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Regulatory Toxicology and Pharmacology 38 (2003) 58–70

Regulatory Toxicology and Pharmacology

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Airborne asbestos concentration from brake changing does not exceed permissible exposure limit

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Received 27 January 2003

Abstract

The use in the past, and to a lesser extent today, of chrysotile asbestos in automobile brake systems causes health concerns among professional mechanics. Therefore, we conducted four separate tests in order to evaluate an auto mechanic's exposure to airborne asbestos fibers while performing routine brake maintenance. Four nearly identical automobiles from 1960s having four wheel drum brakes were used. Each automobile was fitted with new replacement asbestos-containing brake shoes and then driven over a predetermined public road course for about 2253 km. Then, each car was separately brought into a repair facility; the brakes removed and replaced with new asbestos-containing shoes. The test conditions, methods, and tools were as commonly used during the 1960s. The mechanic was experienced in brake maintenance, having worked in the automobile repair profession beginning in the 1960s. Effects of three independent variables, e.g., filing, sanding, and arc grinding of the replacement brake shoe elements, were tested. Personal and area air samples were collected and analyzed for the presence of fibers, asbestos fibers, total dust, and respirable dust. The results indicated a presence in the air of only chrysotile asbestos and an absence of other types of asbestos. Airborne chrysotile fiber exposures for each test remained below currently applicable limit of 0.1 fiber/ml (eight-hour time-weighted average).

Keywords: Asbestos exposure; Chrysotile; Automotive brake; Brake change; Drum brake; Brake lining

1. Introduction

In the past, and to a lesser extent today, automotive brake friction compounds contained chrysotile asbestos as a component. The chrysotile content of brakes ranges from 33 to 73% by weight (Jacko and DuCharme, 1973; Lynch, 1968; Meylan et al., 1978; Williams and Muhlbaier, 1982). Chrysotile provides strength and flexibility and allows brakes linings to be molded from powdered resins (Hatch, 1970). The primary purpose of the chrysotile is not heat resistance, but to act as an aggregate for the resins and other materials. Prior research and testing indicate that nearly all of the chrysotile in brake friction pads and shoes is sacrificed during braking action and converted into non-asbestos material which is emitted as part of the brake dust (Anderson et al., 1973; Jacko and DuCharme, 1973; Rowson, 1978; Weir et al., 2001; Williams and Muhlbaier, 1982). In addition, Weir et al. (2001) show that the few remaining asbestos fibers have binder material deposited along their length and, thus are less likely to enter into the respiratory system. Moreover, fibers with lengths $\geqslant 5\,\mu m$ constitute less than 1% of all chrysotile fibers in brake drum dust (Rödelsperger et al., 1986). For drum style brakes, a quantity of the overall brake wear dust is typically retained inside the brake drums and thus may pose an inhalation risk to mechanics during brake replacement/repair. It has been estimated that in the USA about 100 000 (National Institute for Occupational Safety and Health, 1977) to 900 000 (National Institute for Occupational Safety and Health, 1975) individuals have a potential for exposure to asbestos due to brake

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0273-2300/03/$ - see front matter © 2003 Elsevier Science (USA). All rights reserved.
doi:10.1016/S0273-2300(03)00069-2

maintenance/repair work. Although epidemiological evidence supports a notion that disease from this exposure is unlikely (Hansen, 1989; Rushton et al., 1983; Wong, 1992, 2001), many workers are concerned about their health. Therefore, this potential exposure has been the subject of numerous environmental and industrial hygiene studies.

Early studies utilized phase contrast microscopy (PCM) to investigate the potential exposures. These studies (Hatch, 1970; Hickish and Knight, 1970; Knight and Hickish, 1970) generally focused on specific segments of the brake replacement operation, reporting results without the time of exposure. These data ranged from <1 fiber(s)/ml of air (f/ml) to 87 f/ml for some short term samples. Hickish and Knight (1970) did report a set of data for an entire shift of brake cleaning involving 11 cars, that is 0.68 f/ml time-weighted average (TWA), though not for a complete brake repair/replacement operation. These early studies are supplemented by a series of studies conducted by the U.S. National Institute for Occupational Safety and Health (NIOSH) beginning in 1972. These studies were conducted at a number of different brake repair facilities, primarily in the Midwest and Northeast (Dement, 1972; Johnson, 1976; Nicholson et al., 1982; Roberts, 1980a,b; Roberts and Zumwalde, 1982). Most of the studies show PCM exposure estimates for automobile brake replacement/repair to be at or below the existing U.S. Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 0.1 f/ml [eight-hour (8 h) TWA]. More recent studies, using optical and/or electron microscopy as the analytical procedure, found similar results (Cheng and O'Kelly, 1986; Kauppinen and Korhonen, 1987; Rödelsperger et al., 1986).

None of these industrial hygiene brake studies covers the complete brake replacement process in a controlled, scientifically designed manner. Most studies simply deal with randomly selected vehicles having unknown brake composition and operational histories. Most often the historical tests are conducted in nonreproducible settings, typically without consideration of any background airborne fiber exposures not directly related to the brake replacement process. Based on the dates of the historical tests, it is likely that many of the passenger vehicles tested were equipped with disc style front brakes that may yield different levels of exposure than vehicles with four wheel drum style brakes. No studies attempt to quantify the relative effects of filing, sanding, and grinding of friction materials on the brake replacement process. While some of the published studies utilize transmission electron microscopy (TEM), most results are determined using PCM. Thus, the actual level of asbestos exposure remains uncertain. None of the published work extends beyond airborne fiber exposures to study the amounts of total and respirable dust experienced by automobile mechanics particularly when using compressed air blowout for brake assembly clean out. Only recently, Weir et al. (2001) reported a well-designed study on asbestos exposure during brake inspection and replacement of light-duty vehicle's rear drum brakes. They focused mainly on the effects of the use of compressed air to remove dust from drum brakes and on the arc grinding process.

