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CHARACTERIZATION OF ASBESTOS EMISSIONS FROM BRAKES

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by

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ABSTRACT

Particulate emissions from disc and drum brakes were collected and analyzed for asbestos content. Although the original brake lining is about 50% asbestos, the emitted particles average only 0.029% asbestos. The remaining fibers are broken down from thermal and abrasive wear during the braking process. The median length of the asbestos fibers emitted is 0.5 micrometers compared to the original brake fibers which are in the millimeter size range. Increased asbestos emissions occur at higher wheel velocities and deceleration rates. Average automobile emission rates are 2.2 micrograms of airborne asbestos per brake application. The amount of asbestos emitted from brakes is extremely small compared to other asbestos sources. Samples downwind of freeways do not show significant increases over upwind asbestos levels. Reported asbestos levels for tollbooth areas are shown to be consistent with the asbestos emission measurements made in this study.

INTRODUCTION

The major component of the lining used in brakes is chrysotile asbestos, comprising 40 to 60% of the final product. Approximately 46-million kilograms of asbestos are used in brake linings annually compared to the total U.S. asbestos consumption of 730-million kilograms.[1,2] During the braking process, the potential exists for asbestos release to the air or roadway.

Asbestos levels have caused concern since the early 1900's when the chronic lung impairment, asbestosis, was diagnosed in workers exposed to asbestos.[3] Mesothelomia, a rare type of tumor made of pleural or peritoneal cells is also associated almost exclusively with asbestos. Cancers of the lungs, larynx, and digestive system have all been linked to asbestos exposure although a latency period exists of up to 40 years.

The Occupational Safety and Health Administration has set a time-weighted average work standard of two fibers longer than 5 micrometers per cubic centimeter of air as measured by optical microscopy. Standards as low as 0.5 fibers/cm^3 have been discussed but there are no immediate implementation plans. Although this is an indication of the amount of asbestos present, as much as 98% of the fibers from common asbestos sources are too small to be seen optically.[4]

Chrysotile asbestos is a hydrated magnesium silicate, $Mg_3Si_2O_5(OH)_4$, which dehydroxylates around 810°C so that very little of the free asbestos is expected to survive the high temperatures at the brake-rotor interface. However, asbestos from brake linings has been suggested as one source of the high incidence of lung cancer in urban areas.[5] One study indicated that 2 to 15% of the brake emissions consist of asbestos,[1] but two other studies have shown that nearly all of the asbestos in the original lining decomposed to nonfibrous forms.[5,6] Jacko and DuCharme determined that only 0.23% of the brake particulate is asbestos.[6] This would mean that over 99% of the original asbestos is degraded during thermal and abrasive stress caused during braking. On the other hand, asbestos has been found near roadways and in ambient samples taken near tollbooths.[7,8]

A brake-testing facility was constructed to help resolve the conflicting reports of airborne asbestos emissions from brakes. Brake emissions were collected in simulations of the normal range of driving conditions and particulate samples were analyzed for asbestos content. The significance of brake emissions will be considered on the basis of the contribution of brakes to ambient asbestos levels.

EXPERIMENTAL

A brake-wear test facility was designed for generation and collection of brake emissions. Design of the facility and operational details of particulate collection have been described previously.[9,10] Nuclepore or Millipore filters were used for asbestos collection and analysis. These were analyzed by optical and electron microscopy.

Optical measurements were made using the standard OSHA procedure for counting fibers greater than 5 micrometers in length. Using a phase-contrast technique at a magnification of 400X, 1/10 000th of the total filter area is scanned.

Because asbestos fibers occur in a very wide size range, it seems appropriate to consider mass concentration in addition to fiber counts. In order to make such calculations for the optical measurements we assumed that regardless of length each fiber had a diameter of 0.25 micrometer and a density of 2.56 g/cm^3.

