INDUSTRIAL HYGIENE ASSESSMENT OF SEVEN BRAKE SERVICING FACILITIES

ASBESTOS

Paul Johnson
Ralph D. Zumwalde
Dennis Roberts

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Industrial Hygiene Section
Industry-wide Studies Branch
Division of Surveillance, Hazard Evaluations, and Field Studies
National Institute for Occupational Safety and Health
Cincinnati, Ohio

INTRODUCTION

A major objective of the National Institute for Occupational Safety and Health (NIOSH) is to determine environmental exposures of working populations through research, surveys, and industrywide studies. Accordingly, NIOSH is presently conducting research to characterize dust exposure resulting from vehicle brake servicing operations. Of particular interest are the small diameter, potentially respirable asbestos fibers generated by these operations. Limited studies have suggested that such emissions may be associated with asbestos-induced diseases.[1]

An estimated workforce of 900,000 brake mechanics and garage workers in the U.S. are potentially exposed to asbestos.[2] An estimated 118 million pounds of asbestos are used annually in the U.S. for the production of brake friction materials.[3] In addition to asbestos, other materials which are used in the manufacture of brake linings such as lead, zinc, copper, and iron pose other potentials for exposures. Rohl and Langer identified thirty materials or compounds that make up the binders, fiber reinforcers, and the property modifiers as being present during brake lining manufacturing.[2]

SELECTION OF FACILITIES SURVEYED

The purpose of the study was to investigate and characterize dust exposures resulting from vehicle brake maintenance and repair operations taking into account the work practices utilized. Therefore, it was necessary to locate facilities where brake servicing operations were performed in different manners (i.e. equipment used, number of vehicles serviced, personal protection, etc.). Six of the seven sites selected for the investigation were automobile brake service facilities which performed from 2 to 45 brake jobs per week at an average of 65 minutes per vehicle. At the seventh site studied, a truck service center, brake servicing took six to nine hours per vehicle with an average of three brake jobs per week. Detailed airborne dust sampling surveys were conducted at each facility.

Description of Brake Servicing Operations

The servicing parameters found at each facility were basically as follows. The vehicle is driven into a repair stall or bay for a brake system examination. Pending repairs, the wheels are elevated, removed, and then inspected. Loose dust is cleaned from the drums and brake assemblies by vacuuming, wiping, brushing, using compressed air, or a combination of these methods. Parts are then replaced or repaired as needed and the brake system is reassembled and adjusted. Test driving the vehicle for proper fitting and adjustment is the final phase of the servicing operation.

A brief description of the individual facilities is outlined as follows:

Facility A

This facility, a fleet service garage, was responsible for complete automotive maintenance and reapir with the exception of internal engine repair and exterior painting. The shop normally operates eight hours per day, five days per week. Of the seven employees working at the facility, only three are full-time brake mechanics. Brake servicing operations were performed (an average of two to five jobs per week) in either of two service stalls.

Facility B

Although Facility B was an automobile brake service shop, front-end alignment and tire sales were also part of the shop mechanics' duties. The three full-time mechanics worked from two service stalls, 12 hours per day 5½ days per week. Brake maintenance operations consisted of 10 to 14 jobs per week.

Facility C

Major services at this automobile brake service shop consisted of front-end alignment, shock absorber servicing, and brake maintenance. The normal work week was made up of five, nine-hour days and one, six-hour day. Three service stalls were used by the three full-time employees for brake servicing operations. Brake servicing averaged four to six jobs per week.

Facility D

Major services provided at this auto brake shop were front-end alignment, shock absorber service, and brake maintenance. The three full-time employees worked from two service stalls, 9-hours per day, six days per week. The number of brake jobs averaged 20 to 30 per week.

Facility E

Plant E was the largest of the automobile brake service shops surveyed. Other services provided by this facility were front-end alignment and shock absorber replacement or repair. The five full-time mechanics worked from four service stalls, nine hours per day, six days per week. Brake maintenance operations consisted of 35 to 45 jobs per week.

Facility F

The major services at this facility were front-end alignment, muffler installation, and brake maintenance. Automobile brake repair operations were performed by the shop's three employees and consisted on the average of four to five brake jobs per week. Normal brake servicing at this facility took about 1 hour and 45 minutes per vehicle.

Facility G

This shop, a truck brake maintenance facility, involved a somewhat different operation and exposure. Servicing operations were more complex and, therefore, involved more employees and fewer vehicles serviced. The four service bays at the facility were used by seven mechanics. Other service operations included pad grinding, riveting, and punching (pad removed and/or replaced on shoe), sand blasting of old shoes, and milling of wheels.

Sampling and Analysis

Personal and general air samples were collected at each facility on different occasions during a two-year period. Brake servicing operations, as well as other areas within each facility were monitored to provide asbestos exposure data. Personal air samples were collected in the breathing zone of the brake mechanics using Millipore type AA, 37 mm diameter, 0.8 μm pore size, membrane filters at a sampling flow rate of 2.0 liters per minute (ℓpm). The filters were changed periodically during the work shift to prevent overloading of the collection media. Peak exposures were determined by using Gast pumps calibrated at 11.0 and 10.6 ℓpm. These samples were collected on identical media as above but only during the time in which workers were cleaning dust from the brake drums and assemblies. Analysis of the membrane filters for asbestos fibers was conducted in accordance with the procedures outlined by the Occupational Safety and Health Administration[4] and the NIOSH Manual of Analytical Methods P & CAM #239.[5] These procedures require the counting of fibers greater than 5 micrometers in length and require the counting of fibers greater than 5 micrometers in length and with at least a 3 to 1 length to width ratio using phase contrast optical microscopy at a magnification of 400-450X.