In order to clarify the remaining uncertainties, we have conducted a well-designed, carefully controlled, and executed industrial hygiene study to evaluate the potential for exposure to airborne asbestos fibers during brake shoe replacement on passenger vehicles. Air sampling was conducted for airborne fibers, asbestos fibers, total dust, and respirable dust. The published literature generally focuses on the fiber generating tasks and offers little insight regarding the full workday asbestos dose experienced by brake mechanics. Therefore, the purpose of this testing was to evaluate brake change-related asbestos exposure with respect to OSHA PEL.

2. Materials and methods

2.1. Protocol

The protocol defined the sampling and analytical methods to be used in these tests. It contained descriptions of the automobile service facility and provided a preliminary description of the activities that were to be conducted each day of the test (for details see Supplement at http://ceoram.hsc.usf.edu/homepage.htm). The protocol was based on prior research conducted by Jacko and DuCharme (1973) and Sheehy et al. (1989). Each test was videotaped using available lighting and two flood lights (for videos see the Supplement). The mechanic was provided with a portable shop light to use as needed.

2.2. Automobiles and driving

Four Chevrolet Impalas (brown 1965, blue 1966, red 1965, and white 1968; see the Supplement) were purchased, inspected to ensure the cars met Pennsylvania (PA, USA) safety requirements and registered for normal public highway use. The four automobiles were then fitted with new replacement chrysotile-containing brake shoes and, as required, any other brake-related hardware to guarantee normal brake system function and performance, e.g., drums, springs, pins, etc. A professional automobile mechanic utilized for this testing selected and installed all these necessary brake system components. The make and models of automobiles selected for this research were chosen based on their high sales volumes and the brake system specifications which were common to these and several other makes and models of cars for the mid-1960s era. The specific model years selected all had similar fender and wheel well design. Only the brown Impala had power-assisted brakes.

After fitting with new brake shoes, each car was driven for approximately 2253 km (1400 miles) over public roads in the eastern suburbs of Pittsburgh, PA. For a map showing the route see the Supplement. All four cars were driven prior to tests conducted in July 2001. All but the brown Impala were driven prior to separate tests conducted in October 2001, one in excess in case of a mechanical problem. Two teams of drivers were used, each team drove on alternate days. Each driver would drive a car for two laps over the approximately 33.8 km (21 miles) road course before changing to another car. The drivers (male and female) ranged in ages from the 20's to the 60's and were chosen to represent a variety of driving skills and styles.

2.3. Automobile repair facility

A former automobile repair facility located in New Kensington, PA, was used for the brake-changing portion of this research (see the Supplement). The general layout of the service area of the building is shown in Fig. 1. The automobile service area was approximately 30.2 m long, 13.3 m wide, and had a ceiling that varied in height from 4.8 to 5.2 m (total volume ~2000 m^3). The overall facility contained offices located on the north side of the building with service areas to the south. Four concrete slabs formed the service area floor; three slabs contained two repair bays each and a larger bay for trucks occupied a single slab section. An electric motor driven vertical air compressor Gardner Denver Model VR5-8 (827 300 N/m^2, i.e., ~120 psig; Gardner Denver, Quincy, IL) was installed in the building and used for all brake changes. For all testing, a filtered exhaust fan unit HEPA-AIRE Model H5000C (Abatement Technologies, Duluth, GA), that was located approximately 16 m away from the brake changing activity, was used to ventilate the building (average flow rate, ~1 m^3/s). This provided a nominal air exchange rate of 1.8 service area equivalent volumes per hour. Ventilation smoke testing showed no air movement towards the exhaust fan's suction inlet outside a range of 8 m. All tests were performed with all seven building outside overhead doors closed. Typically automotive garages operate with the shop doors open in order to provide adequate, but uncontrollable, ventilation. Given the minimal dust capture capability of our exhaust system we believe the use of mechanical ventilation had less dilution effect than if shop doors remained open.

2.4. Air sampling

Air was sampled to determine the number, concentration, or type of suspended particulate in the air. Air sampling, as conducted in these tests, involved using pumps to draw known amounts of air through filters. The particulate trapped on the filters were then subjected to various analytical test methods. The analytical methods followed in this study are recognized standard measurement procedures.

2.4.1. Airborne asbestos sampling: background and rationale

Analysis of air samples from workplace settings for asbestos is generally performed by one of two methods

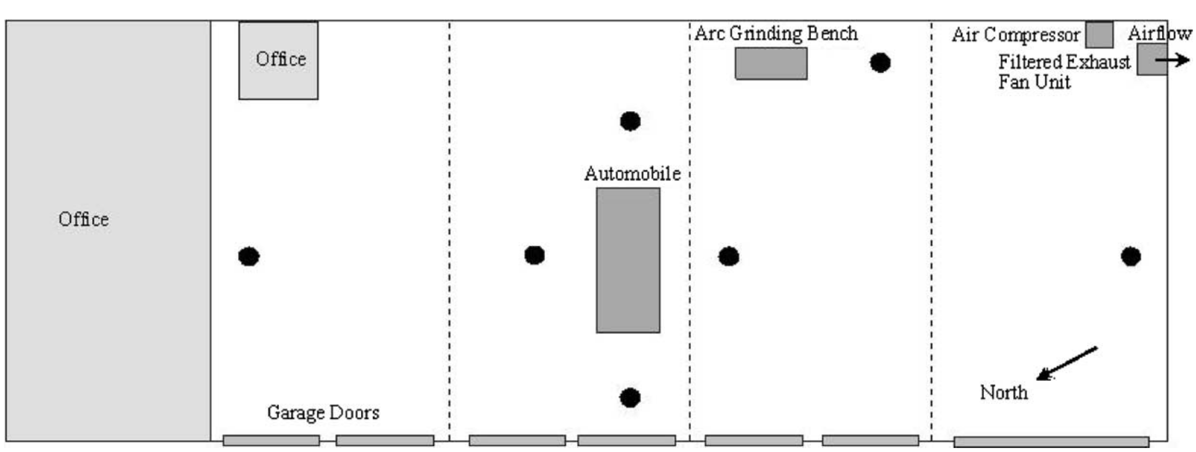

Fig. 1. Schematic drawing of the repair facility showing the location of the vehicle in the building and the area samples (circles). The dotted lines show the divisions between the concrete slabs in the floor. The four area samples near the automobile are within 3 m. Another area sample was within 3 m of the bench. The sample next to the office was within 1.5 m of the wall; the sample at the other end of the service bay was also within 1.5 m of the wall.

