Airborne Asbestos Concentration from Brake Changing

In the Matter of
General Consulting

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SUMMARY

At the request of counsel, RJ Lee Group, Inc. and Clayton Group Services, Inc. have jointly conducted an industrial hygiene evaluation of a professional automobile mechanic's exposure to airborne dust and asbestos fibers while performing routine brake system maintenance. This evaluation also included sampling to determine the potential for bystander exposure to asbestos fibers. The evaluation focused on 1960 era road vehicles having four wheel drum braking systems using four nearly identical automobiles in the series of separate tests. These tests were designed to study the possible effects of three independent variables e.g., sanding, filing and arc grinding of the replacement brake shoe elements. All other conditions were maintained constant to the extent possible. Each wheel assembly of each automobile was blown-out using compressed air after removal of the drum.

In preparation for testing, each automobile was fitted with new replacement asbestos-containing brake shoes and then driven over a predetermined road course consisting of urban and metropolitan public roads. This driving followed established protocol for brake system testing and continued until each automobile accumulated at least 1,400 miles, which is sufficient to establish steady state wear and brake dust retention inside drums. After the driving, each car was separately brought into an actual automotive 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 automobile mechanic was experienced in brake system maintenance, having worked in the automobile repair profession beginning in the 1960s.

During the conduct of each test, industrial hygiene air sampling was performed collecting both personal and area air samples. Analysis of collected samples included fibers, asbestos fibers, total dust, and respirable dust. Air sampling and analysis followed NIOSH published methodology using methods 7400, 7402, 0500, and 0600 respectively.

The results of analysis for collected samples indicate airborne asbestos fiber exposures for each test remained at or below OSHA PEL's for asbestos including the currently applicable limit of 0.1 fiber/cc 8-hr TWA.

INTRODUCTION

RJ Lee Group, Inc. and Clayton Group Services, Inc. have been retained to conduct industrial hygiene research to evaluate the potential for exposure to airborne asbestos fibers during brake shoe replacement on automobiles. In the past, and to a lesser extent today, automotive brake friction compounds contained chrysotile asbestos as a component. Asbestos provides strength and flexibility and allows brakes to be molded from powdered resins.[1] The primary purpose of the chrysotile is not heat resistance, but to act as a binder for the resins and other materials.

Prior research and testing indicates that nearly all of the chrysotile asbestos 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.[2,3,4,5] 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.

This resulting potential exposure has been the subject of numerous environmental and industrial hygiene studies. Early studies utilized phase contrast microscopy (PCM) to study the potential exposures. These studies[6,7,8] generally focused on specific

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[1] D. Hatch (1970). "Possible Alternatives to Asbestos as a Friction Material", *Annals of Occupational Hygiene*, **13**, p. 25 – 29.

[2] M. Jacko and R. DuCharme (1973). *Brake Emissions: Emission Measurements from Brake and Clutch Linings from Selected Mobile Sources*, US Environmental Protection Agency, NTIS Number PB-222372.

[3] R. L. Williams and J. L. Muhbaier (1982). "Asbestos Brake Emissions", *Environmental Research*, **29**, p. 70-82.

[4] D. M. Rowson (1978). "The Chrysotile Content of Wear Debris of Brake Linings", *Wear*, **47**, p. 315-321.

[5] A. E. Anderson, R. L. Gealer, R. C. McCune, and J. W. Sprys (1973). "Asbestos Emissions from Brake Dynamometer Tests", preprint 730549, Society of Automotive Engineers (SAE).

[6] D. E. Hickish and K. L. Knight (1970). "Exposure to Asbestos During Brake Maintenance", *Annals of Occupational Hygiene*, **13**, p. 17 – 21.

[7] K. L. Knight and D. E. Hickish (1970). "Investigations into Alternative Forms of Control for Dust Generated During the Cleaning of Brake Assemblies and Drums", *of Occupational Hygiene*, **13**, p. 37 – 39.

[8] W. V. Lorimer, A. N. Rohl, A. Miller, W. J. Nicholson, and I. J. Selikoff (1976). "Asbestos Exposure of Brake Repair Workers in the United States", *The Mount Sinai Journal of Medicine*, **43**, p. 207 – 218.

segments of the brake replacement operation, reporting results without the time of exposure. These data ranged from < 0.1 f/cc to over 50 f/cc for some peak samples. Hickish and Knight[6] did report a set of data for an entire shift of brake cleaning (0.68 f/cc TWA), though not for a complete brake repair/replacement operation.

These early studies are supplemented by a series of studies conducted by NIOSH beginning in 1972. These studies[9,10,11,12,13,14,15] were conducted at a number of different brake repair facilities, primarily in the Midwest and Northeast. All of the studies show PCM exposure estimates for automobile brake repair/replacement to be at or below existing OSHA permissible exposure limits. More recent studies[16,17], using optical and/or electron microscopy as the analytical procedure, found similar results. All of these additional studies reported exposure estimates at or below existing OSHA standards.

None of these existing industrial hygiene brake studies covers the complete brake replacement process in the 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 non-reproducible settings, typically without consideration of any background airborne fiber considerations 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

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[9] J. M. Dement (1972). U.S.P.H.S. Survey: Cincinnati Municipal Garage, Automobile Brake Servicing Operation, NIOSH report # 32.11, March 16, 1972.

[10] P. L. Johnson (1976). "Preliminary Industrial Hygiene Survey at Auto Brake Clinic, Cincinnati, Ohio", NTIS publication PB81-228827.

[11] D. R. Roberts (1980). "Reading Brake and Alignment Service, Reading, Ohio", NTIS Publication PB81-245193.

[12] D. R. Roberts ad R. D. Zumwalde (1980). Industrial Hygiene Survey Report of the New York Sanitation, Traffic, and Police Brake Servicing Facilities, Queens, New York, NIOSH, May 12, 1980.

[13] D. R. Roberts (1980). "Industrial Hygiene Report – Asbestos at Allied Brake Shop, Cincinnati, Ohio", NTIS Publication PB81-241879.

[14] W. J. Nicholson (1982). "Investigation of Health Hazards in Brake Lining Repair and Maintenance Workers Occupationally Exposed to Asbestos", NTIS Publication PB83-220897.

[15] D. R. Roberts and R. D. Zumwalde (1982). Industrial Hygiene Summary Report of Asbestos Exposure Assessment for Brake Mechanics, NIOSH report # 32.4, November 22, 1982.

[16] K. Rödelsperger, H. Jahn, B. Brückel, J. Manke, R. Paur, and H. J. Woitowitz (1986). "Asbestos Dust Exposure During Brake Repair", *American Journal of Industrial Medicine*, **10**, p. 63 – 72.

with disc style front brakes which may yield different levels of exposure than vehicles with four wheel drum style brakes. No studies attempt to quantify the effects of sanding, filing, and grinding on the brake replacement process.

While some of the published studies utilize Transmission Electron Microscopy (TEM), most results are determined using phase contrast microscopy (PCM). Thus the actual level of asbestos exposure is 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.

This research covers the actual process of brake repair performed on 1960 era 4 wheel drum brake automobiles by a professional automobile mechanic in an actual automobile repair facility using methods and tools typical of the 1960 time period.

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. Industrial Hygiene air sampling was conducted for airborne fibers, respirable dust, and total dust.

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[17] T. Kauppinen and K. Korhen (1987). "Exposure to Asbestos During Brake Maintenance of Automotive Vehicles by Different Methods", *American Industrial Hygiene Association Journal*, **48**, p. 499 – 504.

EXPERIMENTAL DESIGN

A. Protocol

The protocol for these tests were developed by Mr. Charles L. Blake, CIH with the assistance of RJ Lee Group, Inc. The protocol (see Appendix A) defined the sampling and analytical methods to be used in these tests, 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. The protocol was based on prior research conducted by Jacko[2] et al and Sheehy et al.[18]

Each test was videotaped using available lighting and two flood lights. The mechanic was provided with a portable shop light to use as needed.

B. Driving

Four mid-60's vintage Chevrolet Impalas (see Figure 1) were purchased, inspected to ensure the cars met Pennsylvania safety requirements and registered for normal public highway use. The four automobiles were then fitted with new replacement asbestos-containing brake shoes and, as required, any other brake related hardware to guarantee normal brake system function and performance, eg 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.