Electron microscopy was necessary for counting and sizing the smaller fibers. Transmission electron microscopy was found to be preferable to scanning electron microscopy. A transmission electron micrograph of a brake fiber is shown in Fig. 1. The method used for counting and sizing fibers consisted of the following steps:

1. A section of the Nuclepore or Millipore filter is ashed in a low-temperature asher to remove organic material.
2. A methanol/water mixture is added to the residue and this is placed in an ultrasonic nebulizer to disperse the fibers.
3. The solution is filtered onto a 47-mm, 0.2-micrometer-pore Nuclepore filter.
4. The filter is carbon-coated and placed upside down on 3 TEM grids in a petri dish containing chloroform to dissolve the filter.
5. Two of the three grids are observed with a TEM at a magnification of 20 000X. Ten grid holes in each grid are counted and sized for asbestos fibers. If the fiber identity is uncertain, a selected-area electron diffraction pattern is taken for positive identification.
6. From the volume of the fibers and the density of asbestos, the mass of asbestos is calculated. The repeatability between the two grids averages 32%.

A study of electron microscopy methods for characterizing airborne asbestos has been conducted for use by the Environmental Protection Agency.[11] Their optimum method is the same as the one used here except the ashing, ultrasonification, and refiltration steps were eliminated. The ashing procedure was found to give increased fiber count and decreased fiber length which could be due to either breakup of fibers or reduced interference in detection of fibers. For our samples, the ashing procedure seemed to be a necessary step for the removal of interfering material. The EPA study showed a laboratory intercomparison to give a precision of chrysotile mass concentration of 22% for lab samples, 44% for field samples with ashing, and 54% for field samples without ashing. The ashing step improved the precision of the method, probably due to the removal of interferences.

Figure 1. Transmission Electron Micrograph of Brake Debris Showing Asbestos Fiber (40 000 X).

RESULTS

Asbestos Content of Airborne Brake Emissions

Twenty-four asbestos analyses were made on particulate emissions from drum brakes and 23 from disc brakes. The mass measured by TEM and optical microscopy are both shown in Table I. There are large uncertainties involved in the optical microscopy mass due to the paucity of large fibers. Typically, only 0, 1, or 2 fibers were visible in the counting area. However, these few fibers have an enormous effect on the mass when extrapolated to the area of the entire filter. For instance, a single 10-micrometer fiber would approximately double the mass as determined with the TEM.

Table I. Asbestos Emissions from Brakes

Test	Velocity	Deceleration	Mass Particulate	Mass Asbestos TEM	Mass Asbestos Optical	% Asbestos
	km/h	m/s^2	μg	ng	ng	
Disc Brakes						
26B	40	1.8	88	3.5	-[a]	0.0040
28	40	4.9	443	62	ND[b]	0.014[c]
29B	40	4.9	109	3.7	-	0.0033
14B	64	1.2	609	9.7	-	0.016
17B	64	1.8	622	57	-	0.0093
32	64	1.8	73	3.1	-	0.0042
34B	64	1.8	430	4.1	-	0.00095
37	64	1.8	98	180	-	0.18
6	64	2.5	82	13	75	0.11
7	64	2.5	2985	85	ND	0.0028[c]
8A	64	2.5	60	14	-	0.024
8B	64	2.5	734	130	-	0.017
9	64	4.9	99	11	44	0.056
10	64	4.9	2817	76	ND	0.0026[c]
11A	64	4.9	85	29	13	0.049
11B	64	4.9	399	8.4	-	0.0021
2	65	0.2	111	8.5	19	0.025
3	65	0.2	381	12	-	0.0032
4	65	0.3	141	11	62	0.052
5	65	0.6	364	26	44	0.019
22	88	1.8	452	38	-	0.0085
36	88	1.8	341	14	-	0.0041
41	88	1.8	498	13	-	0.0027

(continued on next page)

Table I. (continued from previous page)

Test	Velocity	Decelera-tion	Mass Particulate	Mass Asbestos TEM	Mass Asbestos Optical	% Asbestos
	km/h	m/s^2	µg	ng	ng	
Drum Brakes						
59	40	1.8	310	14	-	0.0046
60B	40	1.8	104	26	-	0.025
70M	40	2.5	247	18	7.5	0.0075
51	40	4.9	283	79	75	0.054
52	40	4.9	354	16	125	0.040
53B	40	4.9	214	13	13	0.067
62	40	4.9	89	12	75	0.098
49	64	1.2	373	20	-	0.0055
50B	64	1.2	231	19	-	0.0081
56	64	1.8	431	6.7	25	0.0074
57B	64	1.8	335	5.0	110	0.034
43	64	1.8	590	42	-	0.0072
44B	64	1.8	412	2.9	19	0.0053
46	64	2.5	619	17	-	0.0028
47B	64	2.5	427	8.8	31	0.0093
63	64	4.9	121	6.5	99	0.087
64	64	4.9	337	13	19	0.0095
64M	64	4.9	428	23	-	0.0055
65B	64	4.9	269	5.4	-	0.0020
66	88	1.8	98	3.5	38	0.042
67M	88	1.8	315	13	-	0.0040
68AM	88	1.8	134	71	190	0.19
68BM	88	1.8	422	10	13	0.0055
69M	88	1.8	373	10	47	0.015

[a] No optical fibers visible in counting area.