in the U.S., i.e., NIOSH Methods 7400 (National Institute for Occupational Safety and Health, 1994a) and 7402 (National Institute for Occupational Safety and Health, 1994b). In situations where fibers other than asbestos may be encountered, a combination of these methods is used to measure airborne asbestos fibers for compliance with the worker protection standards established by OSHA. OSHA regulations specify use of PCM for the NIOSH Method 7400 to determine occupational exposure to asbestos. In addition, OSHA regulations permit discriminate counting using the NIOSH Method 7402 with TEM to differentiate asbestos fibers from non-asbestos fibers (Occupational Safety and Health Administration, 1998). Application of the NIOSH Method 7402 allows asbestos fiber concentrations to be designated as the phase contrast microscopy equivalent (PCME) for purposes of evaluating personal exposure samples. PCME concentrations are determined by multiplying the observed PCM concentration by the fraction of all fibers that are asbestos as determined by the NIOSH Method 7402 [$\mathrm{PCME} = (\mathrm{PCM})_{7400} \times (\text{Asbestos fibers/Total fibers})_{7402}$].

OSHA established PELs are for airborne fiber concentrations to reduce the risk of workers developing asbestos-related diseases caused by breathing airborne asbestos fibers over a working lifetime. OSHA sets a maximum 8-h average daily exposure limit, 8-h TWA, which accommodates the normal daily exposure variations that typically occur with asbestos. Prior to 1971, the exposure limits were recommended by American Conference of Governmental Industrial Hygienists (ACGIH). OSHA PEL for airborne asbestos has undergone a continuing series of revisions since the early 1970s. OSHA's first PEL for airborne asbestos was established in May of 1971 and set an exposure limit of 12 f/ml. In June of 1972, OSHA set the PEL at 5 f/ml. In July of 1976, this PEL was reduced to 2 f/ml. OSHA reduced the PEL again in June of 1986 by a factor of 10, establishing the new PEL at 0.2 f/ml. In August of 1994 OSHA set the PEL at the current level of 0.1 f/ml and an excursion limit, a 30 min PEL, at 1.0 f/ml (Federal Register, 1994).

The airborne fiber concentrations for the air samples collected in this study were determined by PCM using the NIOSH Method 7400. While PCM is the method required by OSHA for evaluation of worker exposures, this method, as written, does not discriminate asbestos fibers from any other types of fibers seen with the microscope. All particles meeting the counting criteria are counted as fibers. Therefore, fibers in each air sample collected in this study were identified and counted by TEM using the NIOSH Method 7402. A fiber as defined by these methods is any object seen within a specified area of the microscope field that is longer than 5.0 μm, greater than 0.25 μm in width, and is at least three times longer than it is wide. Those particles meeting the physical characteristics of a fiber were further analyzed to determine if they were chrysotile or other type of asbestos fibers. The ratio of chrysotile to total fibers was determined and multiplied by the PCM result to estimate the total chrysotile concentration (as PCME). The results of this analysis were then converted to 8-h TWA for comparison with OSHA's current and historical PELs, and with historical exposure data (Martonik et al., 2001). Two reports were generated for each group of air samples, one for the PCM analysis and the other for the TEM analysis. The reports were prepared in general accordance with the requirements of the American Industrial Hygiene Association (AIHA) and the National Voluntary Laboratory Accreditation Program.

2.4.2. Airborne dust sampling

Brake wear dust typically contains many particles that are neither asbestos nor fibers. In an effort to quantify the airborne concentrations of brake wear dust experienced by the mechanic during these tests separate sampling was done for total dust and the respirable fraction of this total dust. This sampling and the associated analyses were performed according to NIOSH Methods 0500 (National Institute for Occupational Safety and Health, 1994c) and 0600 (National Institute for Occupational Safety and Health, 1998), respectively. The samples thus collected are gravimetric for all particles collected on the filters during the sampling period. These two NIOSH methods do not discriminate the various types of particles collected. Respirable dust samples represent those particles with equivalent aerodynamic diameters distributed around 3 μm. The airborne particles were sampled and passed through a BGI-4L Respirable Dust Cyclone (BGI Incorporated, Waltham, MA) to separate the fine respirable particles from the coarse, non-respirable particles. The fine particles were captured on a poly(vinyl chloride) membrane filter (37 mm disposable cassette), while the coarse particles were trapped and thus excluded from the measured mass. One report, prepared in general accordance with the requirements of AIHA, was generated for each test.

2.4.3. Sampling locations

Indoor area air samples were collected at seven locations within the building, as well as on the mechanic in his breathing zone. Fig. 1 shows the locations of the area samples within the building. The samples collected in proximity with the automobile were within 3 m (~10 ft) of the vehicle. Two area samples were located about 1.5 m from each end wall of the service bays and 10.7 m (North) or 15.2 m (South) from the respective side of the test automobile. One area sample was located 3 m from the bench used for the filing, sanding, and arc grinding tests. Outdoor area air samples were collected upwind and downwind of the building. These outdoor sampling locations varied from day-to-day depending on the direction of the prevailing wind. All area air samples were collected at breathing zone height, i.e., 1.5 m above floor. The samples for total and respirable particulate were personal, collected in the worker's breathing zone.

2.4.4. Sample collection parameters

Outdoor area air samples were collected for each entire day of testing at a flow rate of 9–10 L/min using high volume rotary vane vacuum pumps, Gast Model 1531-107B (Gast Manufacturing, Benton Harbor, MI). Indoor area air samples for fibers were planned to run for test duration at 10 L/min or less, using Gast Model 1531-107B vacuum pumps. These flow rates were selected to achieve optimum analytical sensitivity. During the first baseline test, it was observed that the membrane filters inlet faces began to discolor after 20 min run time. This was an indication of possible filter overloading with particulate matter, a condition, which can obscure collected fibers and interfere with the PCM analysis. On observing the filter discoloration all samples but the shop wall area samples were changed to fresh cassettes and continued to run at preset flow rates. Despite this change of cassettes, filter overloading did again occur which interfered with the PCM analysis of the indoor area air samples. For subsequent tests, sample collection times were further reduced and indoor area air sample flow rates were lowered to 5 L/min or less, which allowed successful PCM analysis of samples.