After fitting with new brake shoes, each car was driven for approximately 1,400 miles over public roads in the eastern suburbs of Pittsburgh, PA. The map of the course is

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[18] J. W. Sheehy, T. C. Cooper, D. M. O'Brien, J. D. McGlothlin, and P. A. Froelich (1989). *Control of Asbestos Exposure During Brake Drum Service*, US Department of Health and Human Services, NTIS Number PB-90168501.

shown in Figure 2. All four cars were driven prior to the July tests. Only the red, blue, and white cars were driven prior to the October tests.

Two teams of drivers were used, each team on alternate days. Each driver would drive a car for 2 laps over the approximately 21 mile road coarse before changing to another car. The drivers (male and female) ranged in ages from the 20's through the 60's and were chosen to represent a variety of driving skills and styles.

C. Automobile Repair Facility

A former automobile repair facility (Figure 3) located in New Kensington, PA was used for the brake-changing portion of this research. The general layout of the service area of the building is shown in Figure 4. The automobile service area is approximately 99 ft long, 43.5 ft wide and has a ceiling that varies in height from 15.9 ft to 17.2 ft (total volume approximately 71,000 ft^3). The overall facility comprises offices located on the north side of the building with service areas to the south. Several concrete slabs (shown by the dotted lines in Figure 4) form the service area floor; each slab encompasses two repair bays.

A 120 psig air compressor was installed in the building and used for all brake changes.

For all testing, a filtered exhaust fan unit (HEPA-AIRE® model H5000C) was used to ventilate the building (nominal flow rate, approximately 2100 acfm). This provided a nominal air exchange rate of 2 service area equivalent volumes per hour. All tests were performed with all building outside doors closed.

D. 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 are then subjected to various analytical methods.

1. Asbestos in Air Sampling; Background and Rationale

Analysis of air samples for asbestos is generally performed by one of two methods in the United States. The combination of NIOSH Standard Methods 7400[19] and 7402[20] methods is used to measure airborne asbestos fibers for compliance with the worker protection standards established by the U. S. Occupational Safety and Health Administration (OSHA). The Asbestos Hazard Emergency Response Act (AHERA)[21] provides a method for determining the presence of asbestos fibers inside buildings after an asbestos removal project. The AHERA Method is an outgrowth of earlier EPA methodologies.[22] OSHA does not accept the AHERA method to determine compliance with its worker protection standards.[23]

OSHA regulations specify use of phase contrast microscopy (PCM) under the NIOSH 7400 method to determine occupational exposure to asbestos. In addition, OSHA regulations permit discriminate counting under the NIOSH 7402 method of transmission electron microscopy (TEM) to differentiate asbestos fibers from non-asbestos fibers. Application of the NIOSH 7402 method 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 NIOSH 7402 [PCME = PCM x $(\text{Asbestos/Total Fibers})_{7402}$].

OSHA established workplace standards (PEL's) for airborne fiber concentrations to reduce the risk of workers developing asbestos related diseases caused by breathing airborne asbestos fibers over a working lifetime. Specifically, these standards apply to

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[19] NIOSH 7400, "Asbestos and Other Fibers by PCM", NIOSH Manual of Analytical Methods. Current version listed as "issue 2, 15 August 1994".

[20] NIOSH 7402, "Asbestos by TEM", NIOSH Manual of Analytical Methods. Current version listed as "issue 2, 15 August 1994".

[21] Federal Register, Part III, 40 CFR Part 763, "Asbestos Containing Materials in Schools; Final Rules and Notice", October 30, 1987.

[22] G. Yamate, S. C. Agarwal, and R. D. Gibbons (1984). "Methodology for the Measurement of Airborne Asbestos by Electron Microscopy", EPA Contract 68-02-3266.
A. V. Samudra and C. F. Harwood (1977). Electron Microscope Measurement of Airborne Asbestos Concentrations: A Provisional Methodology Manual, U.S. Environmental Protection Agency, EPA 600/2-77-178, August 1977.

[23] Letter, D. T. Crane (OSHA Salt Lake Technical Center) to J. Johnson (OSHA Philadelphia Office), June 24, 1998.

a period of exposure that occurs for eight hours a day, five days a week, for forty-five years. The OSHA standards set maximum eight-hour average daily exposure limits called eight-hour time weighted averages (8-hour TWA's) which accommodate the normal daily exposure variations that typically occur with asbestos. The expression for calculation of the 8-hr TWA is $(C_1 * t_1 + C_2 * t_2 + C_3 * t_3)/8$. For example, if a person is exposed to 1.0 f/cc for one hour of the day, 0.6 f/cc for one hour of the day, and 0 f/cc for 6 hours of the day, the 8 hour TWA exposure is 0.2 f/cc {(1 f/cc * 1 hr. + 0.6f/cc *1hr + 0 f/cc * 6.0 hr) / 8 hr = (1 + 0.6 +0)/8 = 0.2 f/cc}.

OSHA's PEL's for airborne asbestos have undergone a continuing series of revisions since the early 1970's. OSHA's first PEL for airborne asbestos was established in 1971 and set an 8-hour TWA exposure limit of 12 asbestos fibers per cubic centimeter of air (f/cc). In June of 1972, OSHA set the PEL at 5 f/cc based on eight-hour time weighted average exposures. In July of 1976, this PEL was reduced to 2 f/cc, 8-hour TWA. OSHA reduced the PEL again in June of 1986 by a factor of 10, establishing the new PEL at 0.2 f/cc, 8-hour TWA. In October of 1994 OSHA reduced the PEL to the current level of 0.1 f/cc, 8-hour TWA (see Figure 5).

The airborne fiber concentrations for the air samples collected in this test were determined by phase contrast microscopy (PCM) using the NIOSH 7400 Method. 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.

Following analysis by the NIOSH 7400 method, both asbestos and non-asbestos fibers in each air sample collected in this test were identified and counted by Transmission Electron Microscopy (TEM) using the NIOSH 7402 method. A fiber as defined by this method is any object seen within a specified area of the microscope field that is longer than five micrometers (5 μm), greater than 0.25 μm in width, and is at least three times longer than it is wide. Using this TEM method, those particles meeting the physical characteristics of a fiber may be further analyzed to determine if they are asbestos fibers. The ratio of asbestos to total fibers is determined and multiplied by the PCM result to estimate the total asbestos concentration (PCM Equivalent, PCME). The results of this analysis were then converted to 8-hour Time Weighted Averages (TWA) for comparison against OSHA's current and historical PEL's, and with historical exposure data.[24]

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 standard methods 0500 and 0600 respectively. The samples collected for total and respirable dust determinations are gravimetric (weighed) 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 are sampled and passed through a cyclone style device to separate the fine respirable particles from the coarse, non-respirable particles. The fine particles are captured on a filter, while the coarse particles are trapped and thus excluded from the measured mass.

Current OSHA regulations permit an exposure to total "inert or nuisance dust" of 15 mg/m^3 per day (TWA) and 5 mg/m^3 per day (TWA) of respirable dust.[25] ACGIH has recommended slightly lower exposure levels (10 mg/m^3 and 3 mg/m^3, respectively).

3. Sampling Locations

Asbestos in air samples were collected at seven locations within the building, as well as on the mechanic in his breathing zone. Figure 4 shows the locations (blue circles) of

[24] Martonik, J. F., E. Nash, and E. Grossman (2001). "The History of OSHA's Asbestos Rulemakings and Some Distinctive Approaches that They Introduced for Regulating Occupational Exposure to Toxic Substances", *American Industrial Hygiene Association Journal*, 62, 208 - 217.

[25] 29 CFR Part 1910.1000. Tables Z-1 and Z-3. Version referenced: July 1, 2001.

the asbestos area samples within the building. The samples collected in proximity with the automobile were within 10 ft of the vehicle. Two area samples were located about five feet from each end wall of the service bays, or about 40 ft from the automobile. One area sample was located 10 ft from the bench used for the filing, sanding and arc grinding tests. Outdoor ambient 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 above floor (5 ft).

The samples for total and respirable particulate were personal, collected in the worker's breathing zone.

4. Sample Collection Parameters

Outdoor ambient air samples were collected for the each entire day of testing at a flowrate of 9 – 10 lpm using high volume line pumps (Gast model 1531).