[b] ND: No determination made.

[c] Asbestos percentage based on electron microscopy count only.

The average number and mass of small and large fibers per filter are shown in Table II. The small fibers greatly outnumber the large fibers by about 300 to 1. However, the mass is evenly divided between the small and large fibers. There are about 90 000 total fibers/ng of asbestos. This is similar to Thompson's findings of 10^5 fibers/ng.[12]

Table II. Comparison of Small and Large Asbestos Fibers[a]

	Disc	Drum
Small fibers/filter	3.4×10^6	3.4×10^6
Mass small fibers (ng)	12	19
Small fibers/ng	2.9×10^5	1.8×10^5
Large fibers/filter	0.7×10^4	1.5×10^4
Mass large fibers (ng)	17	37
Large fibers/ng	430	405
Small/large fibers	460	230
Small/large Mass	0.68	0.51
Total fibers/ng	119 000	61 000

[a] Small fibers are less than 5 micrometers in length
Large fibers are more than 5 micrometers in length

The average asbestos content in the emitted airborne particulate from drum brakes ranged from 0.0020 to 0.19% mass, with an average of 0.031%. The disc brake values ranged from 0.00095 to 0.18%, with an average of 0.027%. These values are similar to those found by Anderson et al.[13] (0.002%) and by Jacko and DuCharme (0.23%),[6] but are much lower than values of 2 to 15% reported by Rohl et al.[1] However, Rohl et al. based their results on x-ray diffraction which is not selective enough to distinguish between chrysotile asbestos and similar minerals. The x-ray diffraction method was rejected by other laboratories who have measured asbestos emissions from brakes.[6] Assuming an initial asbestos content of 50% in the brake lining, our numbers indicate that 99.95% of the asbestos has been degraded to nonfibrous forms. There appears to be no significant difference between the asbestos content of particles from disc and drum brakes. This is somewhat surprising, since higher temperatures are reached in disc brakes and more asbestos breakdown would be predicted. Compared to the airborne emissions, the material which is entrained in the wheel or settles to the roadway has a slightly higher asbestos content of 0.041%.

The median length of the airborne asbestos fibers is 0.48 micrometer compared to the original brake fibers which are of the order of a millimeter in length. The asbestos that settles to the roadway or becomes entrained in the wheel is slightly longer, with a median length of 0.60 micrometer.

Velocity and Deceleration Effects

The brake tests were run at three different velocities (40-, 64-, and 88-km/h) and four different decelerations (1.2-, 1.8-, 2.5-, and 4.9-m/s^2). The percent asbestos and mass of airborne asbestos per stop are shown in Figures 2 and 3 for various velocities and decelerations. Due to statistical problems involved with counting large fibers, the figures are based only on the small fiber mass. Therefore, the values shown are lower than the final asbestos concentrations and are meant only to indicate trends. From Figure 2, there appears to be no obvious trend in the asbestos content with increasing velocity or deceleration. However, there appear to be trends with total mass of asbestos emitted, as shown in Figure 3. As the velocity or deceleration increases, the mass of asbestos emitted increases as do all other brake emissions.[10] This is similar to Jacko and DuCharme's conclusion[6] that heavier braking does not produce a higher percentage asbestos in the emitted material.