Random samples from each facility surveyed, as well as those samples having high fiber concentrations, as determined by the optical counting method, were analyzed on a transmission electron microscope utilizing selected area electron diffraction and an energy dispersive X-ray analyzer. Sample preparation and analysis were performed in the manner described in the NIOSH Technical Report, "Review and Evaluation of Analytical Methods for Environmental Studies of Fibrous Particulate Exposure".[6]

Samples were observed at 17.000X magnification with fibers ($\geq$ 3:1 aspect ratio) sized by length and diameter. Selected area electron diffraction (SAED) was attempted on all observed fibers for possible identification. In addition, energy dispersive X-ray analysis was performed on individual fibers to determine their elemental composition.

Airborne samples collected at Facilities E and G were analyzed for trace metals by atomic absorption spectrophotometry in accordance with the NIOSH Manual of Analytical Methods, Volumes 1 and 3.[5,7]

RESULTS

Facility A

Fibrous dust concentrations (fibers > 5 µm in length) found at Facility A, a fleet grage, were similar to those found in passenger car brake service shops. A time-weighted average (TWA) concentration of 0.12 fibers/cc was found for one mechanic from the personal samples collected. General area airborne samples indicated a range of concentrations from 0.02 to 0.07 fibers/cc in the brake service area (Table 1).

Facility B

A TWA concentration of 0.12 fibers/cc was found for a mechanic. Two general area samples collected near the servicing of brakes indicated concentrations of 0.09 and 0.13 fibers/cc (Table 2).

Facility C

A TWA concentration of 0.03 fibers/cc was found from the personal samples collected for a brake mechanic. General area sample concentrations ranged from 0.01 to 0.17 fibers/cc (Table 3). A three minute sample collected near a mechanic while cleaning a brake drum using compressed air resulted in a peak concentration of 1.82 fibers/cc.

Facility D

The TWA concentrations for brake mechanics I and II at Facility D were 0.15 fibers/cc and 0.10 fibers/cc, respectively. General area sample concentrations ranged from 0103 to 0.14 fibers/cc for samples collected at various locations within the facility (Table 4).

Facility E

The sample results from the 1976 survey conducted at Facility E indicated personal TWA exposures of 0.08, 0.12, 0.07 and 0.10 fibers/cc for the four brake mechanics. General area sample concentrations ranged from 0.04 to 0.19 fibers/cc (Table 5-A).

Air samples were also collected at this facility in 1977 during a five-day period (Table 5-B). Sample results indicated TWA exposures for Mechanic I, II, III and the Partsman to be 0.18, 0.07, 0.11 and 0.11 fibers/cc, respectively. These exposure concentrations represent a time-weighted average for all personal samples collected during the 5 day period. TWA concentrations for general area samples collected during the week ranged from 0.05 to 0.06 fibers/cc. Short duration samples 30-60 seconds) were collected to determine peak exposure concentrations to asbestos dust during the servicing of brake shoes.

Peak concentrations ranged from 0.45 (dry brush cleaning) to 14.54 (compressed air cleaning) fibers/cc.

Facility F

Personal samples collected from two mechanics at Facility F (Table 6) indicated exposures of 0.02 and 0.03 fibers/cc, respectively, while the one general area sample had a concentration of 0.01 fibers/cc of air.

Facility G

Facility G, which was surveyed in 1976 and again in 1977, was involved in the maintenance of truck brakes. Worker exposures tended to be somewhat different as the servicing was more complex and the number of vehicles serviced per day much less. However, due to larger wheels and drums, the brake pad replacement operation made it difficult for the workers to avoid the generated airborne dust. Consequently, the exposures were higher than those found during automobile brake maintenance.

Personal samples collected during the first survey in 1976 (Table 7-A) compared similarly to those sample results found at the auto brake service shops. The TWA concentration for brake mechanic I was 0.05 fiber/cc while the concentration for mechanic II was 0.18 fiber/cc. The second survey conducted in 1977 (Table 7-B), however, was found to be distinctly higher. The concentration for brake mechanic I was 1.68 fibers/cc, for mechanic II, 0.53, and for mechanic III, 0.52 fibers/cc of air. General area samples collected in the 1976 survey indicated concentrations which ranged from 0.03 fibers/cc in the eating area, 0.03 to 0.11 fibers/cc in the bay areas and 0.12 to 1.18 fibers/cc in the Relining Department.

In contrast, general area samples collected in 1977 at this facility indicated the following range of concentrations; Office - 096 to 1.68 fibers/cc; Garage (east side) - 0.26 to 1.72 fibers/cc; Garage (west side) - 0.24 to 1.71 fibers/cc. It is readily noted that these concentrations are higher than those of the general area sample results found at the auto brake service shops. The areas of highest exposure concentrations at the truck brake service shop appear to be in the vicinity of the rivet, punch, and pad grinding operations. The rivet operator's TWA concentrations were 3.41 fibers/cc (1976) and 4.47 fibers/cc (1977), while that of the punch operator was 0.68 fiber/cc (1976) and 7.52 fiber/cc (1977).