Indoor area air samples for fibers were planned to run for test duration at 10 liters per minute or less, using line operated vacuum pumps. These flowrates were selected to achieve optimum analytical sensitivity. During the first baseline test (July 12th), it was observed that the open faced filters began to discolor after 20 minutes run time. This is an indication of possible filter overloading with particulate matter; a condition which can obscure collected fibers and interfere with 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 occur which interfered with the PCM analysis of the area air samples.

For subsequent tests, sample collection times were further reduced and indoor area air sample flow rates were lowered to 5 LPM or less, which allowed successful PCM analysis of samples.

Personal air samples for fiber analysis were collected in series at flowrates of 3 LPM or less for time periods of approximately 30 – 45 minutes. The total time periods from driving the test car into the shop through completion of the post repair test drive were covered by personal air sampling for each test conducted. Filter cassettes for airborne fiber analysis were changed during each test as needed to prevent filter overloading, portable battery powered air pumps (AMETEK α-1) were used for personal sampling.

Personal air samples for total dust analysis ran for the duration of each test at flow rates approximately 2 LPM. Personal air samples for respirable dust analysis also ran for test duration but at a flowrate of 2.2 LPM. Battery powered air sampling pumps (MSA Escort ELF) were used for dust sampling with pumps attached to the mechanic's belt and samples 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 airflow standard (Gilibrator with base P/N D 800268 and bubble generation P/N D800285).

E. Analytical and Reporting Procedures

The analytical protocols followed in this test are recognized standard measurement procedures.

1. Airborne Asbestos

The asbestos-in-air samples were analyzed using phase contrast microscopy (PCM, NIOSH 7400) and transmission electron microscopy (TEM, NIOSH 7402).

Two reports were generated for each group of air samples – one for 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 (NVLAP).

OSHA regulations require the asbestos exposure data to be determined using PCM analyses. In mixed-fiber atmospheres, OSHA permits the use of TEM[26] to adjust the PCM data and thereby determine asbestos fiber exposure concentrations. The combined data (PCME) is then compared to current and past OSHA standards. Accordingly, the PCM and TEM data must be combined to determine the PCME concentrations.

2. Airborne Dust Not Otherwise Specified Samples

The air samples collected for dust were analyzed according to NIOSH 0500 (total dust) and NIOSH 0600 (respirable dust).

One report was generated for these samples for each test. Each report was prepared in general accordance with the requirements of the American Industrial Hygiene Association (AIHA).

F. Brake Tests

Six complete brake shoe change-out tests were conducted at the repair facility. These tests took place over three days (July 12, July 13, and October 19, 2001). For each test the wheel and tire assemblies were first removed followed by each brake drum. After placing the drum on the floor, each brake assembly was blown out using compressed shop air. To facilitate video taping of the testing and to further control inter-test variables, the mechanic started on the driver's side of each test vehicle, completing that side before moving to the passenger side. All brake replacement tests were performed by skilled a professional automobile mechanic using tools and procedures common to the mid 1960s. This mechanic is experienced in that period's customs and practices having begun his professional career in that era.

The first test of each series was a baseline test involving removal and replacement of brake shoes with no additional manipulation of the brake shoes. For the second test, the new replacement brake shoes were filed to bevel the square edges of the shoe priors to installation. For the third test, the new shoes were sanded to bevel the edges and to remove the outermost wear surfaces on each shoe. Test four involved arc grinding the new shoes to precisely match each shoe's radius to that of its companion

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[26] Letter, D. T. Crane (OSHA Salt Lake Technical Center) to J. Johnson (OSHA Philadelphia Office), June 24, 1998.

brake drum. An AMMCO arc grinder (model 8000) with a model 8925 dust collection bag was used for test four. After the fourth test, 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 was a repeat of test 1, while test 6 was a repeat of test 4. During test 6 the same arc grinder was used as in test 4, but an older style dust collection bag was used (part number 2044).

RESULTS

Two periods of driving were conducted for these tests. The driver's logs are contained in Appendix C. The route is approximately 21 miles in length; driving which involved several stops at intersections, averaged about an hour per lap while obeying all posted speed limits. Records of the weather during the driving times were collected from National Weather Service web sites and are contained in Appendix D. 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 brake shoes was sampled and analyzed according to EPA methodology.[27] The shoe was found to contain 30% chrysotile asbestos. Appendix E contains the analytical report.

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 collected, placed in plastic vials, and retained. Bulk samples were collected of brake wear dust and retained. The dust collection bags from the arc grinding tests were also retained with the captured dust.

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[27] R. L. Perkins and B. W. Harvey (1993). *Method for the Determination of Asbestos in Bulk Building Materials*, U.S. Environmental Protection Agency, EPA Report No. EPA/600/R-93/116.

A. Brake Changes

Six complete brake shoe changes and one cleaning test were conducted over the course of three days. Table 1 summarizes the time spent for each complete test (from driving the vehicle into the service bay to return from the final test drive), as well as the time spent actually performing the specified operation (filing, sanding, or arc grinding), and the time spent blowing compressed air. All repair and brake shoe manipulations (eg filing, sanding, grinding) operations 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 limited building ventilation rates.

B. Outdoor Ambient Air Samples

Samples of the outdoor ambient air were collected on the three days of testing at two upwind and one downwind locations. These data are summarized in Table 3. No asbestos fibers were detected in the outdoor ambient air during these tests. Appendix F contains the PCM and TEM laboratory reports and count sheets for every fiber air sample.

C. Personal Airborne Fiber Samples

The personal samples collected and analyzed for airborne fiber content are summarized in Table 4. Results are presented as the average airborne fiber concentration during each test duration, and as 8-hour TWA's for each test done during a single 8-hour shift. The highest 8-hr TWA observed in these tests occurred during the first arc grinding test with a PCME 8-hour TWA of 0.0935 f/cc. Figure 6 shows the distribution of fiber samples.

D. Area Airborne Fiber Samples

The area samples collected and analyzed for airborne fiber content are summarized in Table 5 by grouping the samples into "Within 10 ft" (the four samples around the car), "More than 10 ft" (the two samples at either end of the repair facility), and "Bench" 10 feet from the workbench used for filing, sanding and arc grinding. Figure 7 shows the distribution of concentrations for all area samples. Figure 8 summarizes the data by location, Figure 9 by general location.

PCM vs. TEM

The PCM results correlate well with the TEM results for total fiber count as shown in Figure 10. There is a statistically significant relationship between the data sets ($TEM = PCM^{0.92}$, $p < 0.0001$). Prior reports[28] had failed to find significant correlation between TEM and PCM data because those studies compared different fiber size distributions. These results demonstrate that the PCM data are valid surrogate measurements for dimensionally similar TEM data[29] and that the PCM data are valid for the assessment of exposures resulting from brake shoes.

E. Airborne Dust Samples

The airborne dust sample data (total and respirable) are summarized in Table 6. With the exception of the filing and the second arc grinding test, all of the respirable dust samples indicated concentrations remained below the detection limit for the method.

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[28] C. M. Spooner and M. J. Thorpe (1986). "Airborne Asbestos in Buildings: A Comparison of Phase-Contrast and Transmission Electron Microscopic Results", *Journal of the National Asbestos Council*, 4, p. 32 – 41.
J. G. Snyder, R. L. Virta, and J. M. Segreti (1987). "Evaluation of the Phase Contrast Microscopy Method for the Detection of Fibrous and Other Elongated Particulates by Comparison With a STEM Technique", *American Industrial Hygiene Association Journal*, 48, p. 471 – 477.
J. M. Dement and K. M. Wallingford (1990). "Comparison of Phase Contrast and Electron Microscopic Methods for Evaluation of Occupational Asbestos Exposure", *Applied Occupational and Environmental Hygiene*, 5, p. 242 – 247.

[29] A. Marconi, E. Menichini, and L. Paoletti (1984). "A Comparison of Light Microscopy and Transmission Electron Microscopy Results in the Evaluation of the Occupational Exposure to Airborne Chrysotile Fibres", *Annals of Occupational Hygiene*, 28, p. 321 – 331.

DISCUSSION

Five 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 & 5) arc grinding using two different dust collection techniques. Each of these operations occurred as part of an overall brake replacement job as is normally done for vehicle maintenance purposes.