Total Asbestos Emissions

Approximately 3.3 mg/stop of particles are emitted from a disc brake which can be broken down into 55% airborne material, 12% roadway, and 34% wheel-entrained.[10] Assuming an average asbestos content of 0.030% in airborne

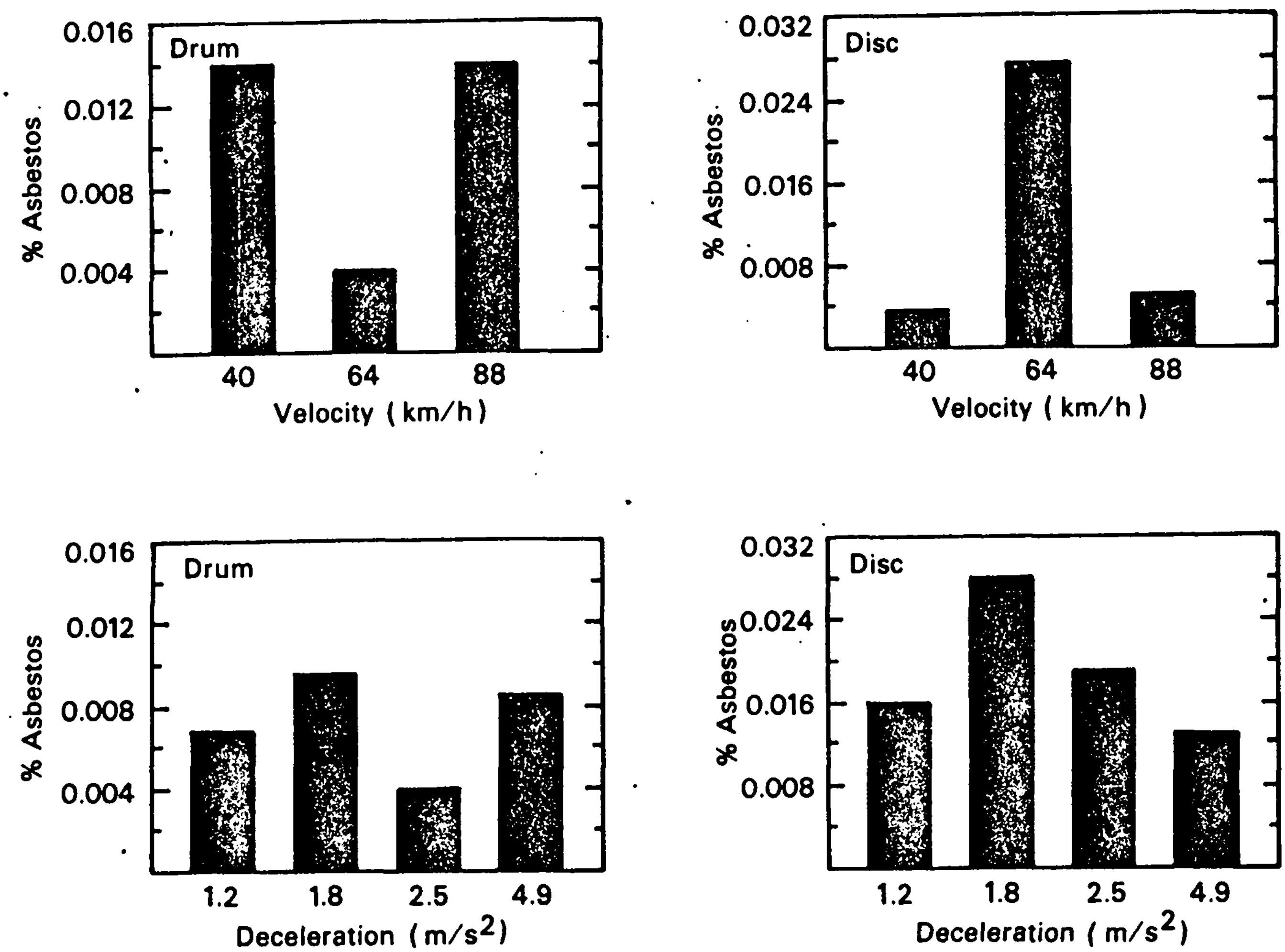

Figure 2. Asbestos Content of Airborne Brake Emissions as a Function of Velocity and Deceleration.

