(9) H = 4.89 miles/gal

(10) I = 5.78 miles/gal

(11) (J + K + L + M) = (C/D)

(12) N = 1.609 km/mile

(13) (0.08879 = J = 1.609 / 2.09E+12) = (C/D)

(14) (0.05559 = K = 1.609 / 5.59E+11) = (C/D)

(15) (0.0842 = (L + M) = 1.609 / 1.18E+11) = (C/D)

(16) 1.609 = (C/D) = ((J = 0.08879/2.09E+12) + (K = 0.05559/5.59E+11) + ((L + M) = 0.0842/1.18E+11))

(17) Results of BOIMOD modeling.

Table A-1. (Continued)

Column Designator (1)	U	V	W	X	Y	Z	AA	AB
AREA	CONCENTRATION CARS (ug/m3)(18)	CONC. LIGHT TRUCKS (ug/m3)(19)	CONC. HEAVY TRUCKS (ug/m3)(20)	COMBINED CONC (ug/m3)(21)	CONCENTRATION CARS (ng/m3)(22)	CONC. LIGHT TRUCKS (ng/m3)(23)	CONC. HEAVY TRUCKS (ng/m3)(24)	COMBINED CONC. (ng/m3)(25)
Large								
1 Baltimore, MD	6.37E-05	2.99E-05	1.16E-04	2.09E-04	0.0637	0.0299	0.1156	0.2092
2 Chattanooga, TN	7.38E-06	3.47E-06	2.23E-05	3.31E-05	0.0074	0.0035	0.0223	0.0331
3 Denver, CO	3.09E-05	1.45E-05	5.22E-05	9.76E-05	0.0309	0.0145	0.0522	0.0976
4 Detroit, MI	2.45E-05	1.15E-05	4.35E-05	7.95E-05	0.0245	0.0115	0.0435	0.0795
5 Houston, TX	1.67E-05	7.85E-06	3.63E-05	6.09E-05	0.0167	0.0079	0.0363	0.0609
6 Los Angeles, CA	8.83E-05	4.15E-05	1.28E-04	2.58E-04	0.0883	0.0415	0.1284	0.2583
7 Miami, FL	4.41E-05	2.07E-05	5.64E-05	1.21E-04	0.0441	0.0207	0.0564	0.1212
8 Rochester, NY	2.08E-05	9.77E-06	2.08E-05	5.14E-05	0.0208	0.0098	0.0208	0.0514
9 St. Louis, MO	2.00E-05	9.40E-06	6.22E-05	9.16E-05	0.0200	0.0094	0.0622	0.0916
10 Wichita, KS	1.09E-05	5.11E-06	2.49E-05	4.08E-05	0.0109	0.0051	0.0249	0.0408
Medium								
11 Boise, ID	8.69E-06	4.09E-06	1.86E-05	3.14E-05	0.0087	0.0041	0.0186	0.0314
12 Charleston, WV	1.81E-05	8.52E-06	7.75E-05	1.04E-04	0.0181	0.0085	0.0775	0.1042
13 Duluth, MN	1.01E-05	4.73E-06	1.41E-05	2.89E-05	0.0101	0.0047	0.0141	0.0289
14 Eugene, OR	2.23E-05	1.05E-05	4.71E-05	7.99E-05	0.0223	0.0105	0.0471	0.0799
15 Lincoln, NE	1.40E-06	6.59E-07	2.78E-06	4.84E-06	0.0014	0.0007	0.0028	0.0048
16 Montgomery, AL	6.33E-06	2.98E-06	1.69E-05	2.63E-05	0.0063	0.0030	0.0169	0.0263
17 Odessa, TX	1.40E-05	6.59E-06	5.19E-05	7.25E-05	0.0140	0.0066	0.0519	0.0725
18 Portland, ME	1.89E-05	8.89E-06	3.63E-05	6.41E-05	0.0189	0.0089	0.0363	0.0641
Small								
19 Elmira, NY	3.30E-05	1.55E-05	3.36E-05	8.22E-05	0.0330	0.0155	0.0336	0.0822
20 Napa, CA	1.78E-05	8.36E-06	1.47E-05	4.09E-05	0.0178	0.0084	0.0147	0.0409
21 Ocala, FL	2.49E-05	1.17E-05	2.64E-05	6.30E-05	0.0249	0.0117	0.0264	0.0630
22 Pine Bluff, AR	1.42E-05	6.70E-06	2.54E-05	4.64E-05	0.0142	0.0067	0.0254	0.0464
23 Rochester, MN	1.24E-05	5.82E-06	1.59E-05	3.41E-05	0.0124	0.0058	0.0159	0.0341
24 Santa Fe, NM	1.16E-05	5.48E-06	1.24E-05	2.95E-05	0.0116	0.0055	0.0124	0.0295
Baltimore, MD*	2.43E-05	6.11E-06	9.20E-06	3.94E-05	0.0243	0.0061	0.0092	0.0394