Metal Analyses

Trace metal analyses were performed on airborne samples collected during the 1977 survey at Facility E (Table 8) and at Facility G (Table 9). Samples were analyzed for trace amounts of the following metals: lead, iron, zinc, chromium, nickel, cobalt, copper, manganese, and aluminum. As noted in Tables 8 and 9 most of the metals were either non-detectable or found in trace amounts.

Fiber Characterization

Samples selected for transmission electron microscopy (TEM) were sized by length and diameter and fiber concentrations (fibers/cc) determined for total fibers and fibers > 5 μm in length. These concentrations were compared to those found by the optical microscopy method and are reported in Table 10. In all but 3 samples, fiber concentrations (> 5 μm) determined by phase contrast optical microscopy were somewhat higher than those determined by TEM. This difference could have been caused by particulate loss during the preparation of samples for TEM. Another factor which may reflect the difference found in sample comparisons is the small number of fibers observed on each sample. Small differences in the number of fibers counted by both methods would produce significant differences in concentrations.

Besides determining the concentrations for fibers > 5 μm in length, total fibers observed were counted and concentrations calculated. As would be expected, the greatest number of fibers observed were shorter than 5 μm in length (82%).

In addition to fiber sizing and counting, identification was attempted on all fibers utilizing selected area electron diffraction (SAED) and energy dispersive X-ray analysis. Approximately 50% of the fibers analyzed by SAED could not be identified due to ambiguous diffraction patters. The remaining fibers were identified as chrysotile (30% and forsterite (20%). When energy dispersive X-ray analysis was performed on the fibers, confirmation of the SAED analysis was made for the chrysotile and forsterite fibers. Those fibers which revealed ambiguous SAED patterns were either too small for diffraction analysis or had undergone elemental changes probably as a result of intense heat. The elemental composition of some of hese fibers appeared to indicate a stage of metamorphosis between chrysotile and forsterite.

DISCUSSION

Airborne asbestos sample results for all facilities appear to be within the current OSHA asbestos standard. This standard states:

> "The 8-hour time-weighted average (TWA) airborne concentration of asbestos fibers to which any employee may be exposed shall not exceed 2 fibers, longer than 5 micrometers in length, per cubic centimeter of air (fibers > 5 μm/cc). The ceiling airborne concentration to which no employee may be exposed shall not exceed 10 fibers > 5 μm/cc."

However, when the results are compared to the NIOSH recommended standard, in which the 8-hour TWA exposure to asbestos is 0.1 fibers > 5 μm/cc with a ceiling exposure of 0.5 fibers > 5 μm/cc for any 15 minute sampling period, many of the exposures to brake servicing mechanics indicate concentrations which exceed these recommendations. Although most of the reported TWA exposures are based on sampling times less than 8 hours, (usually 3 to 8 hours) the randomness of the sample collection throughout the work day at each facility suggests a consistent range of exposure concentrations for any given operation. These ranges of exposure appear to be dependent upon the work practices utilized in servicing brakes. It is readily apparent that compressed air cleaning, and to a lesser extent dry cleaning can produce peak exposures which exceed both the OSHA standard and the NIOSH recommended standard.

The airborne exposures found at these facilities compare favorably to studies performed by other investigators. Studies by Lorimer et al[1] and Rohl et al[2] reported peak concentrations to asbestos fibers ranging from 6.6 to 29.8 fibers/cc when compressed air cleaning was used. In addition, the elevated exposures found during the use of dry brush cleaning in Facility E (0.45 - 0.91 fibers/cc) were likewise substantiated by Rohl et al[2] study in which they found exposures ranging from 1.3 - 3.6 fibers/cc.

The one truck brake servicing facility (G) surveyed indicated high asbestos fiber exposures during the riveting and grinding of truck brake shoes (0.68 - 7.52 fibers/cc). A similar magnitude of exposures were found by Lorimer et al[1] in which workers beveling truck brakes were exposed to concentrations of 26.3 to 72.0 fibers/cc. The practice of refurbishing and custom fitting brake shoes in automobile brake servicing facilities appears to be limited. However, the need for custom fitting of brake shoes in the truck servicing facilities is often necessary. As demonstrated, the exposures found in refurbishing truck brakes add greatly to the asbestos dust burden of the worker.

The electron microscopy (EM) analysis performed on selected air samples indicates that a majority of the airborne fiber exposures consist of small fibers (< 5 μm in length and < 1 μm in diameter). These results were confirmed by studies of Rohl et al[2], Lorimer et al[1], and Lynch[8] in which they found 80-90% of the fibers observed by EM to be below the resolution of the optical microscope. The results of the EM analysis also suggests that many of the chrysotile fibers released during braking had undergone a decomposition phase and changed both physical and chemical characteristics to that of forsterite. These findings were supported by the study of Lorimer et al.[1]

The human toxicological siginficance for the inhalation to chrysotile fibers is well documented. However, the health effects of exposure to forsterite, or transition fibers of chrysotile-forsterite are not well documented. In studies by Davis and Coniam[9] and Koshi[10] in which fibers of chrysotile, chrysotile-forsterite, and forsterite were injected into the pleural and peritoneal cavities of mice the results suggest varying degrees of toxic effects for all types. The mechanism responsible for these observed toxic effects is unclear, but animal studies by Pott et al[11,12] and David et al[13] indicate that the morphology and size of the fiber are responsible for its carcinogenicity. It is suspected by Pott et al[12] that a fiber with a diameter < 1 μm and a length > 3 um has the greatest carcinogenic potential, likewise, Stanton et al[14] suggests that fibers < 1.5 μm in diameter and > 8 μm in length pose the greatest risk in producing pleural sarcomas.