Personal air sampling for each test conducted covered the total time periods from driving the test car into the shop through completion of the post repair test drive. Personal air samples for fiber analysis were collected in series at flow rates of 3 L/min or less for time periods ranging from 30 to 72 min, using portable battery powered ALPHA-1 Constant Flow Air Samplers (Ametek, Mansfield and Green Division, Largo, FL). Filter cassettes were changed during each test as needed to prevent filter overloading. Personal air samples for total dust analysis ran for the duration of each test at flow rates of approximately 2 L/min. Personal air samples for respirable dust analysis also ran for test duration but at a flow rate of 2.2 L/min. Battery powered air sampling pumps, Escort Elf (Mine Safety Appliances Company, Pittsburgh, PA), were used for dust sampling with pumps attached to the mechanic's belt and samples collection devices located in the mechanic's breathing zone. All air-sampling pumps were checked for calibration at the beginning and end of each sampling day using a primary flow calibrator, The Gilibrator PN D-800268 and a bubble generator P/N D800285 (Gilian Instrument, West Cladwell, NJ).

2.5. Brake tests

The cars tested had dual servo style drum brakes, which have two different shoes on each wheel, i.e., a primary and a secondary shoe. Six complete (four wheels) brake shoe change-out tests were conducted at the repair facility. These tests took place over three days (July 12–13 and October 19, 2001). For each test the wheel and tire assemblies were first removed followed by each brake drum. The drum was placed on the concrete floor creating a shock which broke loose surface bound brake dust and effectively "cleaned" the drums. This technique was used at the discretion of the mechanic who was instructed to use techniques common to the 1960s. Then, each brake assembly was blown out using compressed shop air. To facilitate videotaping of the testing and to further control intertest variables, the mechanic started on the driver's side of each test vehicle, completing that side before moving to the passenger side. A skilled professional automobile mechanic using tools and procedures common to the mid-1960s performed all brake replacement tests. This mechanic was experienced in that period's customs and practices having begun his professional career in that era.

Test 1 was a baseline test involving removal and replacement of brake shoes with no additional manipulation of the brake shoes. For test 2, the new replacement brake shoes were filed to bevel the square edges of the shoe friction material prior to installation. For test 3, the new shoes were sanded to bevel the edges and to remove the outermost wear surfaces on each shoe. Test 4 involved arc grinding of the new shoes to precisely match each shoe's radius to that of its companion brake drum, using an AMMCO Model 8000 Brake Shoe Grinder with No. 8050 Universal Brake Shoe Clamp and with an Dust Collection System Model 8925 (AMMCO Tools, North Chicago, IL). After test 4, the repair facility was swept and cleaned by the mechanic. This cleaning procedure was treated as a separate test and area and personal air sampling was conducted. Test 5 (baseline 2) was a repeat of the test 1, while test 6 (arc grinding 2) was a repeat of the test 4. During test 6 the same brake shoe grinder was used as in the test 4, but an older style dust collection bag, part number 2044 (AMMCO Tools, North Chicago, IL), was used.

3. Results

Two periods of driving were conducted for these tests (for drivers' log books see the Supplement). Driving which involved several stops at intersections averaged about 1 h per lap while obeying all posted speed limits. Each vehicle was driven for about 67 laps. Records of the weather during the driving times were collected from the National Weather Service's web site (see the Supplement). Little rain fell during the driving. However, the last scheduled driving day prior to the October testing did have significant showers during the final laps. Because this rain occurred at the end of the scheduled driving, an additional lap was driven under dry conditions with the three cars before moving them to the repair facility. One of the new replacement asbestos-containing brake shoes was sampled and analyzed using polarized light microscopy according to the U.S. Environmental Protection Agency's Method 600 for the determination of asbestos in bulk building materials (Perkins and Harvey, 1993). The shoe was found to contain by area 30% chrysotile (see the Supplement). Review of batch formulation data provided by the brake shoe manufacturer (AlliedSignal, Troy, MI) indicates the primary shoes contained 72% asbestos and the secondary shoes contained 50% by weight. Commercial chrysotile asbestos (serpentine type) usually contains trace amounts of tremolite asbestos (amphibole type). Authors are not aware of any efforts by suppliers of commercial chrysotile asbestos to reduce tremolite levels in their products. Thus, brake shoes fabricated in 2000 and used in this study should be representative to those produced in 1960s, as regards trace tremolite content. Over 100 air samples for asbestos analysis and 14 air samples for dust analysis were collected during these tests. All replaced brake shoes were collected, placed in plastic bags, and retained. Debris from the filing and sanding tests were also collected, placed in plastic vials, and retained. Bulk samples of brake wear dust were collected and retained. The dust collection bags from the arc grinding tests were also retained with the captured dust.

3.1. Brake changes

Six complete brake shoe changes and one cleaning test were conducted. Table 1 summarizes the time spent for each complete test (from initially driving the vehicle into the service bay until return from the test drive conducted after completion of brake change activities), as well as the time spent actually performing the specified operation (filing, sanding, arc grinding, or cleaning), and the time spent blowing compressed air. All replacement and brake shoe manipulations were performed at the discretion of the mechanic and took as long as necessary to obtain acceptable brake assembly and finishing. The environmental conditions for each test are summarized in Table 2. The temperature in the repair facility rose several degrees during the course of each test because of the closed shop doors and, therefore, limited building ventilation rate.

Table 1
Test conditions

Date	Test	Duration of test (min)	Procedure	Duration of procedure (min)	Duration of blowing (s)[a]
July 12, 2001	1	92	Baseline 1	—	29
July 12, 2001	2	102	Filing	9.7	46
July 13, 2001	3	95	Sanding	4.1	34
July 13, 2001	4	107	Arc grinding 1	19.9[b]	39
July 13, 2001		30	Cleaning	30	—
October 19, 2001	5	85	Baseline 2	—	22
October 19, 2001	6	96	Arc grinding 2	17.8[b]	22

[a] Total time spent blowing compressed air on the brake mechanisms on all four wheels of the automobile.
[b] Total time spent at the bench, including set-up and adjustment of brake shoe grinder. Actual grinding took 12.5 min for test 4 and 6.9 min for test 6.