* For this entry, the emissions were determined by an alternate method. See Section 2.2 for an explanation of the method.

(18) T x P

(19) T x Q

(20) T x R

(21) T x S

(22) U x 1000 ng/ug

(23) V x 1000 ng/ug

(24) W x 1000 ng/ug

(25) X x 1000 ng/ug

APPENDIX B

Secondary Concentrations of Asbestos in a Garage Occurring from Brake Repair

Appendix B

Secondary Concentrations of Asbestos in a Garage Occurring from Brake Repair

The purpose of this appendix is to estimate the asbestos concentration in a garage resulting from dust cleaning. From the brake dust cleaning scenario in the text, dust cleaning was assumed to take place for 0.3 hours, resulting in an asbestos concentration of 0.71 f/cc near this operation. If it is assumed that this concentration is contained in a 5 m^3 volume around the consumer, the number of released asbestos fibers in the garage after 0.3 hours is as follows:

$$0.71\ f/cm^3 \times 1 \times 10^6\ cm^3/m^3 \times 5\ m^3 = 3.6 \times 10^6\ f$$

Based on a typical one-car garage volume of 60 m^3 (Jennings et al. 1985), the average concentration throughout the entire garage is 3.6×10^6 f/60 m^3 or 5.9×10^4 f/m^3. The average concentration would decrease at this time since no additional releases are expected and because fresh air will exchange with the contaminated air in the garage.

The following equation was used to estimate the average asbestos concentration in the garage for the remaining 2.4 hours that the consumer will require to finish the brake job:

$$C_{avg}\ (t_1 - t_o) = \frac{-CoV}{mQ}\ e^{-m(Q/V)t}\Big|_{t_o}^{t}$$

where

C_{avg} = Average concentration over the period
t_1 = Length of exposure = 2.4 hours
t_o = Assume start of exposure = 0
C_o = Initial concentration = 5.9×10^4 /m^3
m = Mixing factor = 0.5 (Jennings et al. 1985)
Q = Ventilation flow rate = 60 m^3/hr
(For 1 air exchange/hour, which is typical from Jennings et al. 1985)
V = Garage volume = 60 m^3 (Jennings et al. 1985)

This equation is from Jennings et al. (1985) and it is for estimation of gaseous contaminant concentration in an indoor environment. It is assumed that the asbestos particles (<5 um), which will be released during brake dusting, are so fine that they will behave in a manner similar to gases. Substituting into the above equation:

$$C_{avg}\ (2.4 - 0) = \frac{-\dfrac{5.9 \times 10^4\ f/m^3 \times 60\ m^3}{0.5 \times 60\ m^3} \times e^{-0.5\ \frac{60\ m^3/hr}{60\ m^3} \times 2.4} + \dfrac{5.9 \times 10^4\ f/m^3 \times 60\ m^3}{0.5 \times 60\ m^3} \times e^{-0.5\ \frac{60\ m^3/hr}{60\ m^3} \times 0.0}}{2.4 - 0}$$

$$= \frac{(-1.2 \times 10^5 \times 0.30) + (1.2 \times 10^5 \times 1.0)}{2.4}$$

$$= 3.5 \times 10^4\ f/m^3 \text{ or } 0.035\ f/cm^3$$