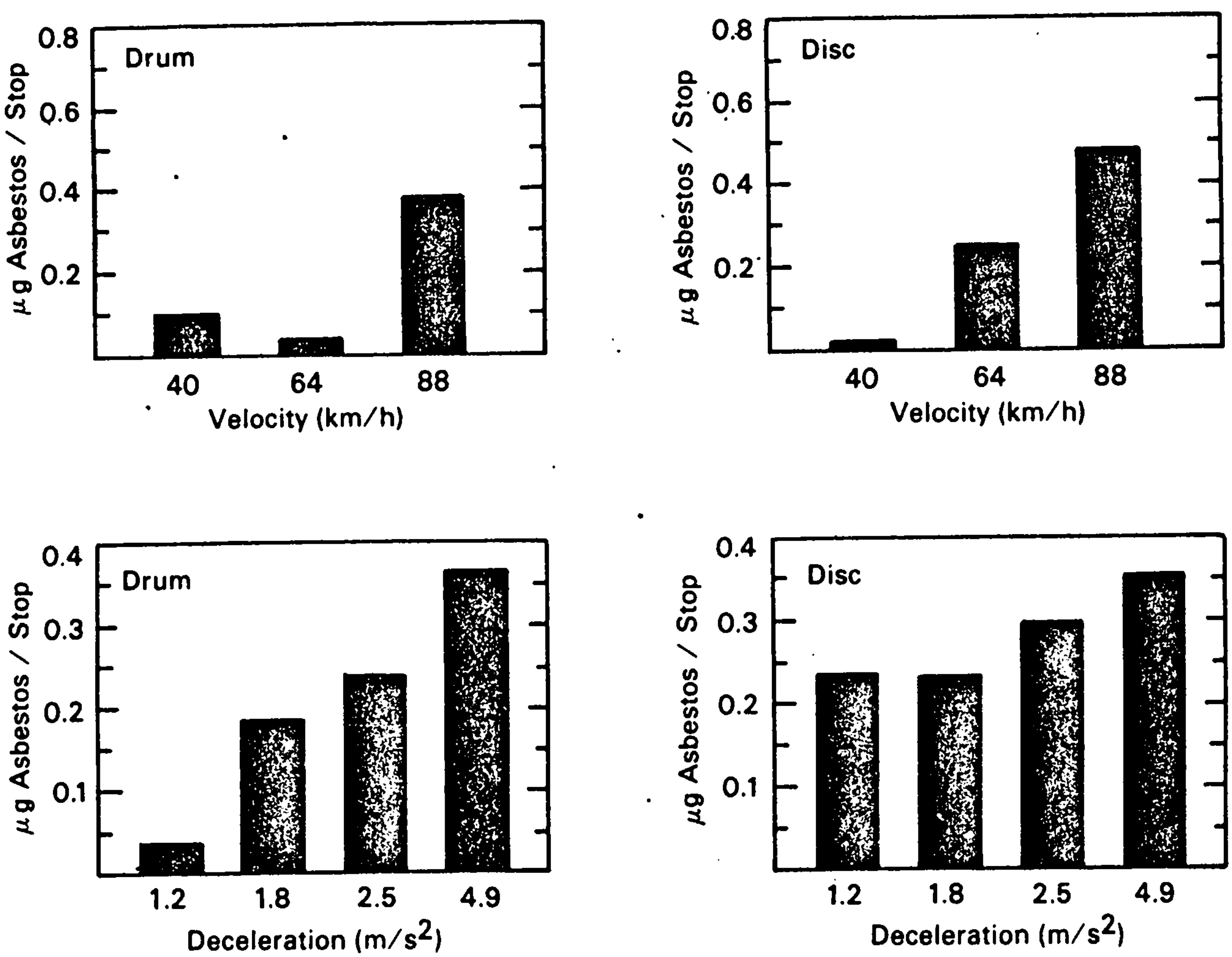

Figure 3. Mass of Airborne Asbestos Emitted per Brake Application as a Function of Velocity and Deceleration.

and 0.040% in roadway material and four brakes per vehicle, there is an average of 2.2 micrograms airborne asbestos, 0.63 microgram roadway asbestos, and 1.8 micrograms entrained asbestos per brake application or a total of 4.6 micrograms asbestos per vehicle per stop. The wheel-entrained estimate may be high since the wheel was cleaned after each test. There were 114-million registered automobiles in the United States in 1977, traveling an average of 16 000 km each.[14] The number of vehicle stops per unit distance has been determined for a variety of driving cycles and averages 1.2 stops/km (2.0 stops/mile).[6] Therefore, there would be 4.9 metric tons of airborne asbestos, 1.4 metric tons of roadway asbestos, and 4.0 metric tons of entrained asbestos for a total of 10 metric tons of asbestos emitted annually from brakes. This is somewhat lower than Jacko and DuCharme's estimate of a maximum annual emission of 27 metric tons from automobiles.[6] These values can be compared to total man-made disposals and emissions of asbestos in 1974 of 534 554 metric tons of which 532 307 was disposed to land, 2093 was emitted to the air, and 154 was emitted to the water.[2] Asbestos emitted from automobile brakes accounts for approximately 0.0019% of the total U.S. asbestos emissions, or 0.23% of airborne asbestos emissions. Brake asbestos emissions appear to be an extremely small contributor to total asbestos emissions.