CONCLUSION

Results of this study and of other studies indicate varying concentrations of asbestos fiber exposures which appear to be dependent upon the type of brake servicing operation and work practices utilized. It is apparent that when brake shoes are beveled, ground, riveted, etc. that exposures to asbestos fibers can be quite high. Likewise, exposures generated during the cleaning of brake shoes and drums with compressed air and dry brush methods can be high for short durations of time.

NIOSH has undertaken a comprehensive industrial hygiene study to address the following areas:

1. Document work practices (i.e. protective clothing, respirator protection, eating and smoking practices, etc.)
2. Document the use of engineering controls (i.e. vacuum cleaners, local exhaust ventilation, etc.)
3. Document housekeeping practices (i.e. disposing of old brake and clutch materials, rags, etc.)
4. Determine 8-10 hour TWA exposures and peak exposures to workers as determined by the different work practices (i.e. compressed air, dry and wet brushing, etc.) utilized while engaged in brake servicing operations.
5. Characterize and identify airborne fiber exposures using optical and transmission electron microscopy.

Based on the data from other studies and the data from this study demonstrating significant asbestos exposures during brake servicing operations, NIOSH has published interim procedures, "Recommended Procedures for Asbestos Brake and Clutch Servicing" to minimize asbestos dust exposures.[15] These recommended procedures are periodically updated as research data and engineering controls become available.

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Table 1

Facility A
Automobile Fleet Garage
Fiber Air Sample Results
Optical Microscopy

Operation	Sample #	Volume (liters)	Concentration Fibers > 5 μm/cc
Brake and Front End Mechanic			
	B-104	30	0.15
	B-99	152	0.16
	B-102	160	0.07
			TWA 0.12
General Area			
Right Front	B-105	120	0.03
Left Center	B-98	262	0.02
Right Front	B-101	216	0.07
Shop	B0103	232	0.03

TWA - Time-Weighted Average exposure for period of time samples

Table 2

Facility B
Automobile Brake Shop
Fiber Air Sample Results
Optical Microscopy

Sample Location	Volume (liters)	Time (min.)	Concentration Fiber > 5 µm/cc
Brake Mechanic	758	379	0.10
	190	95	0.15
			0.12
General Area near brake servicing operation	312	156	0.09
	282	141	0.13

TWA = Time-Weighted Average exposure for period of time sampled

Table 3

Facility C
Automobile Brake Shop
Fiber Air Sample Results
Optical Microscopy

Type Sample	Volume (liters)	Time (min)	Concentration Fibers > 5 µm/cc
Personal			
#1 compressed air/ cleaning drums	6	3	peak 1.82
#2	164	22	0.07
#3	174	87	0.05
#4	306	243	0.02
			TWA 0.03
General Area			
East Front	548	274	0.01
North Side	546	282	0.01
North Side	186	98	0.02
South Side	122	61	0.17
East Front	196	98	0.05
South Side	142	71	0.02
South Side	471	235	0.01

TWA - Time-Weighted Average exposure for period of time sampled

Table 4

Facility D
Automobile Brake Shop
Fiber Air Sample Results
Optical Microscopy

Operation	Sample #	Volume (liters)	Time (min)	Concentration Fiber > 5 μm/cc
Brake & Front End Mechanic				
I	B-38	50	25	0.03
	B-37	28	14	0.37
	B-46	106	53	0.14
				TWA 0.15
II	B-36	76	38	0.21
	B-51	72	36	0.05
	B-44	4	2	2.33
	B-39	214	107	0.04
				TWA 0.10
General Area				
W. Back Wall	B-40	98	49	0.09
E. Front	B-41	50	25	0.03
N. Side	B-42	64	32	0.09
W. Back Wall	B-50	82	41	0.06
S. Side	B-49	82	41	0.07
E. Front	B-48	82	41	0.14
N. Side	B-47	84	42	0.04
W. Back Wall	B-32	130	65	0.12
S. Side	B-43	82	41	0.13
N. Side	B-34	116	58	0.13
E. Front	B-35	136	68	0.05

TWA - Time-Weighted Average exposure for period of time sampled

Table 5-A

Facility E
Automobile Brake Shop
Fiber Air Sample Results
Optical Microscopy

Operation	Sample #	Volume (liters)	Time (min)	Concentration Fibers > 5μm/cc
Brake & Front End Mechanic				
I	B-3	440	220	0.06
	B-11	104	52	0.07
	B-30	50	25	0.12
	B-22	92	46	0.14
				TWA 0.08
II	B-1	466	233	0.05
	B-2	252	126	0.07
	B-19	80	40	0.12
	B-29	52	26	0.27
	B-12	72	36	0.58
				TWA 0.12
III	B-9	210	105	0.13
	B-27	72	36	0.11
	B-13	284	142	0.02
				TWA 0.07
IV	B-10	208	104	0.03
	B-18	42	21	0.33
	B-20	240	120	0.12
	B-8	102	51	0.12
				TWA 0.10
General Area				
Stall 4	B-25	84	42	0.19
Stall 5	B-7	452	226	0.07
Stall 1	B-14	102	51	0.10
Stall 5	B-26	60	30	0.10
Stall 2-3	B-24	128	64	0.08

Table 5-A (continued)

