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Brake and Clutch Emissions Generated During Vehicle Operation

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the brake system plus more in the clutch mechanism, it becomes apparent that an air pollution problem may exist. Considered in another light, there are perhaps 1 billion pieces of friction material in vehicles in the United States gradually being pyrolyzed and ground to dust. The brake systems in the vehicles utilizing these friction materials can thus be considered as chemical reactors, each emitting organic and inorganic compounds including asbestos and its decomposition products to the atmosphere. The compositions of the gaseous and solid emissions are not well-known nor are the particle sizes and shapes of the solid emissions well-known.

OBJECTIVES

Because of the possible damage which asbestos emissions can produce in the human respiratory system, it is desirable to identify and quantify these emissions.

Thus the objectives of this paper are to:

1. Describe the methodology used to generate, collect, and analyze brake and clutch emissions.
2. Report the asbestos contents in emissions from a test vehicle.
3. Estimate the total asbestos emissions for all vehicles in the country.

TECHNICAL APPROACH

The detailed technical approach may be summarized as follows:

1. Select a suitable vehicle and linings representative of the marketplace.
2. Conceive, design, and build brake and clutch emissions collectors.
3. Test and check out a typical collector on an inertial dynamometer and install instrumentation on the test vehicle.
4. Select and run suitable driving test schedules representative of consumer-type driving.
5. Collect and analyze emissions to obtain the asbestos content and the particle size distribution.
6. Estimate the asbestos emission for all passenger vehicles and extend the data to trucks to obtain a result for all vehicles operating in the United States.

A passenger car was selected for testing because of the following factors:

1. Vehicle braking cannot be simulated realistically on small-scale friction test machines with the present state-of-the art.
2. Full-scale brake and clutch dynamometers provide fairly good simulation and can be used for checking out the emissions collection system; however, separate tests for brakes and clutches would be required thus increasing program costs. On the vehicle, disc and drum brakes and clutches can be tested simultaneously.

INSTRUMENTATION

METHODOLOGY AND CRITERIA - The collection of particulate and gaseous emissions from any vehicle friction couple has never, to the authors' knowledge, been reported in the literature. To define the extent of these emissions, a collection system was devised which combined the functions of separation and storage. Unique emissions collectors for both disc and drum brakes and for a clutch were conceived, designed, and built as the main embodiment of this instrumentation. The collectors separated the wear debris into three different fractions: a sump sample which included the wear debris on the lining surfaces, in the rivet holes, and on the brake drum; a surface sample which included the wear debris on the brake and collector shroud surfaces, and an airborne sample collected on membrane filters.

The major requirements for the emissions sample collection system may be summed up as follows:

1. Collect all particulate and gaseous emissions.
2. Store collected emissions unchanged.
3. Prevent intrusion of contaminants.
4. Maintain ordinary braking and clutching conditions.
5. Be operable at high temperatures.
6. Permit easy separation and analysis of emissions.

MATERIAL SELECTIONS - For the results to be representative of average consumer-type vehicle usage, a vehicle intermediate between compact and luxury was selected. The vehicle was equipped with front disc brakes, rear drum brakes, and a dry clutch. All friction material used contained asbestos. Three vehicle tests were run.

The first vehicle test was run with the original equipment friction materials. The second vehicle test simulated a partial reline—fronts only relined—while the rears were repeated to give a replicate test and an indication of emissions trends for friction materials with continued use. The third vehicle test simulated a complete brake reline and included turned discs and drums. The friction materials selected for the program were representative of those supplied by the industry—five different manufacturers (Abex, Bendix, Raybestos-Manhattan, Thiokol, and Worldbestos) produced the original equipment and aftermarket disc pads and drum linings which were selected in part because of their high-volume usage.

VEHICLE INSTRUMENTATION - A passenger car of medium weight (4850 lb test weight) produced in high volume was selected. It was equipped with a three-speed manual transmission, ventilated cast-iron disc brakes on the front, and cast-iron drum brakes on the rear. This vehicle was selected in order that the emissions from clutches and from disc and drum brakes could be tested simultaneously on a vehicle size representing a large percentage of the present vehicle population.