Table 2
Environmental conditions

Date	Test	Procedure	Temperature (°C)	Relative humidity (%)	Air flow (m^3/s)
July 12, 2001	1	Baseline 1	26.1–27.8	42–38	0.94
July 12, 2001	2	Filing	24.5–31.7	36–29	0.99
July 13, 2001	3	Sanding	17.8–24.5	64–42	0.99
July 13, 2001	4	Arc grinding 1	26.7–29.5	36–32	0.94
July 13, 2001		Cleaning	27.8	31	0.94
October 19, 2001	5	Baseline 2	12.8–17.8	41–34	1.04
October 19, 2001	6	Arc grinding 2	18.9–21.1	32–29	1.04

3.2. Outdoor area air samples

Samples of the outdoor ambient air were collected on the three days of testing at two upwind and one downwind location. These samples were analyzed by PCM and TEM. The results are summarized in Table 3. No asbestos fibers were detected in the outdoor ambient air during these tests.

3.3. Personal airborne fiber samples

The personal samples collected and analyzed for airborne asbestos fiber content are summarized in Table 4. From all types of asbestos only chrysotile fibers were found. Results are presented as the average airborne fiber concentration during the duration of each test and as 8-h TWA (a single 8-h work shift). The highest TWA observed in these tests occurred during the first and second arc grinding test with a PCME of 0.0935 and 0.0347 f/ml, respectively. All other test results were well below 0.02 f/ml. No asbestos was detected during the cleaning test.

3.4. Area airborne fiber samples

Table 5 shows a summary of the area samples collected and analyzed for airborne asbestos fiber content. Only chrysotile asbestos fibers were found. No asbestos was detected during the cleaning test. Samples are grouped into "$\leqslant$3 m" (the four samples around the car), ">3 m" (the two samples at either end of the repair facility), and "Bench" 3 m from the workbench. There was no statistically significant difference in concentration between samples in close proximity to the automobile from those far from the automobile.

3.5. PCM versus TEM

The PCM results correlated well with the TEM results for total (asbestos and non-asbestos) fiber count as shown in Fig. 2. Both analytical methods used by us focused only on fibers longer than 5.0 μm, greater than 0.25 μm in width, and at least three times longer than their wide. Although TEM has the capability to resolve the smallest asbestos fibrils they were not counted since

Table 3
Outdoor area air fiber test data

Day	Location	Sample collection		PCM analysis		TEM analysis		PCM equivalent (f/ml)
		Time (min)	Volume (L)	Fibers	f/ml	Asbestos	Non-asbestos	
July 12	Upwind north	425	3999	9	0.0011	0	4	0
	Upwind south	424	4040	8	0.0010	0	4.5	0
	Downwind	425	4042	10	0.0012	0	4.5	0
July 13	Upwind east	393	3671	8.5	0.0011	0	1	0
	Upwind west	393	3600	15.5	0.0021	0	1.5	0
	Downwind	389	3622	16	0.0022	0	4	0
October 19	Upwind north	262	2679	17	0.0031	0	6.5	0
	Upwind south	262	2772	10.5	0.0019	0	6.5	0
	Downwind	263	2638	13.5	0.0025	0	5	0

PCM and TEM analyses were completed according to NIOSH Method 7400 and 7402, respectively.

Table 4
Personal air fiber test data

Test	Procedure	Sample collection		PCM analysis		TEM analysis	PCM equivalent	
		Time (min)	Volume (L)	Ø[a] (f/ml)	TWA[b] (f/ml)	Fiber ratio[c]	Ø (f/ml)	TWA (f/ml)
1	Baseline 1	92	282	0.0217	0.0042	0.76	0.0164	0.0031
2	Filing	102	313	0.0376	0.0080	0.95	0.0356	0.0076
3	Sanding	95	199	0.0776	0.0154	0.88	0.0684	0.0135
4	Arc grinding 1	103	215	0.4368	0.0937	0.99	0.4358	0.0935
	Cleaning	30	67	0.0146	0.0009	0	0	0
5	Baseline 2	85	175	0.0672	0.0119	0.07	0.0048	0.0009
6	Arc grinding 2	96	198	0.2005	0.0401	0.86	0.1734	0.0347

PCM and TEM analyses were completed according to the NIOSH Method 7400 and 7402, respectively.
[a] Average fiber concentration during each test duration.
[b] TWA is 8-h TWA assuming no exposure other than the test.
[c] Fiber ratios are rounded, thus PCME results show minor variances.

Table 5
Average area air fiber concentrations relative to the location of the samples to the automobile

Test	Location	PCM (f/ml)	PCME (f/ml)
Baseline 1	⩽3 m	0.00027	0.0002
	>3 m	*	*
	Bench	**	—
Filing	⩽3 m	0.0282	0.0128
	>3 m	0.0300	0.0097
	Bench	**	—
Hand Sanding	⩽3 m	0.0133	0.0097
	>3 m	0.0112	0.0092
	Bench	0.0142	0.0091
Arc grinding 1	⩽3 m	0.0296	0.0266
	>3 m	0.0389	0.0389
	Bench	0.0895	0.0828
Cleaning	⩽3 m	0.0069	0
	>3 m	0.0071	0
	Bench	0	0
Baseline 2	⩽3 m	0.0258	0.0060
	>3 m	0.0227	0.0095
	Bench	0.0325	0.0093
Arc grinding 2	⩽3 m	0.0276	0.0186
	>3 m	0.0265	0.0154
	Bench	0.0450	0.0372

PCM and TEM analyses were completed according to the NIOSH Method 7400 and 7402, respectively. *Samples were overloaded. **No samples were collected.

NIOSH Method 7402 does not count fibers <0.25 μm in diameter. There was a statistically significant relationship between the data sets ($TEM = PCM^{0.92}$, $P < 0.0001$). Due to the nearly linear relationship between the data from the two methods, it can be concluded that both analytical procedures were uniformly applied to the samples and represent measurements of the same fiber population. Prior reports had failed to find statistically significant correlation between TEM and PCM data because those studies compared different fiber size distributions (Dement and Wallingford, 1990; Snyder et al., 1987; Spooner and Thorpe, 1986). Our results demonstrate that the PCM data are valid surrogate measurements for dimensionally similar TEM fibers (Marconi et al., 1984) and that the PCM data are valid for the assessment of exposures resulting from brake shoes.