Operation	Sample #	Volume (liters)	Time (min)	Concentration Fibers > 5μm/cc
General Area				
Stall 1	B-23	130	65	0.19
Stall 5	B-17	104	52	0.10
Stall 4	B-16	104	52	0.09
Stall 2-3	B-15	102	51	0.07
Stall 4	B-6	444	222	0.03
Stall 1	B-4	462	231	0.04
Stall 2-3	B-5	454	227	0.08
Shop Wall	B-33	100	50	0.05
S.E. Corner	B-31	40	20	0.15

TWA - Time-Weighted Average exposure for period of time sampled

Table 5-B

Facility E
Automobile Brake Shop
Fiber Air Sample Results
Optical Microscopy

Sample Location	Day of the Week	No. of Samples Collected	Range of Concentrations Fibers > 5 µm/cc	Time-Weighted Average (TWA) Concentration by Day Fibers > 5 µm/cc	TWA by Week
(Personal)					
Brake Mechanic I	1	3	0.05 - 0.1	0.07	0.18
	2	4	0.02 - 0.26	0.12	
	3	3	0.09 - 0.15	0.20	
	4	2	0.05 - 0.06	0.05	
	5	1	0.01 - 0.01	0.01	
Brake Machanic II	1	3	0.03 - 0.09	0.07	0.07
	2	3	0.04 - 0.13	0.09	
	3	3	0.01 - 0.27	0.18	
	4	3	0.06 - 0.10	0.08	
	5	3	0.01 - 0.04	0.02	
Brake Machanic III	1	3	0.03 - 0.06	0.04	0.11
	2	3	0.08 - 0.29	0.12	
	3	4	0.07 - 0.38	0.14	
	4	5	0.07 - 0.24	0.16	
	5	2	0.15 - 0.19	0.17	
Partsman	1	1	0.06 - 0.06	0.06	0.11
	2	2	0.03 - 0.78	0.09	
	3	3	0.01 - 0.30	0.15	
	4	4	0.07 0.24	0.16	
	5	3	0.01 - 0.06	0.03	
(General Area)					
Office	1	2	0.03 - 0.18	0.10	0.06
	2	2	0.01 - 0.02	0.02	
	3	2	0.12 - 0.18	0.17	
	4	2	0.03 - 0.05	0.04	
	5	2	0.01 - 0.07	0.03	
Southside	1	8	0.01 - 0.11	0.05	0.06
	2	7	0.02 - 0.25	0.11	
	3	6	0.01 - 0.32	0.05	
	4	10	0.00 - 0.14	0.06	
	5	2	0.01 - 0.01	0.01	

Table 5-B
(continued)

Sample Location	Day of the Week	No. of Samples Collected	Range of Concentrations Fibers > 5 μm/cc	Time-Weighted Average (TWA) Concentration by Day Fibers > 5 μm/cc	TWA by Week
Northside	1	6	0.01 - 0.06	0.05	0.05
	2	6	0.03 - 0.14	0.06	
	3	7	0.00 - 0.39	0.06	
	4	8	0.01 - 0.13	0.05	
	5	4	0.01 - 0.07	0.04	
(Peak)					
Cleaning with Compressed Air	1	--	--	N/A	N/A
	2	1	2.84	N/A	
Dry Brush Compressed Air	3	2	0.45 0.68	N/A	
Dry Brush - Compressed Air	4	2	0.91	N/A	
	5	--	14.54	N/A	

TWA - Time-Weighted Average exposure for period of time sampled

Table 6

Facility F
Automobile Brake Shop
Fiber Air Sample Results
Optical Microscopy

Sample Number	Volume (liters)	Time (min)	Concentration Fibers > 5 μm/cc
Mechanic B1 (Personal)	360	180	0.02
Mechanic B2 (Personal)	196	98	0.03
B3 (Area)	150	85	0.01

Table 7-A (1976)

Facility G
Truck Brake Shop
Fiber Air Sample Results
Optical Microscopy

Operation	Sample #	Volume (liters)	Time (min)	Concentration Fibers > 5μm/cc
BRAKE REBUILDING				
Brake Mechanic				
I	B-69	102	51	0.09
	B-75	158	79	0.07
	B-87	194	97	0.03
	B-92	152	76	0.03
				TWA 0.05
II	B-60	52	26	0.09
	B-63	84	42	0.72
	B-57	60	30	0.15
	B-79	122	61	0.17
	B-88	194	97	0.03
				TWA 0.18
RELINING DEPARTMENT				
Rivet Operator	B-67	50	25	1.59
"	B-81	76	38	0.38
"	B-96	138	69	5.62
"	B-89	176	88	3.64
"	B-84	168	84	0.19
"	B-78	62	31	3.34
"	B-72	60	30	6.00
"	B-57	112	56	6.79
"	B-58	42	21	6.52
				TWA 3.41
Punch Operator	B-61	72	36	0.18
	B-66	50	25	0.97
	B-71	60	30	0.56
	B-77	62	31	0.78

Table 7-A (1976) (continued)