The vehicle was equipped with standard brake test instrumentation. A front disc brake collector and a rear drum brake collector were installed on the right side of the vehicle. The clutch was sealed by closing the few holes in its casing. The left wheel brakes were left in their normal configuration and were used to monitor the operation of the shrouded brakes. Wear debris was taken from the left brakes as well as from those on the right. The amounts of debris formed and their compositions were used to demonstrate that the brake shroud

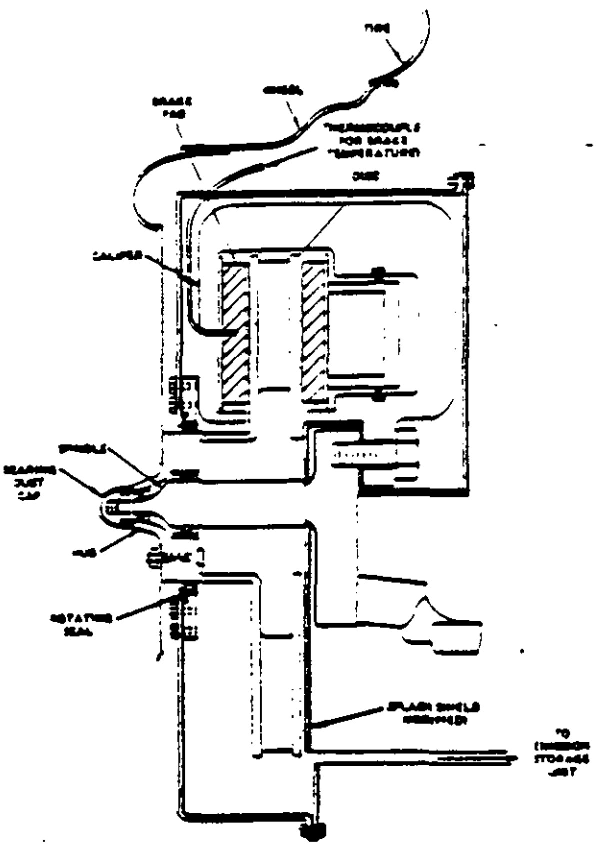

Fig. 4 - Schematic of disc brake shroud

ing did not significantly affect the operation of the brakes on the right side.

EMISSIONS COLLECTION SYSTEMS

OVERALL SYSTEM DESIGN - The basic design concept of each brake emissions collection system is shown in Fig. 1. Air from inside the vehicle was pulled through a bed which removed water and carbon dioxide from the air. The air then passed through a filter to remove all particles larger than 0.2 μm (8×10^{-6} in). The filtered air was then routed to the *sealed brake assembly through clean Teflon tubing.* The airstream, along with wear particles and gases, then passed out of the brake through Teflon tubing which was heated to avoid condensation. This stream passed through two filters to remove the airborne particles and preserve them for analysis. The stream then passed through three cold traps in order to condense and trap the gases evolved during braking and preserve them for analysis. The remaining airstream then passed through a flowmeter, the vacuum manifold, and finally through an air pump run by the vehicle engine where it was expelled to the atmosphere.

Fig. 2 shows, mounted in the front seat of the test vehicle, the front brake inlet air filter and gas collection system, the clutch gas collection system, and the 12 position thermocouple switch and pyrometer used to monitor gas and filter trap temperatures. Fig. 3 shows, as mounted in the rear seat of the test vehicle, the rear brake air filter and gas collection system, the clutch air filter, and the electrical system (bat-

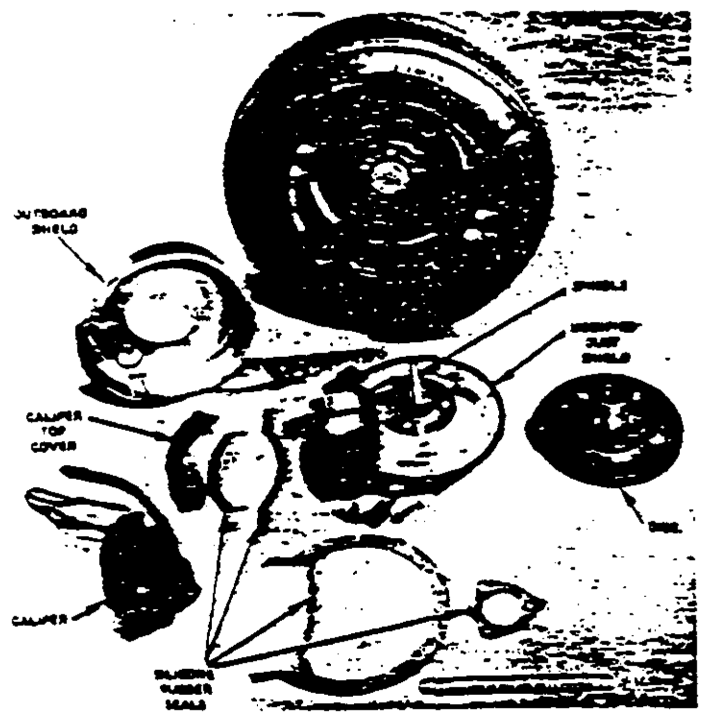

Fig. 5 - Disc brake emissions collector assembly—exploded view

loaded graphite-filled Teflon seal of commercial manufacture. A view of major components of the collector is shown in Fig. 5; the system, as mounted on the vehicle, is shown in Figs. 6 and 7. The main portion of the shroud was coated with black oxide; a water-cooling system was added and an open "mag" wheel was used to aid in cooling the enclosed brake.