Video segment 1 shows a typical blowout of the dust. After the tires and wheel assemblies are removed, the mechanic next removes the brake drums and places them on the floor. Using an air hose, he blows the remaining brake assemblage to remove the loose particulate. The actual time spent blowing the dust totals several seconds per wheel (the total time of Video 1 is 20 seconds, of which 12 seconds were spent actually blowing the dust). The purpose of the air blow is not to produce clean, particle-free surfaces, but to remove gross dust buildup and reduce the amount of material on surface and brake mechanisms.

During the filing test, the mechanic filed all of the replacement brake shoes during a single session, Video Segment 2. The purpose of the filing is to bevel the edges to prevent grabbing of the shoe on the drum and reduce brake noise. 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 minutes, or an average of 1.2 minutes 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, Video Segment 3. The sanding lasted a total of 4.1 minutes, or about 0.5 minutes per shoe.

As part of the test procedure for arc grinding of the brake shoes, the diameter of each brake drum was measured and the radius of curvature on the grinder adjusted accordingly, see Video Segment 4. The purpose of measuring the diameter is to ensure that the surface of the brake shoe matches the inside surface of the brake drum.

The first arc grinding test, Video Segment 5, 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 arc 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 minutes, though only 12.5 minutes of this time was actually spent grinding the shoes (average of 1.6 minutes per shoe).

Because an older style dust collection bag 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. Video Segment 6 shows a portion of the second arc grinding test. This test lasted a total of 17.8 minutes, with 10.9 minutes spent setting up and adjusting the grinder. Only 6.9 minutes were actually used to grind the shoes (about 0.9 minutes per shoe).

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 HEI[30] and Lee, et al[31], and compared with airborne levels in schools, public buildings and outdoor air. Figure 11 shows a graph of the historical levels, in schools and public buildings and ambient levels. Plotted on that graph are the PCME TWA values determined by this testing ranging from the 0.0001 f/cc value for cleaning to near 0.1 f/cc for the first arc grinding test. It is apparent from these tests that the potential for airborne asbestos fiber exposure during automobile brake changing operation is very near current OSHA regulatory levels and certainly below historical OSHA levels.

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[30] Health Effects Institute – Asbestos Research (1991). Asbestos in Public and Commercial Buildings: A Literature Review and Synthesis of Current Knowledge, Health Effects Institute – Asbestos Research, Cambridge, MA.

[31] Lee, R. J., Van Orden, D. R., Corn, M., and Crump, K. S. (1992). Exposure to Airborne Asbestos in Buildings, *Regulatory Toxicology and Pharmacology*, **16**, 93 - 107.

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. The results of total dust analysis expressed as 8-hour TWAs ranged from 0.19 to 0.71 mg/m^3 with a mean of 0.33 mg/m^3 for brake changing tests. The cleaning test resulted in less than 0.102 mg/m^3 total dust exposure. (Table 6)

Analysis of samples for respirable dust expressed as 8-hour TWAs 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 indicated respectively.

Setting aside the 0.243 mg/m^3 indicated for filing, the mean respirable dust exposure concentration was less than 0.10 mg/m^3 or less than one third of that for the total dust (0.33 mg/m^3). It is likely that the respirable fraction of the dust experienced during brake changing is a lower percentage than these data indicate. This is due to the limit of quantification for the respirable dust analysis which appears to overstate the actual amount of respirable dust present.

Current OSHA PEL's for total and respirable particulates not otherwise regulated are 15 and 5 mg/m^3 respectively as 8-hour TWAs. Clearly these limits were not met or exceeded.

Bias Analysis

Several factors affected the results of these tests. The effects are summarized in Table 7. The combined effect of the variables results in potential exposures in commercial brake repair/replacement facilities at or below levels observed in these tests.

CONCLUSIONS

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

I. Asbestos-containing automotive brake shoes used in the normal course of brake replacement/repair did not cause worker exposure to airborne asbestos

fibers in excess of existing OSHA permissible exposure limits. On the basis of these tests and published historical data, the levels of asbestos fibers released from asbestos-containing brake shoes was at or below the original and subsequent OSHA permissible exposure limits or proposed ACGIH fiber-based exposure limits. Only during the use of the arc grinder did the personal exposure approach the present day OSHA PEL.

II. An individual's potential for exposure to asbestos fibers released from brake shoes could be reduced below the levels observed in this study by certain physical and environmental conditions. Such physical and environmental conditions include air flow, exhaust ventilation, room air exchanges, the presence of water or humidity in the air, and the proximity of workers to the brake repair/replacement operations.

III. The airborne asbestos results of this study are consistent with the published literature regarding repair/replacement of automotive brakes. When the complete brake repair/replacement process is sampled, airborne fiber concentrations remain below the present day OSHA PEL.

Table 1. Summary of the Duration of Each Test

Date	Test	Duration of Test, min	Procedure	Duration of Procedure, min	Duration of Blowing, sec**
July 12, 2001	1	92	Baseline	–	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 I	19.9*	39
July 13, 2001		30	Cleaning	30	–
October 19, 2001	5	85	Baseline	–	22
October 19, 2001	6	96	Arc Grinding II	17.8*	22

* Total time spent at the bench, including set-up and adjustment of grinder. Actual grinding took 12.5 min for test 4 and 6.9 minute for test 5.

** Total time spent blowing compressed air on the brake mechanisms on all four wheels of the automobile.

Table 2. Summary of Environmental Conditions for Each Test

Date	Test	Procedure	Temperature, °F	Relative Humidity, %	Air Flow, acfm
July 12, 2001	1	Baseline	79 – 82	42 - 38	2000
July 12, 2001	2	Filing	76 – 89	36 – 29	2100
July 13, 2001	3	Sanding	64 – 76	64 – 42	2100
July 13, 2001	4	Arc Grinding I	80 – 85	36 – 32	2000
July 13, 2001		Cleaning	82	31	2000
October 19, 2001	5	Baseline	55 – 64	44 – 34	2200
October 19, 2001	6	Arc Grinding II	66 – 70	32 – 29	2200

Table 3. Summary of Ambient Fiber Test Data

Day	Location	Sample Collection		PCM Analysis		TEM Analysis		PCM Equivalent
		Time, min	Volume, l	Fibers	f/cc	Asbestos	Nonasbestos	f/cc
7/12	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
7/13	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
10/19	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

Analytical Procedures:

PCM – NIOSH 7400
TEM – NIOSH 7402

Table 4. Summary of Personal Fiber Test Data

Test	Procedure	Sample Collection		PCM Analysis		TEM Analysis	PCM Equivalent	
		Time, min	Volume, l	f/cc	TWA*, f/cc	Fiber Ratio	f/cc	TWA*, f/cc
1	Baseline	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 I	103	215	0.4368	0.0937	0.99	0.4358	0.0935
	Cleaning	30	67	0.0146	0.0009	0	0	0
5	Baseline	85	175	0.0672	0.0119	0.07	0.0048	0.0009
6	Arc Grinding II	96	198	0.2005	0.0401	0.86	0.1734	0.0347

Analytical Procedures:

PCM – NIOSH 7400
TEM – NIOSH 7402

* - TWA is 8-hour TWA assuming no exposure other than the test

Table 5. Average Fiber Concentrations Relative to the Location of the Samples to the Automobile

Test	Location	PCM, f/cc	PCME, f/cc
Baseline 1	Within 10 ft	.00027	0.00020
	More than 10 ft	– *	– *
	Bench	No Samples	
Filing	Within 10 ft	0.0282	0.0128
	More than 10 ft	0.0300	0.0097
	Bench	No Samples	
Hand Sanding	Within 10 ft	0.0133	0.0097
	More than 10 ft	0.0112	0.0092
	Bench	0.0142	0.0091
Arc Grinding I	Within 10 ft	0.0296	0.0266
	More than 10 ft	0.0389	0.0389
	Bench	0.0895	0.0828
Cleaning	Within 10 ft	0.0069	0
	More than 10 ft	0.0071	0
	Bench	0	0
Baseline 2	Within 10 ft	0.0258	0.0060
	More than 10 ft	0.0227	0.0095
	Bench	0.0325	0.0093
Arc Grinding II	Within 10 ft	0.0276	0.0186
	More than 10 ft	0.0265	0.0154
	Bench	0.0450	0.0372