3.6. Airborne dust samples

The personal airborne dust sample data are summarized in Table 6. The results of total dust analysis for brake changing tests expressed as 8-h TWA ranged from 0.193 to 0.708 mg/m^3 with a mean of 0.333 mg/m^3. The cleaning test resulted in less than 0.102 mg/m^3 total dust exposure. Analysis of samples for respirable dust expressed as 8-h TWA indicated concentrations below the 0.095 mg/m^3 detection limit for all but the filing and the second arc grinding test, where 0.243 and 0.103 mg/m^3 were found, respectively. The mean respirable dust exposure concentration was <0.121 mg/m^3 or about one third of that for the total dust.

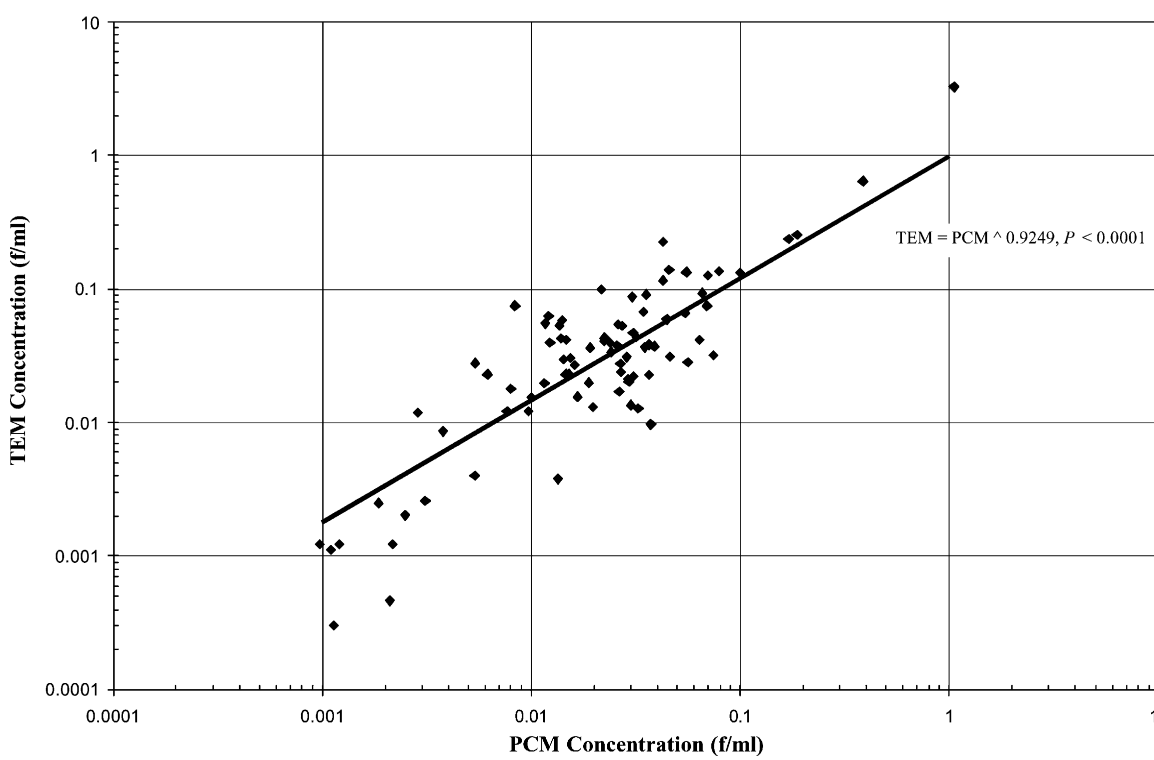

Fig. 2. A comparison between air sampling data generated using NIOSH Method 7400 (PCM concentration) and NIOSH Method 7402 (TEM total concentration). The data show a statistically significant nearly linear relationship.

Table 6
Personal air dust test data

Date	Test	Operation	Time (min)	Total dust (mg/m^3)		Respirable dust (mg/m^3)	
				Observed	TWA[a]	Observed	TWA
July 12, 2001	1	Baseline 1	92	3.693	0.708	<0.495	<0.095
July 12, 2001	2	Filing	102	1.206	0.256	1.143	0.243
July 13, 2001	3	Sanding	95	1.409	0.279	<0.481	<0.095
July 13, 2001	4	Arc grinding 1	107	1.429	0.318	<0.427	<0.095
July 13, 2001		Cleaning	30	<1.639	<0.102	<1.515	<0.095
October 19, 2001	5	Baseline 2	85	1.091	0.193	<0.538	<0.095
October 19, 2001	6	Arc grinding 2	96	1.207	0.241	0.514	0.103

Total dust and respirable dust analyses were completed according to the NIOSH Method 0500 and 0600, respectively.
[a] TWA is 8-h TWA assuming no exposure other than the test.

4. Discussion

We have conducted industrial hygiene research to evaluate the potential for exposure to airborne asbestos fibers during brake shoe replacement on passenger automobiles. The emphasis was put on the 1960s, since in that time period there were no "fiber" based regulations regarding asbestos exposure. This research covers the actual process of brake repair performed on 1960 era four wheel drum brake automobiles by a professional automobile mechanic in an actual automobile repair facility using methods and tools typical of the 1960s. Facility ventilation was controlled as was vehicle placement, and the scope of actual repairs conducted. Brake composition was known, as also was each vehicle's operational history for the brake shoes undergoing replacement. Duplicate baseline testing was conducted to demonstrate reproducibility and to study the effects of adding specific variables to the basic brake removal and replacement process. Those variables tested separately included filing, sanding, and grinding of the friction compound. A separate cleanup test was conducted after finishing a brake replacement and removal of the test vehicle.