DRUM BRAKE COLLECTOR - Fig. 8 shows a cross-sectional view of the collector along with the detail of the rubbing seal. The seal was of the same type as for the disc brake collector. The axle hub used to align the drum was modified with a piece that was concentric to the axle bearings within 0.001 in (0.0025 cm). A tapered lead was used to facilitate mounting of the drum. The close tolerances on the concentricities were necessary in order to obtain reasonable seal life. Figs. 9 and 10 show outboard and inboard views of the system as mounted on the test vehicle.

CLUTCH COLLECTOR - The clutch system consisted mainly of a filtered air inlet and an outlet to the sample storage system with all other external holes sealed.

INERTIA DYNAMOMETER TESTS

The front disc brake emission collector was tested on an inertia dynamometer to check out its operation and its most critical part, the rotating seal. Thermal response tests were made with the results indicating that for normal operation the shrouded disc brake would operate at a slightly higher temperature than the normal brake configuration. A method was devised to determine the leak rate of the collector. The rotating seal was largely responsible for the residual leak; the leak rate was reduced significantly by use of a very small amount of high-temperature grease. The rotating seal underwent durability testing and survived 7 h at 50 mph. A second series of dynamometer tests gave reproducible emissions and temperatures. Finally, a test was made in which the collector and especially the rotating seal were shown to be relatively leak-tight to external liquid and particulate contaminants.

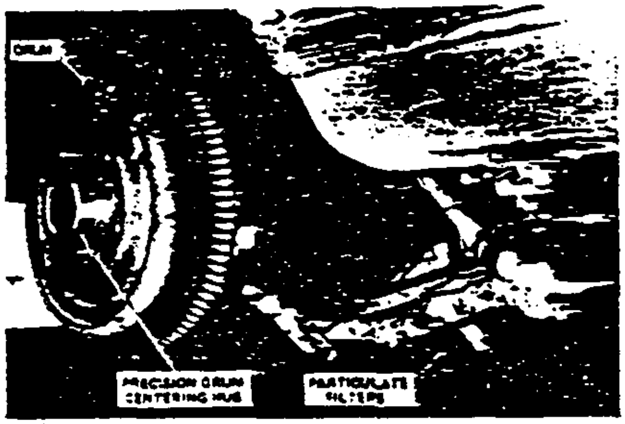

Fig. 9 - Assembled rear drum brake emission collector

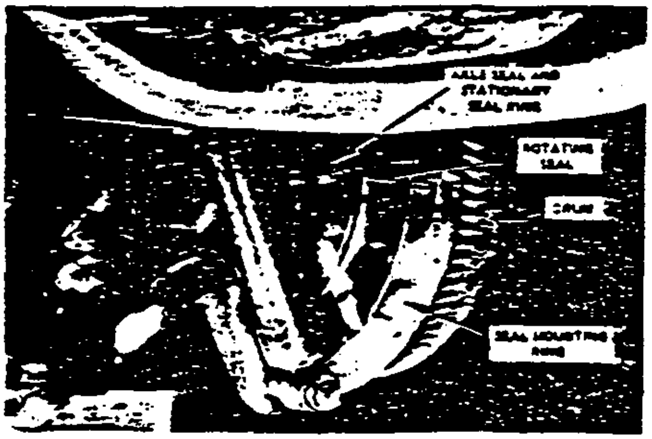

Fig. 10 - Inboard view of assembled rear drum brake emissions collector

VEHICLE TESTS

RATIONALE - For a given vehicle brake system, friction material wear is primarily a function of the duty cycle. For light-duty cycles, where pad and lining temperatures remain under 350°F, low wear results and is primarily due to the abrasive and adhesive wear mechanisms. Heavier duty cycles at higher temperatures give some combination of thermal, abrasive, and adhesive wear. Under severe heavy duty where the use borders on abusiveness, brake fade may occur. The inability of the brakes to hold the friction level results in part from the formation of gases (and wear debris) at the interface.

Although there are many acceptable original equipment manufacturers' friction material tests to measure a specific condition or combination of conditions, there is no one test which adequately matches normal driving conditions which would be representative of all vehicles. Consequently, it became necessary to devise a rational and meaningful vehicle test driving schedule.