DISCUSSION

Despite the very low asbestos emissions from braking, there are literature reports of higher than background asbestos levels in the air near roadways and tollbooths and in roadway debris. These reports will be evaluated in terms of our experimental results.

Urban Asbestos Levels

Asbestos fibers have been measured in areas far removed from asbestos sources. Rural values have been reported of 0.01 to 0.1 ng/m^3.[12] Urban levels are considerably higher, with levels in New York City measured at 10 to 60 ng/m^3.[15] Brake and clutch wear has been suggested as a possible source for these higher urban asbestos levels.[5]

Anderson et al.[13] tested brakes on a brake dynamometer without an enclosure and estimated that 0.0023% of the brake lining was worn away as asbestos fibers. To determine the effect of this asbestos level on urban atmospheric levels, they compared asbestos emissions to lead emissions from cars using leaded gasoline. When gasoline averaged 2.52 g Pb/gal, the typical atmospheric Pb concentration in urban areas was 2 μg/m^3. Based on this and the annual wear rate of brakes, Anderson calculated a maximum urban asbestos level of 0.07 ng/m^3. Using our brake emission data of 2.6 μg of asbestos emitted/km, a similar calculation would yield 0.07 ng/m^3 in urban atmospheres which happens to be identical to Anderson's estimate. These data indicate that the brake-wear contribution to asbestos levels (<0.1 ng/m^3) is small compared to levels actually found in urban areas (>10 ng/m^3).

Bruckman and Rubino[16] have estimated total asbestos emissions in Connecticut. Based on 1.56 x 10^6 autos and 30 micrograms/mile (19 μg/km) of asbestos emitted from brakes,[6] they estimate 1.5 tons/year (1.4 metric tons/year) of asbestos would be emitted. This calculation seems to assume an average distance traveled per car of 48 000 km/year. Using a more realistic value of 16 000 km/year,[14] their average brake emission would be 0.45 metric tons/year. Furthermore, if we use the brake emission rate of 5.7 micrograms/km determined in this study, the average total emissions would be only 0.15 metric ton/year. This compares with total asbestos emissions in Connecticut of 180 metric tons/year. Brake emissions would therefore comprise an extremely small fraction (0.08%) of the total asbestos emissions.

Asbestos Levels Near Freeways and Tollbooths

Asbestos levels have been studied downwind of freeways, where brake emissions are expected to be high. Alste et al.[17] measured airborne asbestos concentrations at three urban sites near freeways in Australia. A measurable asbestos level of 5×10^5 fibers/m^3 was found at only one site with most fibers less than 2 micrometers in length. Braking was suggested as the source of this asbestos although there was no attempt to measure upwind concentrations. The mass can be determined by estimating the volume of fibers, assuming a maximum length of 2 micrometers, a diameter of 0.05 micrometer, and a density of 2.56 g/cm^3. The fiber count of 5×10^5 would correspond to a mass of about 5 ng/m^3. This value is lower than asbestos concentrations in some other urban areas.[15]

Murchio et al.[18] measured asbestos levels downwind of four Los Angeles freeway sites. They found 0 to 12 fibers/L, with an average mass of 27 ng/m^3, but there was no significant difference in upwind and downwind samples. No correlation was found with asbestos levels and number or speed of vehicles. One sample was also analyzed from a toll plaza, an area where heavy braking occurs. During the 2-hour sampling period, 11 500 cars passed through the plaza. Asbestos levels were found to be only 1.4 fibers/L, a value indistinguishable frc… background. The median length of asbestos fibers around the Los Angeles freeway was about 8 micrometers, compared to 0.5 micrometers for the fibers we found emitted from brakes. Based on the asbestos levels near freeways and the asbestos fiber length, it appears that automotive brake emissions are not a significant contributor to ambient asbestos in Los Angeles.