Operation	Sample #	Volume (liters)	Time (min)	Concentration Fibers > 5μm/cc
Punch Operator	B-95	152	76	0.24
"	B-80	74	37	0.70
"	B-97	138	69	0.79
				TWA 0.68
<u>GENERAL AREA</u>				
Eating Area	B-55	224	112	0.03
"	B-94	162	81	0.03
1st and 2nd Bay	B-54	120	60	0.05
"	B-64	248	124	0.03
"	B-65	246	123	0.05
"	B-74	350	175	0.06
"	B-91	64	32	0.05
"	B-56	120	60	0.11
				TWA 0.06
Relining Department	B-53	88	44	0.39
"	B-62	72	36	1.18
"	B-68	48	24	0.54
"	B-76	106	53	0.20
"	B-93	312	156	0.18
"	B-86	172	86	0.12
"	B-70	148	74	0.15
				TWA 0.28

TWA - Time-Weighted Average exposure for period of time sampled

Table 7-B (1977)

Facility G
Fiber Air Sample Results
Optical Microscopy

Operation/Area	Sample #	Volume (liters)	Time (min)	Concentration Fibers > 5μm/cc
BRAKE REBUILDING				
Brake Mechanic I	D-3	240	120	1.09
	D-8	246	123	3.24
	D-13	280	140	0.804
				TWA 1.68
Brake Mechanic II	D-4	184	92	0.289
	D-7	512	256	0.62
				TWA 0.53
Brake Mechanic III	D-15	272	136	0.52
RELINING DEPARTMENT				
Rivet Operator	D-2	160	80	2.0
	D-6	184	92	5.59
	D-9	106	53	7.53
	D-10	168	84	6.84
	D-14	296	148	2.68
				TWA 4.47
Punch Operator	D-12	100	50	7.31
	D-16	126	63	5.90
	D-17	66	33	10.92
				TWA 7.52
Partsman	D-5	400	200	1.21

Table 7-B (1977) (continued)

Operator/Area	Sample #	Volume (liters)	Time (min)	Concentration Fibers > 5μm/cc
<u>GENERAL AREA</u>				
Office	D-1	490	245	1.68
	D-11	440	220	0.96
Garage (East)	C-1	664	69	0.46
	C-4	847	88	0.33
	C-6	529	55	1.72
	C-8	1366	142	0.82
	C-11	1010	105	0.46
	C-14	269	28	0.26
Garage (West)	C-2	740	67	0.65
	C-3	773	70	0 76
	C-5	640	58	1.44
	C-7	574	52	1.71
	C-10	585	53	1.30
	C-12	927	84	0.49
	C-13	298	27	0.24

Table 8

Facility E
Automobile Brake Shop
Air Sample Results
Trace Metal Analysis

Sample Number	Volume (liters)	Location of Sample	Trace Metals mg/filter sample		
			Fe	Pb	Zn
A-16	670	General Area Northside	17.0	8.0	< 1.0
A-17	809	General Area Southside	30.0	11.0	< 1.0
B-15	92	Brake Mechanic I	7.0	< 5.0	< 1.0
B-17	880	General Area Office	9.0	< 5.0	< 1.0
A-21	756	General Area Southside	27.0	< 5.0	< 1.0
A-27	373	General Area Southside	16.0	< 5.0	< 1.0
B-10	450	General Area Office	< 5.0	< 5.0	9.0
A-8	756	General Area Northside	< 5.0	< 5.0	< 1.0
B-11	234	Brake Mechanic III	13.0	< 5.0	3.0
A-74	8.0	Dry Brush Cleaning	65.0	< 5.0	< 1.0
A-76	259	General Area Northside	16.0	< 5.0	< 1.0
A-83	346	General Area Northside	14.0	6.0	< 1.0
A-46	605	General Area Northside	33.0	8.0	< 1.0
A-91	486	General Area Northside	33.0	8.0	< 1.0
B-63	480	General Area Office	7.0	6.0	< 1.0
B-73	276	Brake Mechanic III	29.0	8.0	< 1.0
B-64	326	Partsman	29.0	< 5.0	< 1.0
A-87	373	General Area Southside	22.0	< 5.0	< 1.0
B-70	262	Brake Mechanic II	26.0	< 5.0	< 1.0
B-81	124	Brake Mechanic III	< 5.0	< 5.0	< 1.0
A-99	320	General Area Southside	< 5.0	11.0	< 1.0
B-65	220	Brake Mechanic II	17.0	< 5.0	< 1.0

Table 8 (continued)

Facility E
Automobile Brake Shop
Air Sample Results
Trace Metal Analysis

Sample Number	Volume (liters)	Location of Sample	Trace Metals mg/filter sample Fe	Pb	Zn
A-88	320	General Area Southside	52.0	<5.0	<1.0
A-92	533	General Area Southside	37.0	9.0	<1.0
A-93	670	General Area Northside	17.0	16.0	1.0
B-57	164	Partsman	32.0	< 5.0	1.0
B-48	200	Brake Mechanic III	28.0	6.0	3.0
B-82	90	General Area Office	< 5.0	< 5.0	<1.0
A-89	324	General Area Northside	33.0	< 5.0	<1.0
B-72	228	Partsman	13.0	< 5.0	<1.0
B-53	170	Brake Mechanic II	23.0	< 5.0	<1.0
A-97	324	General Area Northside	12.0	< 5.0	<1.0
B-71	120	Brake Mechanic III	8.0	6.0	<1.0
A-84	972	General Area Northside	9.0	< 5.0	<1.0
B-80	144	Brake Mechanic II	< 5.0	< 5.0	<1.0
B-77	334	Brake Mechanic II	7.0	8.0	<1.0
G-68	216	Brake Mechanic I	59.0	< 5.0	<1.0
B-54	270	Brake Mechanic III	7.0	< 5.0	<1.0
A-86	616	General Area Northside	15.0	9.0	<1.0
B-59	220	Brake Mechanic I	18.0	6.0	1.0
A-71	810	General Area Northside	18.0	11.0	6.0
B-58	206	Partsman	32.0	< 5.0	<1.0
B-46	214	Partsman	43.0	< 5.0	2.0
B-43	106	Partsman	8.0	< 5.0	<1.0
B-78	184	Partsman	12.0	5.0	<1.0