SELECTED VEHICLE-DRIVING SCHEDULES - A total of seven test schedules were chosen and each was followed by a measurements procedure (take emissions samples, measure wear, inspect systems, and replace worn parts). The first three tests—Burnish, After-Burnish (A.B.) Baseline, and Detroit Traffic—represent the low-temperature tests. The final four tests—10 Stop Fade, After-Fade (A.F.) Baseline,

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cedure was also prepared for the sampling, handling, and analysis of the asbestos emissions.

ANALYTICAL PROBLEM DEFINITION - The thermal and mechanical forces which act at the friction couple interface produce a complex chemically and physically altered microstructure which cannot be accurately described at present. Table 3 gives an estimate of the chemical composition of wear debris.

Asbestos is a complex inorganic material with the approximate composition formula:

$$Mg_3\,(SiO_5)\,(OH)_4 \text{ or } 3MgO \cdot 2SiO_2 \cdot 2H_2O$$

The basic unit has a fibril form (1, 2)*. Asbestos is readily identified when alone or in simple mixtures at high concentrations by these analytical methods: x-ray diffraction, thermal methods, microscopy, and infrared analysis. However in complex mixtures or at very low concentrations the analysis for asbestos is very difficult. In brake wear debris, the problem is compounded because the reaction products of asbestos, forsterite and olivine have similar elemental ratios and similar x-ray diffraction patterns. The only sensitive method which can be used is microscopy. In extremely low concentrations, asbestos is identifiable in the electron microscope by its physical shape (tubular fibril) which is distinguishable from that of other fibers and particles.

At the beginning of the program, one optical (3) and three transmission electron microscopy (4-6) methods had been developed by others. Two of the electron microscopy methods were not suitable because they changed the fiber size distribution of the asbestos.

ANALYTICAL METHOD SELECTED - From the available analytical methods and the problems associated with brake wear debris analysis, the following considerations were necessary.

Criteria and Flow Chart - Three important criteria had to be met by the analytical method used: The very small portion of brake debris used had to be representative of the much larger sample collected; the analytical steps could not degrade the particle size distribution of the asbestos fibers obtained; the results obtained must be indicative of the actual asbestos content of the sample. These criteria were met by the analytical scheme outlined in Fig. 11.

Representative Sampling and Low-Temperature Ashing (LTA) - The analysis of brake wear debris indicated the presence of 20-30% by weight of polymeric and carbonaceous material, which in turn produced a fluffy appearance when the material was examined in the scanning electron microscope. The organic portion was therefore removed by LTA. Two representative samplings were used: the first in sample selection for LTA and the second in sample selection for distribution on a filter membrane for subsequent analysis.

Selected Microscopy Methods - In the very early tests, wear debris from a sample dynamometer was collected on the filter train of the 8.0 μ and 0.2 μ Nuclepore filters. Both filters were examined by a combination of optical and transmission electron microscopy. The following observations were made:

1. Asbestos fibers longer than 20 μ were obtained.
2. Very fine fibrils were extremely difficult to detect at less than 5000 diameters magnification.

Based on the above studies, it was deemed necessary to employ two magnifications. To detect fibers greater than 2 μ, a magnification in the range 10,000-40,000 diameters

*Numbers in parentheses designate References at end of paper.

Table 3 - Estimated Chemical Composition Characteristics of Wear Debris

Description	Percent	
Low molecular weight degradation products	2-10	20-30
Polymeric components	12-20	
Carbonaceous material	1-5	
Inorganics:		70-80
Mineral	~10-30	
Olivine	~20-40	
Oxides (from lining)	0-10	
Fe_2O_3 (from rotor)	5-15	
Asbestos	<1	