Analytical Procedures:

PCM – NIOSH 7400
TEM – NIOSH 7402

* - Samples were overloaded

Table 6. Summary of Personal Dust Samples, mg/m^3

				Total Dust		Respirable Dust	
Date	Test	Operation	Time, min	Observed	TWA*	Observed	TWA*
July 12, 2001	1	Baseline	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 I	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	85	1.091	0.193	< 0.538	< 0.095
October 19, 2001	6	Arc Grinding II	96	1.207	0.241	0.514	0.103

Total Dust, NIOSH 0500
Respirable Dust, NIOSH 0600

* - TWA is 8-hour TWA assuming no exposure other than test

Table 7. Bias Analysis – Summarizes the effect of the various factors on the contribution by brake shoes to airborne asbestos concentrations

Parameter	This Study	Commercial Facilities	Effect
Air Exchange	2 equivalent air volumes per hour	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	
Air Blow of Dust	Long enough to remove dust from drums	Long enough to remove dust from drums	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 exposures
Brake Pad Manipulation	Sanding, Filing, Arc Grinding	Sanding, Filing, Arc Grinding	No difference in potential exposure
Concurrent Operations	Only one repair per period	One or more repair per time period	No effect on worker exposures, potential for increased bystander exposure
Humidity	Low	Variable	Higher humidity will reduce potential exposure

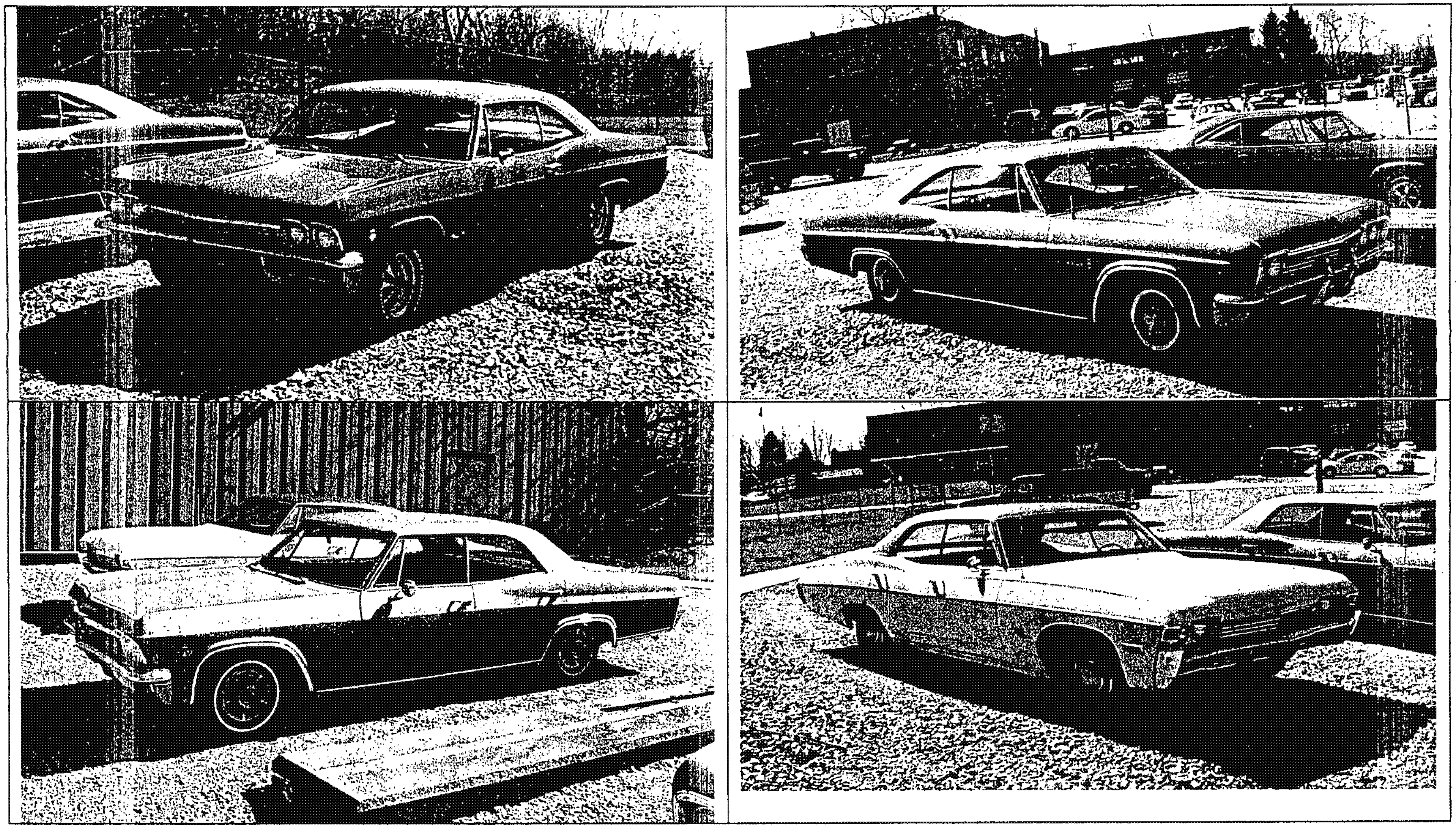

Figure 1. Photographs of the Chevrolet Impalas used in these tests. Model year (clockwise from top left) 1965, 1966, 1968, 1965. The 1965 Impala (brown, lower left) had power assisted brakes; the other automobiles did not.

Figure 2. Map showing the route driven in these tests. The course started at RJ Lee Group's Monroeville laboratory (upper right map) and followed local roads to US 22 in Murraysville (clockwise from RJ Lee Group). This highway was followed west to Rodi Road in Penn Hills, PA (upper left) where a loop was driven through local streets (counterclockwise in map) in Penn Hills and Churchill back to US 22. This highway was taken east to Elliot Road which returned the driver to RJ Lee Group. Each lap was approximately 21 miles and took about an hour to drive.