Table 8 (continued)

Facility E
Automobile Brake Shop
Air Sample Results
Trace Metal Analysis

Sample Number	Volume (liters)	Location of Sample	Trace Metals mg/filter sample Fe	Pb	Zn
B-69	206	Brake Mechanic I	30.0	< 5.0	2.0
A-90	373	General Area Southside	42.0	7.0	< 1.0
A-48	458	General Area Southside	160.0	8.0	1.0
B-33	222	Partsman	31.0	5.0	1.0
A-98	648	General Area Northside	< 5.0	26.0	< 1.0
A-85	916	General Area Southside	30.0	7.0	< 1.0
B-61	172	Brake Mechanic II	17.0	8.0	< 1.0
A-73	5.33	Compressed Air Cleaning	36.0	< 5.0	2.0
A-77	479	General Area Southside	43.0	13.0	< 1.0
A-81	533	General Area Southside	30.0	13.0	< 1.0
A-49	1015	General Area Northside	21.0	11.0	< 1.0
B-32	364	Brake Mechanic II	22.0	7.0	< 1.0
B-36	334	Brake Mechanic II	18.0	6.0	< 1.0
A-44	670	General Area Northside	25.0	< 5.0	< 1.0
A-40	469	General Area Southside	9.0	16.0	< 1.0
B-29	172	Brake Mechanic III	23.0	5.0	< 1.0
B-24	502	General Area Office	14.0	21.0	< 1.0
A-57	618	General Area Southside	33.0	6.0	< 1.0
B-34	226	Brake Mechanic I	30.0	< 5.0	< 1.0
B-45	652	General Area Office	19.0	9.0	< 1.0
A-53	8.0	Dry Brush Cleaning	9.0	< 5.0	< 1.0
A-6	648	General Area Northside	32.0	27.0	1.0

Table 8 (continued)

Facility E
Automobile Brake Shop
Air Sample Results
Trace Metal Analysis

Sample Number	Volume (liters)	Location of Sample	Trace Metals mg/filter sample Fe	Pb	Zn
B-18	162	Brake Mechanic II	24.0	< 5.0	<1.0
B-14	76	Partsman	52.0	5.0	<1.0
A-14	916	General Area Southside	21.0	8.0	<1.0
G-9	242	Brake Mechanic I	19.0	< 5.0	<1.0
A-20	575	General Area Southside	39.0	13.0	<1.0
B-19	370	Brake Mechanic I	35.0	10.0	<1.0
A-41	415	General Area Southside	27.0	< 5.0	1.0
A-38	639	General Area Southside	16.0	11.0	<1.0
A-33	426	General Area Southside	50.0	< 5.0	<1.0
B-25	194	Brake Mechanic I	9.0	< 5.0	9.0
B-26	394	Brake Mechanic II	12.0	8.0	<1.0
A-58	680	General Area Northside	22.0	5.0	<1.0
B-41	370	General Area Office	10.0	6.0	<1.0
B-37	358	Partsman	17.0	7.0	<1.0
A-52	648	General Area Northside	35.0	< 5.0	<1.0
A-51	426	General Area Southside	45.0	< 5.0	<1.0
B-35	160	Brake Mechanic III	68.0	< 5.0	2.0
B-42	200	Brake Mechanic II	14.0	< 5.0	<1.0
A-55	5.32	Compressed Air Cleaning	34.0	< 5.0	<1.0
A-50	660	General Area Southside	15.0	8.0	<1.0
A-47	426	General Area Southside	39.0	9.0	2.0

Table 8 (continued)

Facility E

Automobile Brake Shop
Air Sample Results
Trace Metal Analysis

Sample Number	Volume (liters)	Location of Sample	Trace Metals mg/filter sample Fe	Pb	Zn
A-31	543	General Area Southside	36.0	24.0	1.0
A-37	648	General Area Northside	9.0	41.0	<1.0
A-34	616	General Area Northside	22.0	< 5.0	<1.0
B-21	840	Partsman	14.0	< 5.0	3.0
B-27	108	Brake Mechanic I	21.0	< 5.0	38.0
A-26	400	General Area Northside	6.0	11.0	< 1.0
A-28	554	General Area Southside	11.0	19.0	9.0
B-22	388	Brake Mechanic II	7.0	< 5.0	< 1.0
B-1	188	Brake Mechanic III	14.0	< 5.0	< 1.0
B-16	72	Brake Mechanic III	18.0	< 5.0	12.0
A-10	950	General Area Northside	13.0	< 5.0	4.0
B-3	198	Brake Mechanic I	24.0	< 5.0	2.0
B-8	204	Brake Mechanic II	6.0	< 5.0	< 1.0
A-9	415	General Area Southside	34.0	10.0	2.0
A-12	426	General Area Southside	< 5.0	8.0	< 1.0
B-7	292	Brake Mechanic I	24.0	8.0	< 1.0
B-5	280	Brake Mechanic II	12.0	8.0	1.0

Note: Sample analyses for Mn, Al, Cr, Ni and Co were not detected.