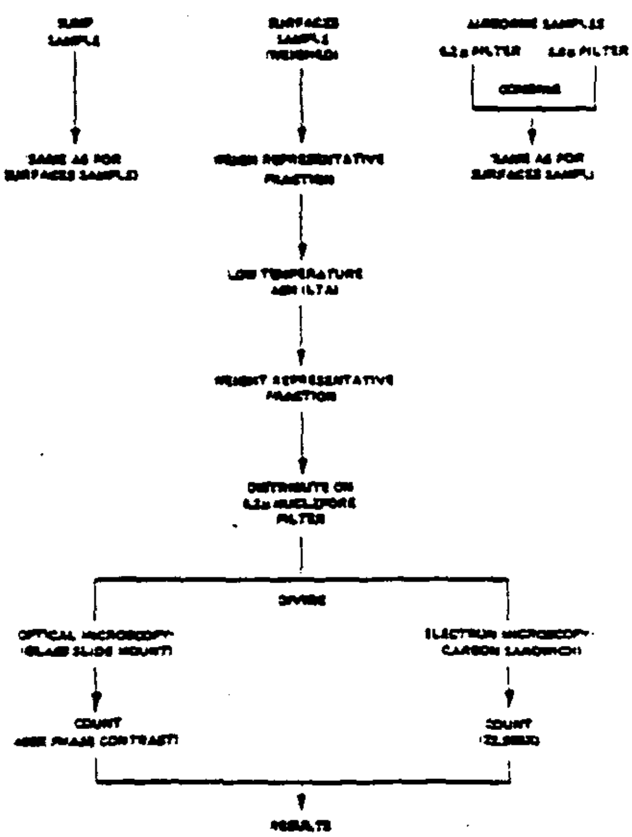

Fig. 11 - Flow chart of particulates analyses

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Table 6 - Brake Temperatures During Burnish and Detroit Traffic Circuits

Test	Remarks	Ambient Temperature, F	Front Disc Brake: Right (Shrouded)	Front Disc Brake: Left (Normal)	Front Disc Brake: ΔT	Rear Drum Brake: Right (Shrouded)	Rear Drum Brake: Left (Normal)	Rear Drum Brake: ΔT
Burnish Vehicle test 1	Initial attempt (no thermal control aids)							
	After 20 stops	10	400	150	250	255	150	105
	After 40 stops	10	340	120	220	200	110	90
	After 60 stops	10	360	160	200	245	150	95
		Range	340-400	120-160	200-250	200-255	110-150	90-105
	Retun (with thermal control aids)							
	After 10 stops	70	280	150	130	205	150	55
	After 40 stops	49	310	150	160	245	165	80
	After 60 stops	65	265	150	115	215	165	50
	After 100 stops	68	280	165	115	220	170	50
	After 160 stops	50	300	170	130	190	130	60
		Range	265-300	150-170	115-160	190-245	130-170	50-80
A.B. Baseline Vehicle test 2	Morning circuit (8:00 a.m.)							
	12 Mile and Woodward	79	270	150	120	150	150	0
	Michigan and Third	80	300	160	140	170	160	10
	Adams and Woodward	82	300	160	140	180	160	20
	Adams and Woodward	82	280	150	130	180	160	20
	12 Mile and Woodward	84	330	190	140	190	160	30
	Afternoon circuit (2:00 p.m.)							
	12 Mile and Woodward	90	310	210	100	160	160	0
	Michigan and Third	91	320	180	140	210	180	30
	Adams and Woodward	91	310	180	130	210	180	30
	Adams and Woodward	91	310	170	140	200	170	30
	12 Mile and Woodward	91	300	160	140	170	150	20
		Range	270-330	150-210	100-140	150-210	150-180	0-30

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only three were in the range 0.50-0.96%; all others were less than 0.50%. The overall average was 0.25%.

For vehicle test 3, the range of asbestos content in brake emissions varies from a high of 0.51% down to a low of 0.003%. Of the analyses reported, three were in the range 0.20-0.51%; all others were less than 0.20%. The overall average was 0.07%.

For all three vehicle tests, the overall average of asbestos content in the brake emissions was 0.23%.

Independent Asbestos Analyses - To provide a systematic independent check on the asbestos analyses, the Environmental Protection Agency (EPA) arranged for Battelle Columbus Laboratories to analyze 24 samples generated during the Program. The Johns-Manville Research and Engineering Center also provided three analyses (7). In 19 of the 24 analyses, the Program results were slightly higher than the corresponding Battelle results (Table 10). The Program

Table 8 - Distribution of Emissions*, %

Vehicle Test	Collector	Front Brakes Right (Shrouded)	Front Brakes Left (Normal)	Rear Brakes Right (Shrouded)	Rear Brakes Left (Normal)
1	Sump	6-31	61-83	9-22	36-65
	Surfaces	63-89	17-39	72-88	35-65
	Airborne	2-15	-	3- 6	-
2	Sump	2-20	63-83	12-22	39-63
	Surfaces	71-93	17-37	60-86	37-61
	Airborne	2-22	-	1- 2	-
3	Sump	2-38	-	9-36	-
	Surfaces	46-86	-	61-87	-
	Airborne	7-19	-	1-11	-

*The ranges give the lowest and highest percentage found for the seven driving schedules as a whole.