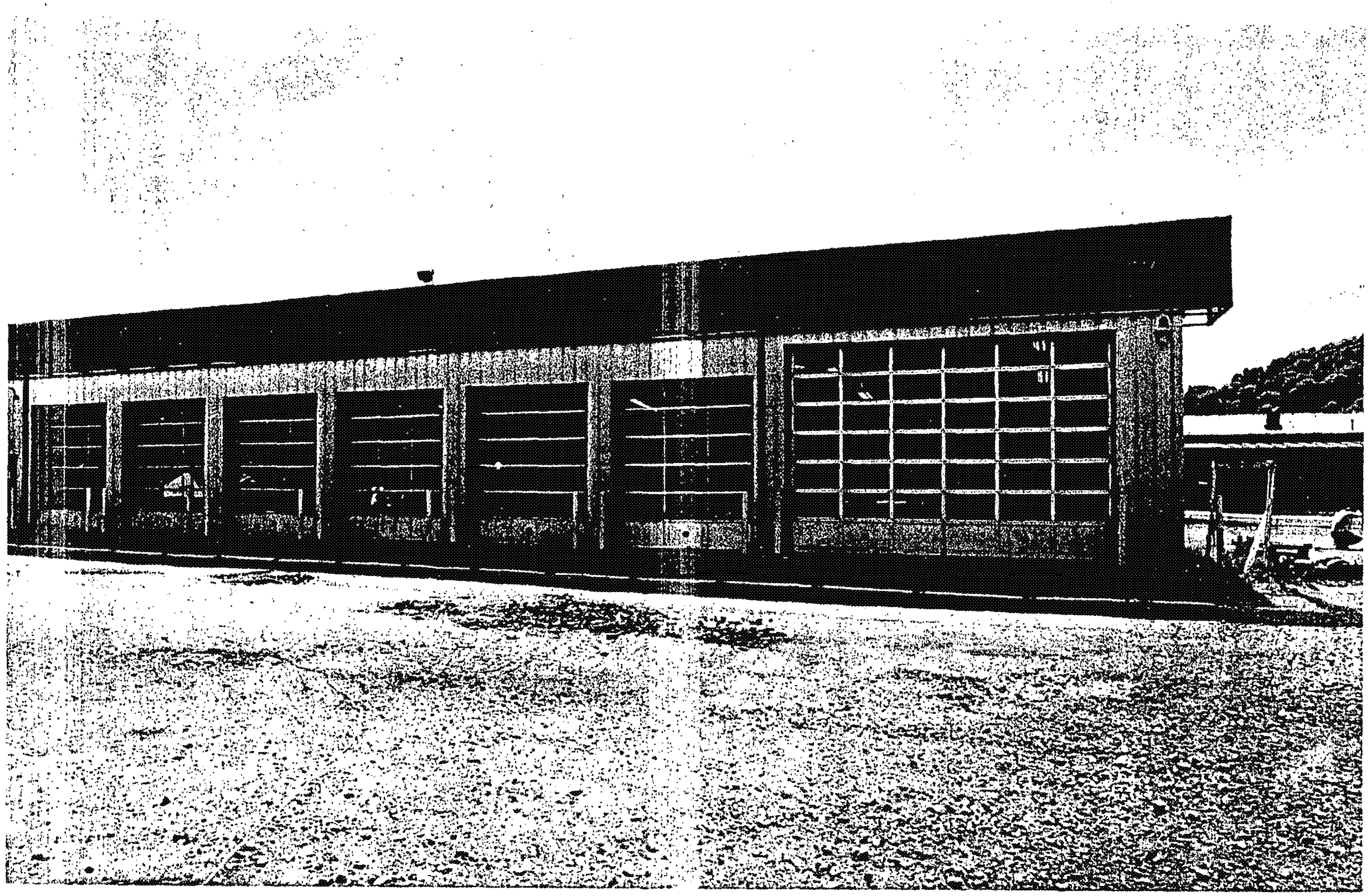

Figure 3. View of the west shop entrance, facing east. The facility is located at 609 Greensburg Road, New Kensington, PA.

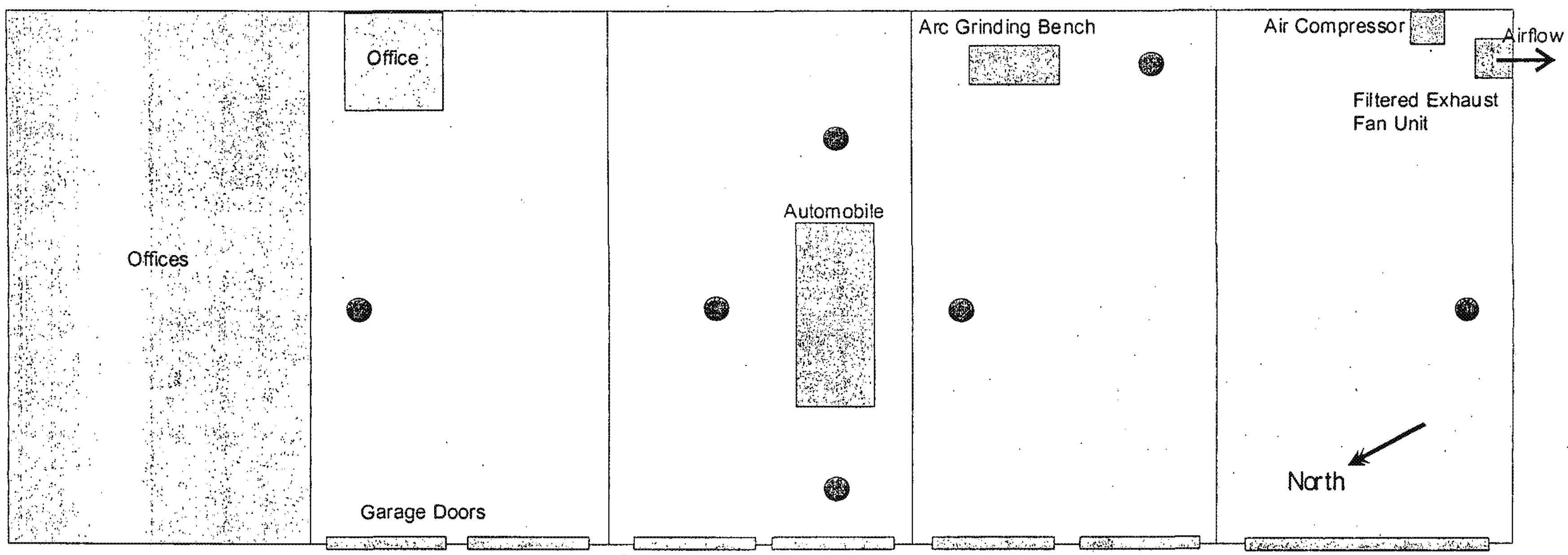

Figure 4. Schematic drawing of the repair facility showing the location of the vehicle in the building and the area samples (blue circles). The service bay area is approximately 99 ft long and 43.5 ft wide. The dotted lines show the divisions between the concrete pads in the floor. The four area samples near the automobile are within 10 ft. The sample next to the office was within 5 ft of the wall; the sample at the other end of the service bay was also within 5 ft of the wall.

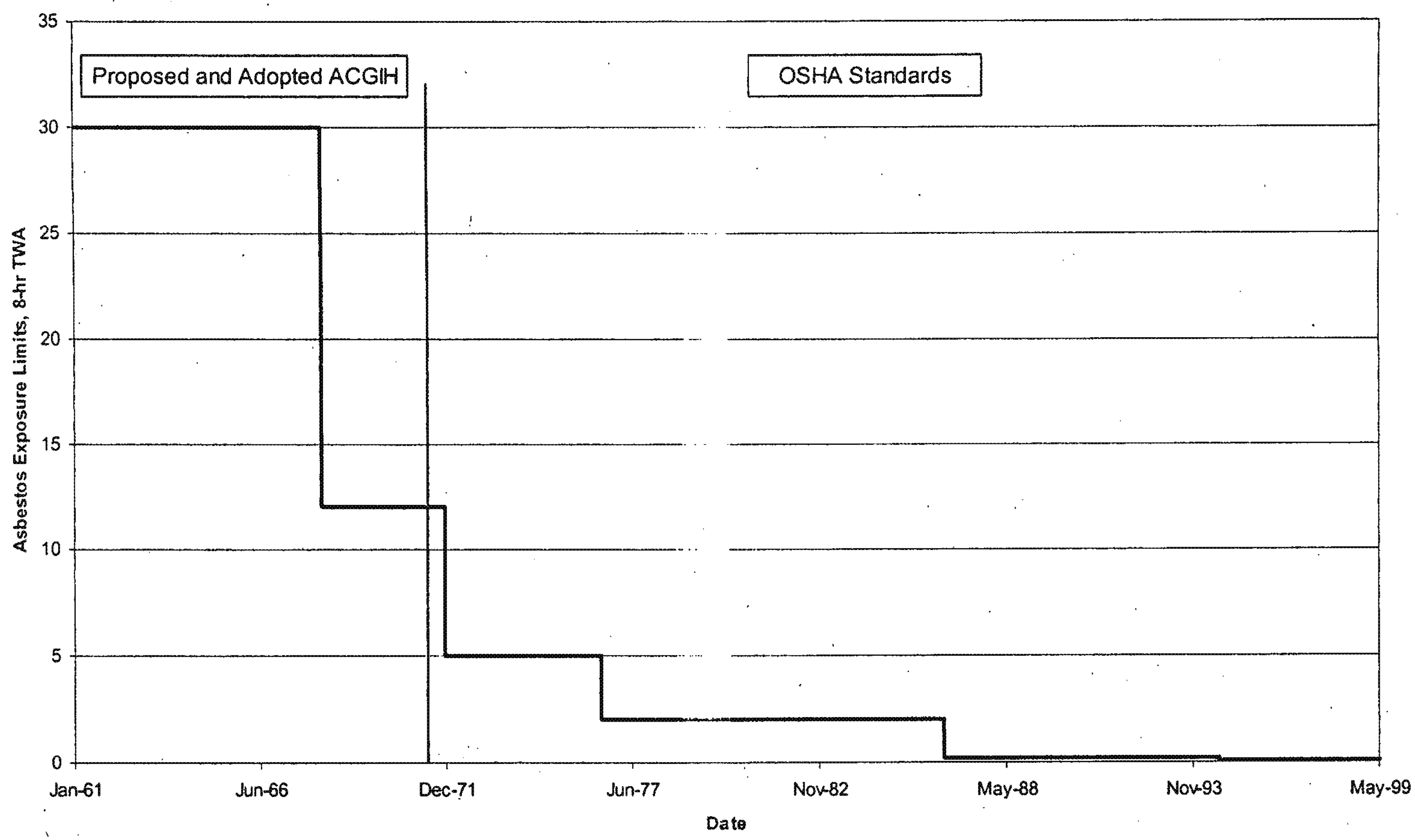

Figure 5. Exposure limits to airborne fibers (TWA). Prior to 1971, the exposure limits were recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). Beginning in 1971, the Occupational Safety and Health Administration (OSHA) established the first federal exposure limits by adopting the proposed ACGIH limits. Periodically since its inception, OSHA has reviewed these limits and reduced them as the knowledge of asbestos epidemiology improved.