Limit of detection (μg)

Lead	5 μg
Zinc	1 μg
Manganese	2 μg
Aluminum	10 μg
Chromium	2.5 μg
Nickel	5.0 μg
Cobalt	5.0 μg
Iron	5.0 μg

Table 9

Facility G
Truck Brake Shop
Air Sample Results
Trace Metal Analysis

Sample Number	Volume (liters)	Location of Sample	Trace Metals mg/filter sample					
			Pb	Fe	Zn	Mn	Cu	Al
C-1	126	Punch Oper.	--	--	--	--	0.6	1.0
C-2	66	Punch Oper.	--	--	--	--	1.0	1.0
C-3	664	Garage-Eastside	16.0	34.0	< 1.6	1.6	--	--
C-4	740	Garage-Westside	16.0	58.0	< 1.6	1.6	--	--
C-5	773	Garage-Westside	10.0	56.0	< 1.6	2.6	--	--
C-6	847	Garage-Eastside	10.0	24.0	< 1.6	1.6	--	--
C-7	640	Garage-Westside	6.0	82.0	< 1.6	2.0	--	--
C-8	529	Garage-Eastside	< 6.0	122.0	< 1.6	2.0	--	--
C-10	574	Garage-Westside	6.0	142.0	< 1.6	2.0	--	--
C-11	1366	Garage-Eastside	--	--	--	--	1.6	< 0.6
C-12	585	Garage-Westend	--	--	--	--	< 0.6	0.6
C-13	1010	Garage-Eastend	--	--	--	--	1.0	< 0.6
C-14	927	Garage-Westend	--	--	--	--	< 0.6	< 0.6

Table 9 (continued)

Facility G
Truck Brake Shop
Air Sample Results
Trace Metal Analysis

Sample Number	Volume (liters)	Location of Sample	Trace Metals mg/filter sample					
			Pb	Fe	Zn	Mn	Cu	Al
D-1	490	Office Area	--	--	--	--	0.6	< 0.6
D-2	160	Rivet Oper.	--	--	--	--	0.6	0.6
D-3	240	Mechanic I	--	--	--	--	1.0	< 0.6
D-4	184	Mechanic II	--	--	--	--	1.0	< 0.6
D-5	400	Partsman	--	--	--	--	0.6	< 0.6
D-6	184	Rivet Oper.	--	--	--	--	1.6	1.0
D-7	512	Mechanic II	6.0	32.0	< 3.2	< 1.0	--	--
D-8	246	Mechanic I	--	--	--	--	1.0	1.0
D-9	106	Rivet Oper.	10.0	154.0	< 3.2	1.6	--	--
D-10	168	Rivet Oper.	< 6.0	148.0	< 3.2	1.6	--	--
D-11	440	Office Area	< 6.0	13.0	< 3.2	< 1.0	--	--
D-12	100	Punch Oper.	< 6.0	15.6	2.6	< 1.0	--	--
D-13	280	Mechanic I	< 6.0	20.0	1.6	< 1.0	--	--
D-14	296	Rivet Oper.	< 6.0	96.0	2.6	1.6	--	--
D-15	272	Mechanic III	< 6.0	16.0	1.6	< 1.0	--	--

Table 9 (continued)

Facility G
Truck Brake Shop
Air Sample Results
Trace Metal Analysis

Sample Number	Volume (liters)	Location of Sample	Trace Metals mg/filter sample					
			Pb	Fe	Zn	Mn	Cu	Al
D-16	126	Punch Oper.	--	--	--	--	0.6	1.0
D-17	66	Punch Oper.	--	--	--	--	1.0	1.0

Note: Sample analyses for Cr, Ni and Co were not detected

Limit of Detection (mg)

Lead	6 mg
Iron	5 mg
Zinc	1.6 mg
Manganese	1.0 mg
Copper	0.6 mg
Aluminum	0.6 mg

Table 10

Fiber Air Sample Results
Comparison Between TEM and Optical Microscopy Analysis

Sample Number	Optical Microscopy	Transmission Electron Microscopy		% Fibers >5 μm in length (TEM)
	>5 μm in length fibers/cc	>5 μm in length fibers/cc	Total fibers fibers/cc	
B-68	0.54	0.25	0.50	50
B-72	6.0	5.97	11.33	53
B-12	0.58	0.17	1.01	17
B-62	1.18	0.67	2.35	29
B-18	0.13	0.10	0.74	14
D-10	6.84	0.07	0.43	17
D-6	5.59	0.33	0.39	83
C-8	0.82	0.02	0.02	100
B-59	0.01	0.0	0.11	0
B-58	0.01	0.0	0.0	0
G-77	0.02	0.19	2.72	14
G-81	0.38	0.16	0.48	33
C-5	1.44	0.0	0.08	0
G-67	0.01	0.0	1.43	0
C-14	0.26	0.09	0.09	100
C-13	0.24	0.04	0.16	25
B-32	0.06	0.0	0.0	0
G-22	0.12	0.01	0.01	100
B-44	0.01	0.0	0.03	0
B-41	0.03	0.0	0.0	0
D-18 (Blank)	0.0	0.0	0.0	0
B-37	0.12	0.42	0.86	33
B-79	0.17	0.10	0.20	33
G-63	0.18	0.14	0.43	25
G-9	0.06	0.05	0.15	40
G-68	0.12	0.50	0.73	41