Table 9 - Summary of Asbestos Analytical Results—Vehicle Test 1, Weight Percent

Schedule	Collector	Front Brakes Right (Shrouded)	Front Brakes Left** (Normal)	Rear Brakes Right (Shrouded)	Rear Brakes Left (Normal)
Burnish	Sump	0.313		-	**
	Surfaces	0.398		0.365	
	Airborne	0.144		0.349	
		(0.452)*		(0.607)	
A.B. Baseline	Sump	1.650		0.179	**
	Surfaces	0.472		0.415	
	Airborne	0.290		0.493	
		(0.804)		(0.362)	
Detroit Traffic	Sump	0.247		0.129	0.991
	Surfaces	0.137		0.373	0.265
	Airborne	0.052		0.092	-
		(0.145)		(0.198)	-
10 Stop Fade	Sump	0.463		0.280	0.275
	Surfaces	0.162		0.071	0.416
	Airborne	0.154		0.132	-
		(0.260)		(0.161)	-
A.F. Baseline	Sump	0.656		0.419	**
	Surfaces	0.507		0.242	
	Airborne	0.134		0.079	
		(0.432)		(0.247)	
15 Stop Fade	Sump	0.602		0.071	0.439
	Surfaces	1.548		0.257	0.472
	Airborne	0.175		0.222	-
		(0.775)		(0.183)	-
Final Baseline	Sump	0.435		0.585	**
	Surfaces	0.290		0.324	
	Airborne	0.167		0.145	
		(0.297)		(0.351)	
	Average	0.452	Average	0.301	

*Average value for wheel where collection took place.
**Not analyzed—indicates that analysis was not required.

Table 10 - Comparison of Analytical Results for Asbestos

Vehicle Test	Schedule	Collector	Front Disc Brakes Program	Front Disc Brakes JM	Front Disc Brakes Battelle	Rear Drum Brakes Program	Rear Drum Brakes JM	Rear Drum Brakes Battelle	Clutch Program	Clutch Battelle
1	Detroit Traffic	Sump	0.247	-	0.21	0.129	-	0.025	-	-
		Surfaces	0.137	0.005	0.011	0.373	0.002	0.006	-	-
		Airborne	0.052	-	0.001	0.092	0.006	0.001	0.291	0.007
	10 Stop Fade	Sump	0.463	-	1.22	0.280	-	0.22	-	-
		Surfaces	-	-	-	-	-	-	-	-
		Airborne	0.254	-	0.31	0.132	-	0.007	-	-
2	Burnish	Sump	0.402	-	0.28	0.484	-	0.10	-	-
		Surfaces	-	-	-	1.416	-	2.38	-	-
		Airborne	0.186	-	0.10	-	-	-	-	-
	Detroit Traffic	Sump	0.304	-	0.62	0.249	-	0.057	-	-
		Surfaces	-	-	-	0.113	-	0.061	-	-
		Airborne	0.234	-	0.006	0.115	-	0.015	-	-
3	Detroit Traffic	Sump	0.018	-	0.135	0.046	-	0.010	-	-
		Surfaces	-	-	-	-	-	-	-	-
		Airborne	0.025	-	0.016	0.037	-	0.044	-	-
		Averages	0.204	-	0.265	0.289	-	0.077	-	-

Program average: 0.247
Battelle average: 0.171
Ratio: Battelle/Program = 0.69

1. Asbestos emissions were higher for new friction surfaces and decreased with use.

2. The drum brake produced more asbestos emissions than the disc brake initially with the difference decreasing as the friction materials continued in use.

3. Heavy (abusive) duty did not necessarily give a higher percent of asbestos: the large amount of debris produced, however, gave a significant rise in asbestos emissions.

4. Asbestos emissions from the brakes were found to decrease from fade or heavy-duty stops (highest) to burnish to moderate braking (lowest).

5. For the disc pads only, there was an increase in asbestos emissions with increased asbestos content in the friction material. (There was no such trend for the drum brake materials.)

6. Both the front disc pads and the drum linings of vehicle test 3 have wear comparable to that found in the other two vehicle tests, yet the asbestos emissions were significantly lower. (Both pads and secondary linings contained brass chips which may have been in part responsible for the more complete conversion of the asbestos in the brake emissions.)

7. For both disc and drum brakes the surfaces sample was the largest of the three (~92%), the sump sample was next (~7%), and the airborne sample was the smallest (~1%).

ESTIMATE FOR ASBESTOS EMISSIONS

The purpose of the following discussion is to develop an estimate of total brake and clutch emissions from the United States population of motor vehicles in use on the roads and highways. Inputs include all of the test results described earlier together with a supplementary data base on United States motor vehicle population and usage and on friction material usage and consumption obtained from other sources.

Because of the uncertainties in all of the data available, emissions can only be considered as a broad range, rather than as a single value, with the expectation that the true average emissions for both individual vehicles and the motor vehicle population in general will be within the range of values calculated below.

DATA BASE - To calculate the asbestos emissions for all vehicles it was necessary to assemble the following data base.