Asbestos levels have been measured at several sites in Connecticut[16] in conjunction with a proposed state air quality standard of 30 ng/m^3. The proposed standard is quite stringent, approximately 0.1% of the level set by OSHA for persons working with asbestos. Rural levels ranged from less than 1 to 6 ng/m^3 and urban levels ranged from less than 1 to 9 ng/m^3.

Higher levels were measured near known sources. Samples taken near tollbooths, where continuous high speed braking takes place, ranged from 3 to 25 ng/m^3. The 25 ng/m^3 figure corresponded to 55 000 cars per day passing through the toll plaza. Based on our brake emission experiments and dispersion estimates from the General Motors Sulfate Dispersion Experiment,[19] we made a rough estimate to see if our results are consistent with these toll booth measurements. During the sulfate dispersion experiment, 5500 cars/h passed the sampling point. The average sulfate emission was 23 mg/car/km and the maximum increase in concentration during the experiment was 15 micrograms per cubic meter. Therefore, an emission rate of 127 g/km/h sulfate (23 mg/car/km x 5500 cars/h) leads to a maximum concentration of 15 micrograms per cubic meter. At the tollbooth, 55 000 cars pass through in a 24-hour period, or 2300 cars/hour. The authors did not distinguish between cars and other vehicles so our estimate will be based on car emissions. Assuming a deceleration rate of 2.4 m/s^2 from 88 km/h, the deceleration time is 10 seconds and the stopping distance is about 120 m. Braking from 88 km/h causes airborne particle emissions of 29 mg/car/stop.[10] Based on an average asbestos content of 0.029%, the airborne asbestos emissions are 8.4 μg/car/stop. As a result, in the braking zone, the asbestos emission rate is 160 mg/km/h. Then, from the sulfate experiment, the maximum expected asbestos concentration due to braking would be 19 ng/m^3 as compared to a measured maximum of 25 ng/m^3. We consider this to be a quite good agreement between these studies.

Asbestos in Roadway Debris

A study by Shaheen[7] documented that asbestos levels have been found in road debris along Maryland highways. Approximately 3.6×10^5 fibers were found per gram of roadway material using optical microscopy. We analyzed three samples from Shaheen's study and three roadside samples that we collected along the San Gabriel River Freeway in Norwalk, California. The results are shown in Table III. We found more asbestos fibers greater than 5 micrometers than Shaheen reported. However, the numbers again are uncertain due to the small number of larger fibers. The median length of the roadside fibers was 0.82 micrometer compared to 0.45 micrometer for brake fibers.

Table III. Asbestos in Roadside Dust

Sample	Location	Mass Dust (mg)	Asbestos Mass <5 μm (ng)	Asbestos Fibers/g >5 μm	Asbestos Mass (a) >5 μm (ng)	% Asbestos
1	MD	2.18	44	9×10^6	87	0.006
2	MD	0.81	7.3	6×10^7	210	0.027
3	MD	2.06	5.2	-	-	0.0002
4	CA	2.06	2.4	1×10^6	43	0.002
5	CA	2.01	1.7	-	-	0.0001
6	CA	2.08	0.52	1×10^7	87	0.004

(a) The mass was calculated based on the 230 large fibers/ng found from brake-wear mass data.

CONCLUSIONS

Asbestos emitted during braking was examined using a specially designed brake-testing chamber. The procedure used to identify the asbestos content is quite similar to the method being considered by the EPA. The average asbestos content in particles emitted from brakes was 0.031% from drum and 0.027% from disc brakes. Over 99.9% of the original asbestos has been degraded during the braking process to nonfibrous forms. The median length of the airborne asbestos is 0.5 micrometer. The percentage asbestos in the brake emissions does not appear to be a function of velocity or deceleration rate. However, increased asbestos emissions occur at higher velocities and decelerations as more particles are emitted. The total annual asbestos emission from automobile brakes in the United States is expected to be 10 metric tons, which is very small compared to other asbestos sources.

Based on ambient studies, brake-wear asbestos comprises a very small portion of total asbestos emissions. Studies made in the vicinity of freeways do not show conclusively that asbestos levels are above background levels. There is evidence of increased asbestos levels near Connecticut tollbooths where braking is at a maximum. However, the levels are still within the very stringent air quality standards proposed for Connecticut.

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