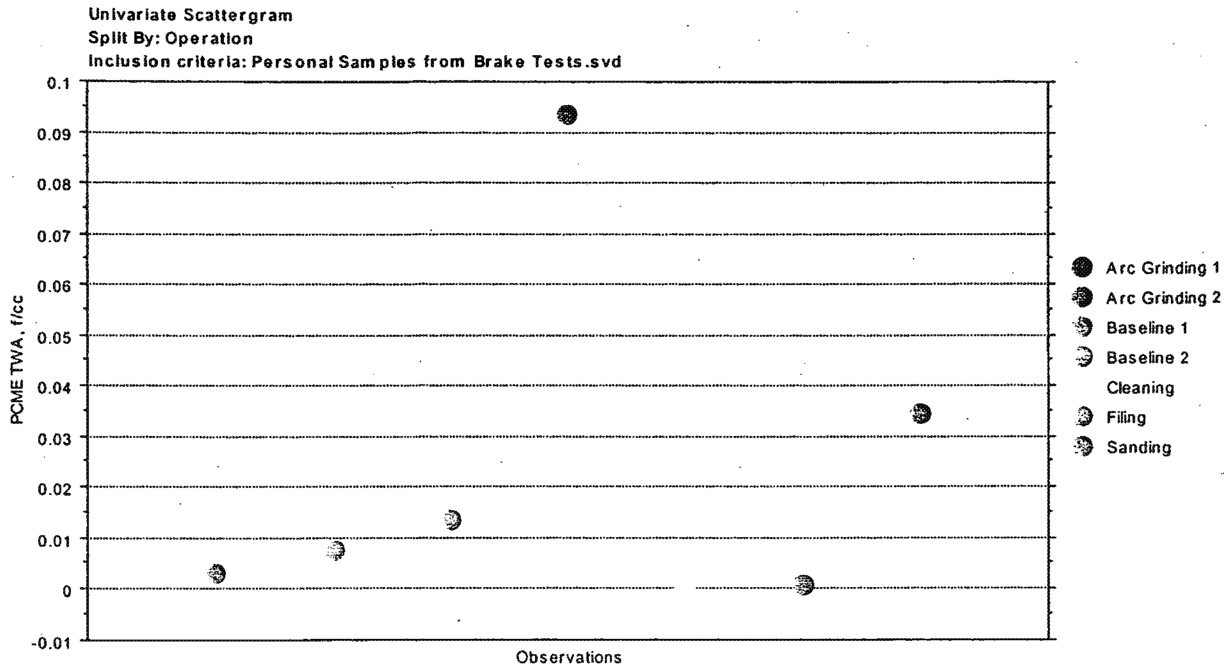

Figure 6. Distribution of the results of personal air samples collected for fiber analyses. With the exception of the two grinding tests, the personal sample PCME TWA values were below 0.01 f/cc.

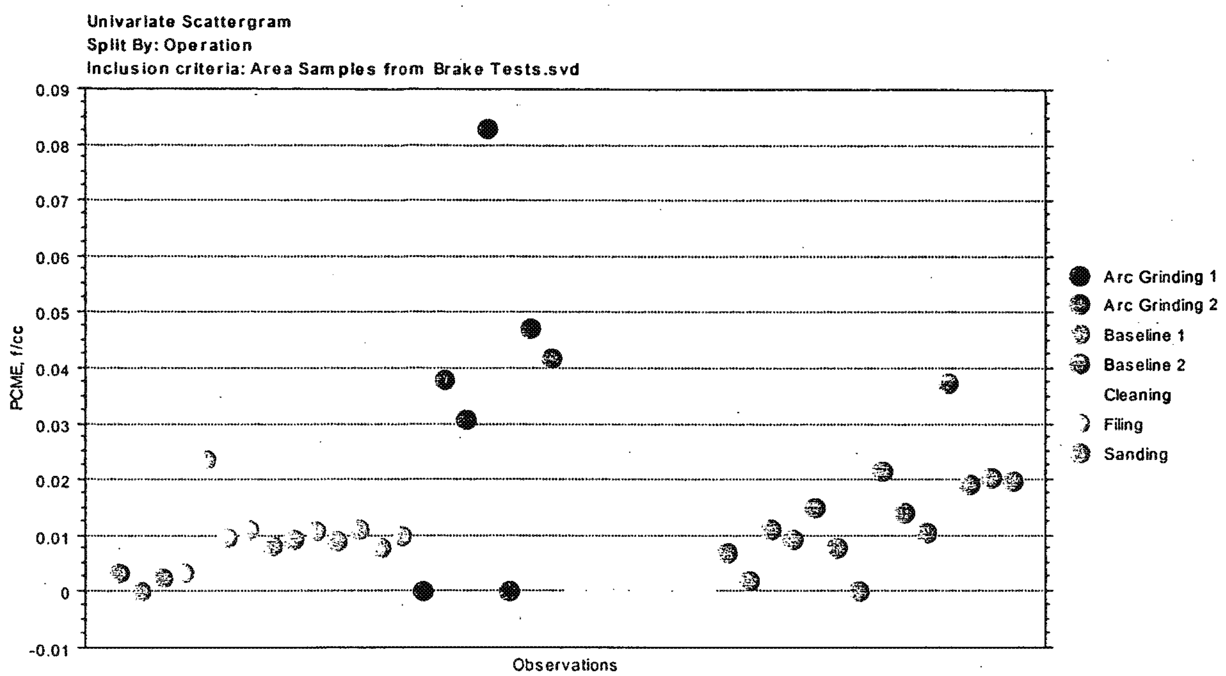

Figure 7. Distribution of the PCME asbestos fiber concentrations for the area samples. The majority of samples were less than 0.03 f/cc.

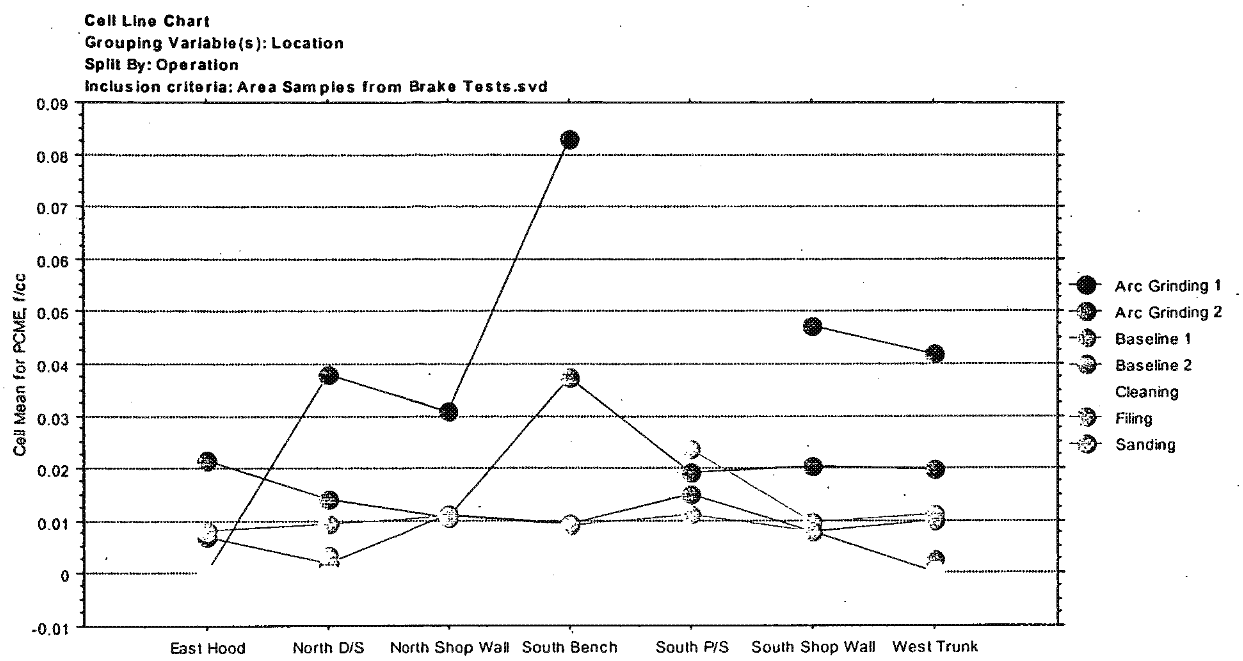

Figure 8. Graph showing the average PCME asbestos fiber concentrations for the area samples, sorted by sample location.