Number of Vehicles in Use - Table 12 lists the total United States motor vehicle population as estimated by both Department of Transportation (DOT), National Highway Traffic Safety and Federal Highway Administration (8), and by the R. L. Polk Co. (9). The Polk census is said to be more precise because it eliminates multiple registrations of the same vehicle. Polk considers that DOT estimates may be as much as 13% too high. Both Polk and DOT omit military vehicles but include all other motor vehicles that are state-licensed including police cars, school buses, and the like. Independently, the General Services Administration reports that 190,000 Department of Defense vehicles are in use worldwide. In addition, there are 6.6 million braked trailers and 38.4 million motor vehicles with dry clutches.

Motor Vehicle Usage - The approximate total number of miles traveled by all United States motor vehicles was 1.249 trillion miles for 1972 according to a recent DOT estimate (8). The average annual mileage for passenger cars is 9978 miles while for trucks it is 9807 miles.

An attempt was made to estimate the proportion of United States driving that takes place in predominantly hilly or mountainous areas where long steep grades are common. Basic data on miles driven in each state were obtained from DOT. The percentage of driving that takes place in mountainous areas, where abusive brake use may be necessary, is estimated to be 11.5% of all driving. The estimate is subjective to a large degree and may be high, but no better data have been located.

Asbestos in Friction Materials - The data in Table 13 indicate that the total amount of asbestos contained in all of the automotive brake friction materials sold each year is calculated to be about 103 million lb which corresponds to ~118 million lb used prior to grinding. Two of the most knowledgeable sources (10, 11) report that 90-120 million lb per year are used. A report from IIT Research Institute suggests that 67 million lb are used annually in brake linings (12). A Bureau of Mines Report (13) based on 1968 data credits only 50 million lb of asbestos to automotive use, a number the authors find to be much too small. Ignoring the two latter values, the three estimates of asbestos contained in brake friction materials range from 90-120 million lb. Using the calculated vehicle of 118 million lb and assuming a 15% grinding and drilling loss, the maximum amount of asbestos incorporated in brake friction materials is taken to be 103 million lb per year.

A compilation of data on clutch friction materials was also made (14). Based on these data, the total amount of asbestos contained in all automotive clutch friction materials sold each year is calculated to be about 4.5 million lb.

AMOUNT OF FRICTION MATERIAL ACTUALLY WORN - For several reasons the amount of brake lining (and asbestos) worn away during a year is significantly less than the total amount installed on vehicles. Brake linings are seldom completely worn away. (Due to the geometry of brake

Table 14 - Compilation of Calculations for Amount of Brake Friction Material Worn Away Annually

Calculation	Total Brake Friction Material, million lb
Installed weight each year	171.4
Discarded on relining, ~25%	42.7
Discarded on vehicles retired	11.7
(7 million cars x 2.38 lb x 40% = 6.7 +	
0.75 million light trucks x 5 lb x 40% = 1.5 +	
0.10 million medium trucks x 15 lb x 40% = 0.6 +	
0.15 million heavy trucks x 41 lb x 40% = 2.4 +	
miscellaneous = 0.5)	
Amount worn away annually	117.0

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Table 18 - Distribution-Weighted Asbestos Emissions from the Test Vehicle

Schedule	Friction Couple	Asbestos Emissions, µg/mile: Vehicle Test 1	2	3	Average	Per Axle	Distribution Weighting Factors: Dropout	Airborne	Severity-Weighting Factors	Weighted Emissions, µg/mile: Dropout	Airborne
Burnish	Disc brake	16.70	36.35	7.21	20.09	40.18	0.85	0.04		0.44	0.02
	Drum brake	59.09	24.43	11.67	31.39	62.78	0.54	0.01	0.013	0.44	0.01
	Clutch	-	-	-	1.11	-	0.10	0.01		0.00	0.00
A.R. Baseline	Disc brake	2.23	4.71	1.96	2.97	5.94	0.85	0.04		0.06	0.00
	Drum brake	9.22	2.38	1.98	4.52	9.04	0.54	0.01	0.013	0.07	0.00
	Clutch	-	-	-	1.11		0.10	0.01		0.00	0.00
Detroit Traffic	Disc brake	2.35	12.75	0.48	5.19	10.38	0.93	0.06		9.02	0.58
	Drum brake	11.07	5.50	0.63	5.73	11.46	0.79	0.02	0.934	8.45	0.21
	Clutch	-		-	1.11	-	0.10	0.01		0.10	0.01
10 Stop Fade	Disc brake	100.60	79.13	8.82	62.80	125.60	0.93	0.06		2.33	0.15
	Drum brake	22.58	146.14	5.03	58.15	116.30	0.79	0.02	0.020	1.84	0.04
	Clutch	-	-		1.11	-	0.10	0.01		0.00	0.00
A.F. Baseline	Disc brake	29.61	6.69	3.51	13.27	26.54	0.93	0.06		0.49	0.03
	Drum brake	5.21	3.28	0.32	2.94	5.88	0.79	0.02	0.020	0.10	0.00
	Clutch		-	-	1.11	-	0.10	0.01		0.00	0.00
									Total	23.34	1.05

ASBESTOS EMISSION ESTIMATE FOR ALL VEHICLES

The test vehicle results can be extended to all passenger vehicles in the following manner.