The distance chosen for driving the test vehicles, i.e., 1400 miles, was based on research done by Jacko and DuCharme (1973) and was a compromise. At 30 000 miles (average brake life) wear dust accumulation on the backing plates is roughly five times the amount measured at 1400 miles. Jacko and DuCharme (1973) also observed that the rate of asbestos fiber emissions from brake systems is highest during the initial wear in and declines as mileage accumulates. Thus, the 30 000-mile brake wear dust would have a smaller percentage of asbestos than the 1400-mile dust. The absolute amount of wear dust, present on backing plates at 30 000 miles, would remain in the same order of magnitude as that for 1400 miles. One of the activities often performed by brake mechanics, is responding to complaints of brake noise, grabbing, or pulling. Such complaints often occur directly after a brake job, and corrective action typically involves brake shoe removal and filing or sanding. For such situations the 1400-mile range is directly relevant.

Four primary operations occurred in these brake replacement tests: (1) blowout of dust (all tests), (2) hand filing of the new shoes, (3) hand sanding of the new shoes, and (4) arc grinding using two different dust collection techniques (Table 1). Each of these operations occurred as part of an overall brake replacement job as is normally done for vehicle maintenance purposes when and if abrasion of friction materials is required. After the tires and wheel assemblies were removed, the mechanic next removed the brake drums and placed them on the floor. Using an air hose, he blew the remaining brake assemblage to remove the loose particulate. The blowout included all brake components except the drum. It lasted only as long as required to achieve the necessary degree of cleanliness that was decided by the professional mechanic. Often times mechanics remove the brake shoes and connecting hardware before blowing off the bare backing plate. In such instances less brake hardware would be blown out than in our tests. On average, the total duration of the blowing procedure was 32 s per car (Table 1). It should be noted that the time spent actually blowing the dust from the wheels was much shorter; e.g., the total time of video titled "Use of air to blow out brake assembly," where only one side of the automobile is treated, was 20 s, of which 12 s were spent on blowing the dust (see the Supplement). Thus, the actual time spent blowing the dust was only several seconds per wheel. The purpose of the air blow was not to produce clean, particle-free surfaces, but to remove gross dust buildup and reduce the amount of material on surface and brake mechanisms. The air blow often causes a very intense dust cloud (see the Supplement), causing worries among auto mechanics, that there may be an asbestos-related problem. Our present study shows that this procedure, in fact, results in increased concentration of total dust. The average total dust of the baseline tests (tests 1 and 5) was 0.451 mg/m^3 8-h TWA, but the respirable dust was below the detection limit of the method (Table 6). More importantly, the average personal asbestos fiber concentration (Table 4) of the baseline tests was only 0.002 f/ml (PCME 8-h TWA), i.e., 50 times below the current OSHA PEL. Blowout made a minor contribution (~5%) of airborne personal asbestos fibers when compared with the abrasive procedures, which physically removed material from the primary and secondary shoes and produced an average personal asbestos fiber concentration of 0.037 f/ml (Table 4). The results from this study are in general accord with the observations of other investigators (Hatch, 1970; Weir et al., 2001). Together, it seems unlikely that the air blow, a standard procedure in the 1960s, was a health risk.

Two other procedures evaluated in this study were the hand filing and hand sanding of the new brake shoes. During the filing test, the mechanic filed all of the replacement brake shoes during a single session. The purpose of the filing was to bevel the edges to prevent grabbing of the shoe on the drum that causes brake noise. It involved tapering the leading edges of the friction material of the two shoes for each wheel plus rounding the square edges along the circumference of all shoes. This procedure is typically done on an as-needed basis, most often in response to customer complaints. The total time spent filing the shoes was 9.7 min, or an average of 73 s per brake shoe. Hand sanding the shoes was performed in a similar manner as the hand filing, with the addition of sanding the brake shoe surface, which would normally be done to remove glazing. The test shoes being new did not have any glaze and thus were softer that if a glaze was present. The sanding lasted a total of 4.1 min, or about 31 s per shoe. As shown in Table 4, also these two procedures resulted in personal asbestos fiber concentrations well below the current OSHA PEL.

Another variable tested in this study was the arc grinding of the new brake shoes. As part of this test procedure, the diameter of each brake drum was measured and the radius of curvature on the brake shoe grinder adjusted accordingly. The purpose of measuring the diameter was to ensure that the surface of the brake shoe matched the inside surface of the brake drum. The first arc grinding test was performed using a post-1972 model dust collection bag (model 8925). The arc grinding process began as the mechanic measured the diameter of the drum, set the brake shoe grinder, and inserted the shoe into the clamp. Grinding was performed on each shoe only until the grinder had covered the entire friction surface of that shoe. For this test, the mechanic first ground the brakes from the driver's side of the vehicle and, later, ground the passenger side brakes. The total time spent at the bench was 19.9 min, though only 12.5 min of this time was actually spent grinding the shoes (average of 94 s per shoe). Because an older style dust collection bag (model from 1960s) was available for the arc grinder, a second test was performed. This testing was conducted in the same manner as the first arc grinding, except for the dust bag. This test lasted a total of 17.8 min, with 10.9 min spent setting up and adjusting the grinder. Only 6.9 min were actually used to grind the shoes (about 52 s per shoe). The average personal asbestos fiber concentration (Table 4) of the arc grinding tests (tests 4 and 6) was 0.0641 f/ml (PCME 8-h TWA), thus below the current OSHA PEL. This finding is in agreement with the study of Weir et al. (2001). Their results suggest, that even in a busy automotive repair facility, a mechanic would be exposed to fiber concentrations considerably below the present day OSHA PEL.

OSHA regulations have been promulgated on the basis of epidemiological results of several major asbestos worker populations. These include textile manufacturing workers, insulators, miners and millers, and friction material manufacturers. Airborne fiber exposures determined by PCM were used to estimate the risk levels on which the regulations are based. Those data have been reviewed by Health Effects Institute—Asbestos Research (1991) and Lee et al. (1992), and compared with airborne asbestos levels in schools, public buildings, and outdoor air. Fig. 3 shows the historical levels along with the PCME 8-h TWA values determined by this study. It is apparent from these tests and published historical data that the potential for airborne chrysotile fiber exposure during automobile brake changing operations is below current OSHA regulatory levels, certainly below historical OSHA limits, and well below levels experienced by some other occupational groups.

Because exposure to high concentrations of any dust, regardless of toxicity, can cause respiratory problems, OSHA under the Code of Federal Regulations 29 CFR 1910.1000 regulates exposure to "inert or nuisance dust" in the work place (Occupational Safety and Health Administration, 1997a,b). Current OSHA PEL for total nuisance dust is 15 mg/m^3 per day and for its respirable fraction is 5 mg/m^3 per day. ACGIH has recommended lower Threshold Limit Values that is 10 and 3 mg/m^3, respectively (American Conference of Governmental Industrial Hygienists, 2002). Therefore, in addition to airborne fiber exposure sampling, personal samples were collected to determine the levels of total and respirable dust experienced by the brake mechanic (Table 6). The results of total dust analysis for brake changing tests, i.e., excluding the cleaning test, showed a mean of 0.333 mg/m^3 (8-h TWA). The mean respirable dust exposure concentration was less than 0.121 mg/m^3 (8-h TWA). Clearly OSHA PELs for dust were not met or exceeded.

We noticed during the course of this study, that several factors affected the results of the tests. The effects are summarized in Table 7. The combined effect of the

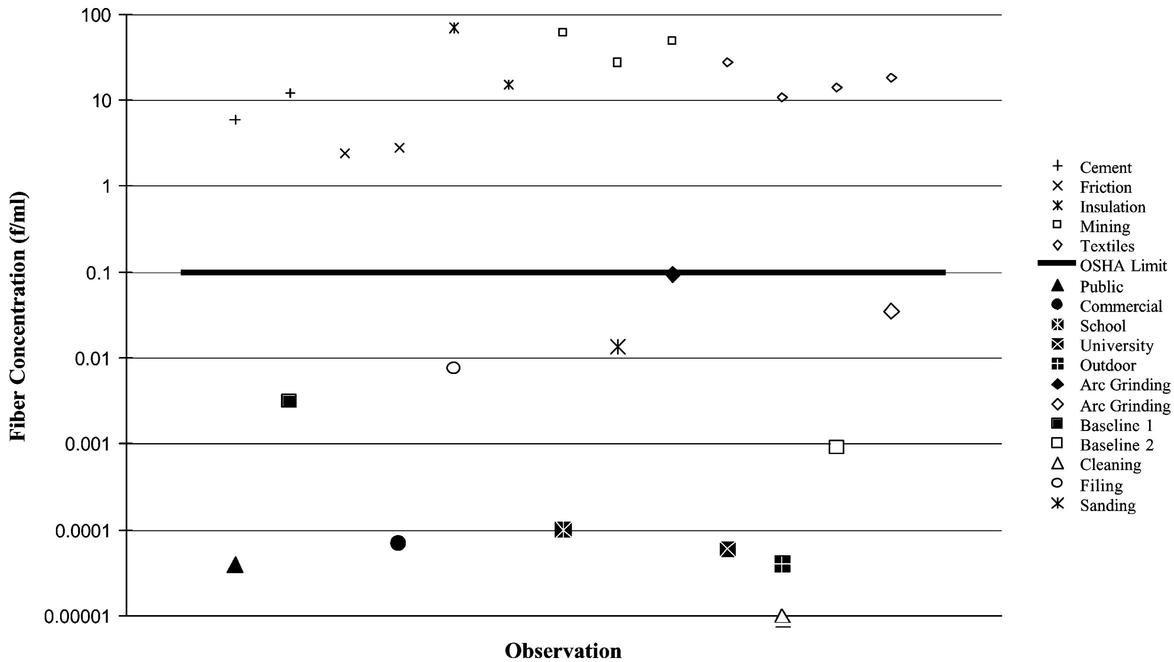

Fig. 3. Historical airborne fiber concentrations (8-h TWA) cited in the epidemiology studies used by OSHA in establishing the current PEL (0.1 f/ml). Also shown are typical airborne concentrations in buildings, as well as the mechanic exposures from the present study.

Table 7
Effect of various factors on airborne asbestos concentrations

Parameter	This study	Commercial facilities	Effect
Air exchange	1.8 equivalent air volumes per h	Variable	Increased air exchanges will remove airborne particles faster, reducing potential exposure
Garage doors	Closed	Closed/open, depending on weather	Open garage doors will increase the ventilation and decrease potential exposure
Size of facility	7 bays	Variable	Insignificant for repair facilities of sufficient size to accommodate brake repair
Air blow of dust	Long enough to remove dust from brake mechanisms	Long enough to remove dust from brake mechanisms	No effect, air blowing is performed to remove dust
Friction material	Brake shoes	Variable	When using brake shoes, similar results are expected; disc brakes will result in lower potential exposure
Brake pad manipulation	Filing, sanding, arc grinding	Filing, sanding, arc grinding	No difference in potential exposure
Concurrent operations	1 per repair period	>1 per repair period	No effect on worker exposure, potential for increased bystander exposure
Humidity	Low	Variable	Higher humidity will reduce potential exposure

variables results in potential exposures in commercial brake repair/replacement facilities at or below levels observed in these tests.

We believe the major asbestos exposure elements of brake changing were documented by this study. Other manipulations, e.g., packing front wheel bearings, turning drums on a drum lathe, replacing front wheel brake drums, etc., do not contribute to exposure at the levels we have documented for filing, sanding, and arc grinding, since brake wear dust contains very few PCME sized asbestos fibers.

5. Conclusions

On the basis of the current testing program and published air measurements collected at various brake repair facilities, the following can be concluded with a reasonable degree of scientific certainty:

1. Replacement of asbestos-containing automotive brake shoes including blowout, filing, or sanding did not cause worker exposure to airborne asbestos fibers in excess of existing 8-h TWA OSHA PEL. Only during the use of the brake shoe grinder did

the personal exposure approach the present day OSHA PEL.

2. The airborne asbestos concentrations observed in this study are consistent with the published literature regarding replacement/repair of automotive brakes. When the complete brake replacement/repair process is sampled, airborne fiber concentrations remain below the original and subsequent OSHA PELs or recommended ACGIH fiber-based exposure limits.

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