Passenger Cars - The estimated total asbestos emission per year can be calculated from the following information:

1. Total asbestos emission per vehicle is 28.51 µg/mile.
2. Number of miles per vehicle is 9978.
3. Number of passenger vehicles is 96,400,000.

From the above, the estimated asbestos emission in pounds per year:

$$\frac{28.51\ \mu g}{\text{mile-vehicle}} \times 10^6 \frac{g}{\mu g} \times 9.978 \times 10^3 \frac{\text{miles}}{\text{year}} \times \frac{1}{454\ g}$$

$$\times\ 96.4 \times 10^6 \text{ vehicles} = 60,400 \text{ lb per year}$$

The distribution of the total asbestos emission calculated for the test vehicle can be determined by applying the percent distributions given earlier. The fate of the 60,400 lb calculated above for the test vehicle is shown in Table 19.

Trucks and Buses - Truck brakes usually tend to operate at higher temperatures than passenger cars. Thus a greater proportion of high-temperature use in severity weighting can be obtained by using a larger fraction of the 10 Stop Fade asbestos emission. For trucks and buses, the test results are arbitrarily weighted, as given in Table 20.

In addition to the severity factors, it is necessary to estimate the total average asbestos emission for a light truck, a medium truck (or bus), and a heavy truck. The value for the test car was 28.51 µg/mile. Assuming that trucks have results proportional to the ratios of the friction material weights, the asbestos emission for trucks are larger than for the test car by the factors shown in Table 21. A slightly larger factor is selected for the clutch as it is used more often in trucks than in passenger cars.

The estimates for the total asbestos emission per light truck, medium truck (or bus), and heavy truck were calculated using the severity and emissions factors given in Tables 20 and 21. These results are shown in Table 22. The total asbestos emission per year for light trucks can be calculated from the following information:

1. Total asbestos emission per vehicle is 87.51 µg/mile.
2. Number of miles per vehicle is 9807.
3. Number of light trucks is 17,100,000.

Estimated asbestos emission in pounds per year:

$$87.51 \frac{\mu g}{\text{mile}} \times 10^6 \frac{g}{\mu g} \times 9.807 \times 10^3 \frac{\text{miles}}{\text{year}} \times \frac{1\text{ lb}}{454\ g}$$

$$\times\ 17.1 \times 10^6 \text{ vehicles} = 32,300 \text{ lb per year}$$

The estimated value for the total asbestos emission from trucks and buses is shown in Table 23.

The distribution-weighting factors for trucks were calculated based on the following considerations. The truck drum brake is designed to be more open than the car drum brake and in many instances no splash shields are used. Based on the estimates, that only about 25% as much debris remains in a truck drum brake as compared with a passenger car drum brake, distribution-weighting factors for trucks were estimated. The distribution of the total asbestos emission estimate is shown in Table 24.

SUMMARY AND CONCLUSIONS

The purpose of this program was to obtain asbestos emission data from brakes and clutches for a vehicle during actual operation. Unique emissions collectors for a disc brake, drum brake, and clutch were conceived, designed, built, and installed on a vehicle. The vehicle was driven through various test cycles to determine the extent and type of brake emissions generated at both low and high temperatures.

Typical original equipment and aftermarket friction materials for both disc and drum brakes were used in the tests. Brake relines were made to simulate consumer-type practices. The particulates were processed and analyzed by a combination of optical and electron microscopy.

Table 25 - Summary of All Brake and Clutch Emissions, pounds per years

Vehicle	No. of Vehicles	Total Asbestos Emissions	Distribution: Dropout	Airborne	Brake Retention
Passenger cars	96,400,000	60,400	49,470	2,220	8,700
Light trucks	17,100,000	32,300	28,420	940	2,940
Medium trucks and buses	2,600,000	16,300	14,330	470	1,500
Heavy trucks	1,200,000	32,900	28,920	950	3,030
Miscellaneous*	6,615,000	16,300*	14,330	470	1,500
	Totals	158,200	135,470	5,060	17,670
	Percent of total		85.6	3.2	11.2

*Estimated equal to medium trucks as weights of friction material used for both categories are almost equal (Table 12). Includes motorcycles, trailers, etc.

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