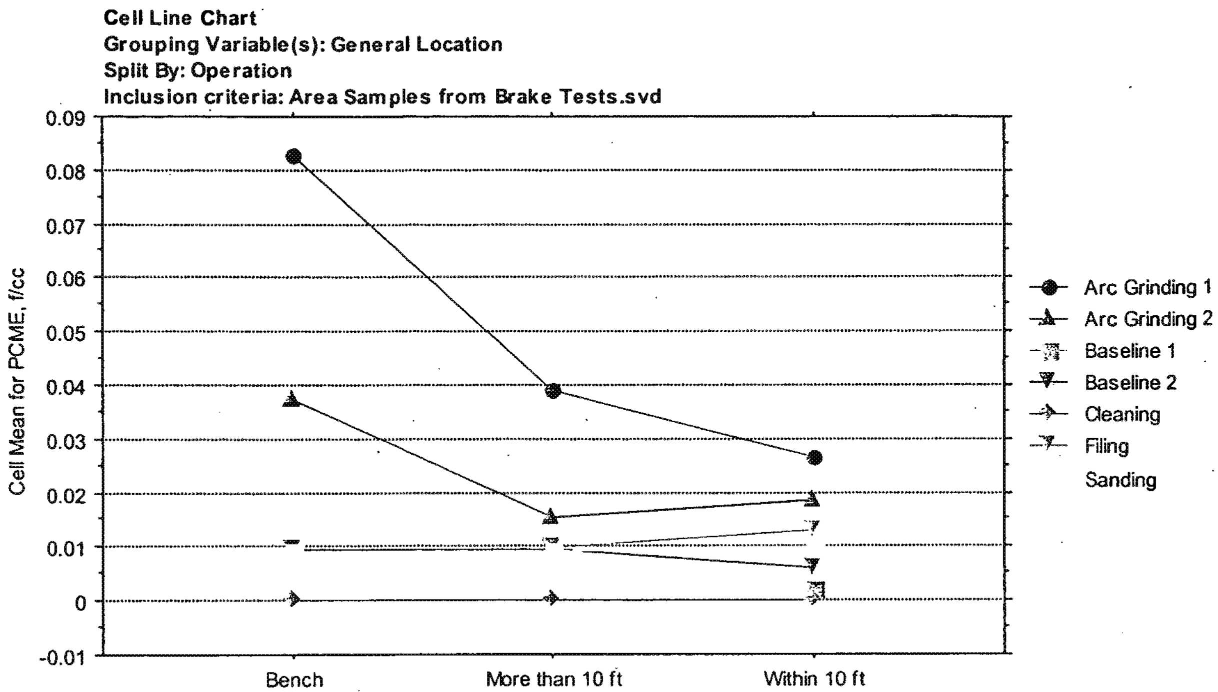

Figure 9. Graph showing the average PCME asbestos fiber concentrations for the area samples relative to the proximity to the automobile. There is no significant difference in concentration between samples in close proximity to the automobile from those far from the automobile.

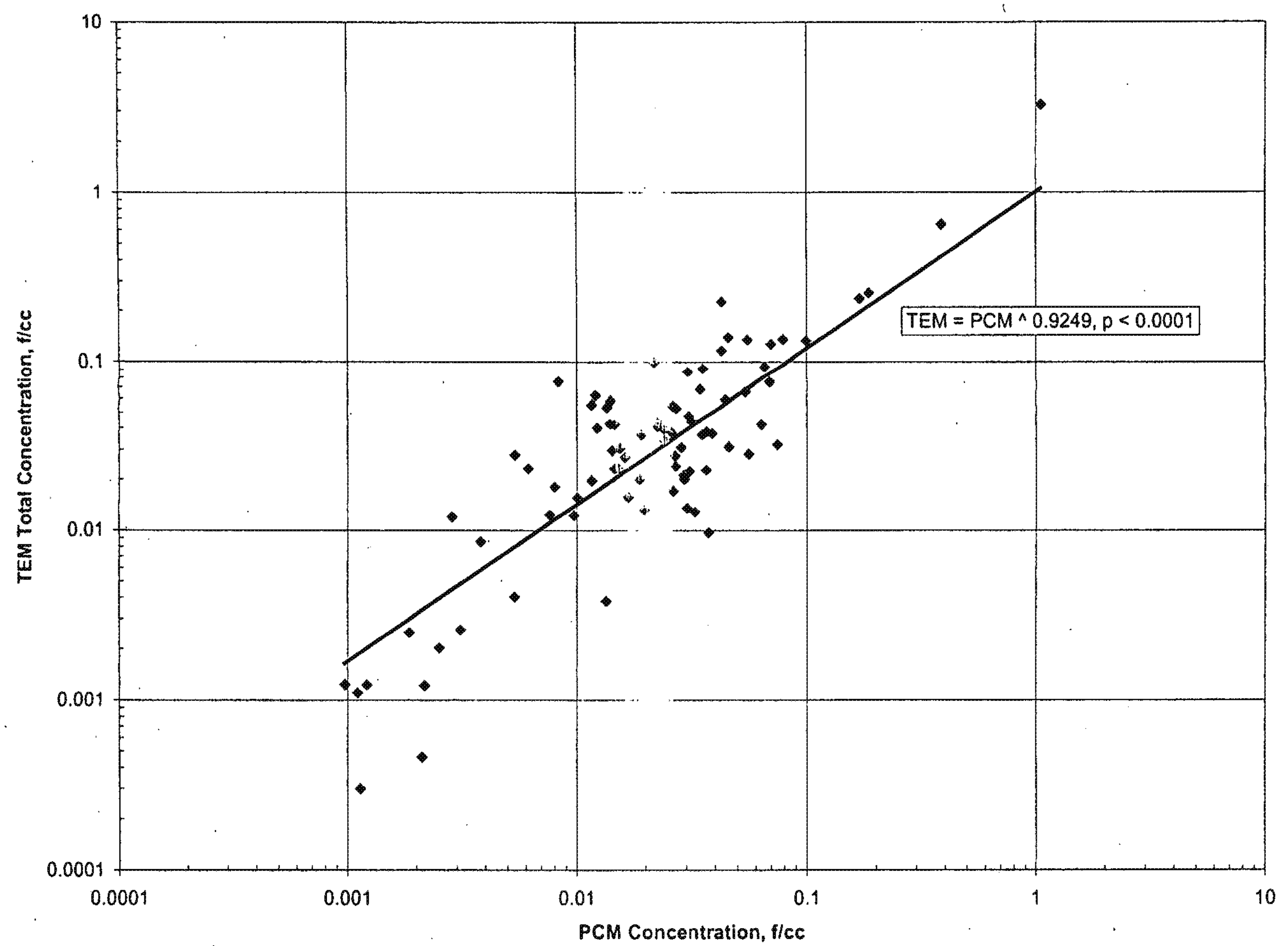

Figure 10. Graph showing a comparison between air sampling data generated using NIOSH 7400 (PCM Concentration) and NIOSH 7402 (TEM total concentration). The data show a statistically significant ($p < 0.0001$) relationship ($TEM = PCM^{0.92}$). Due to the nearly linear relationship between the data from 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.

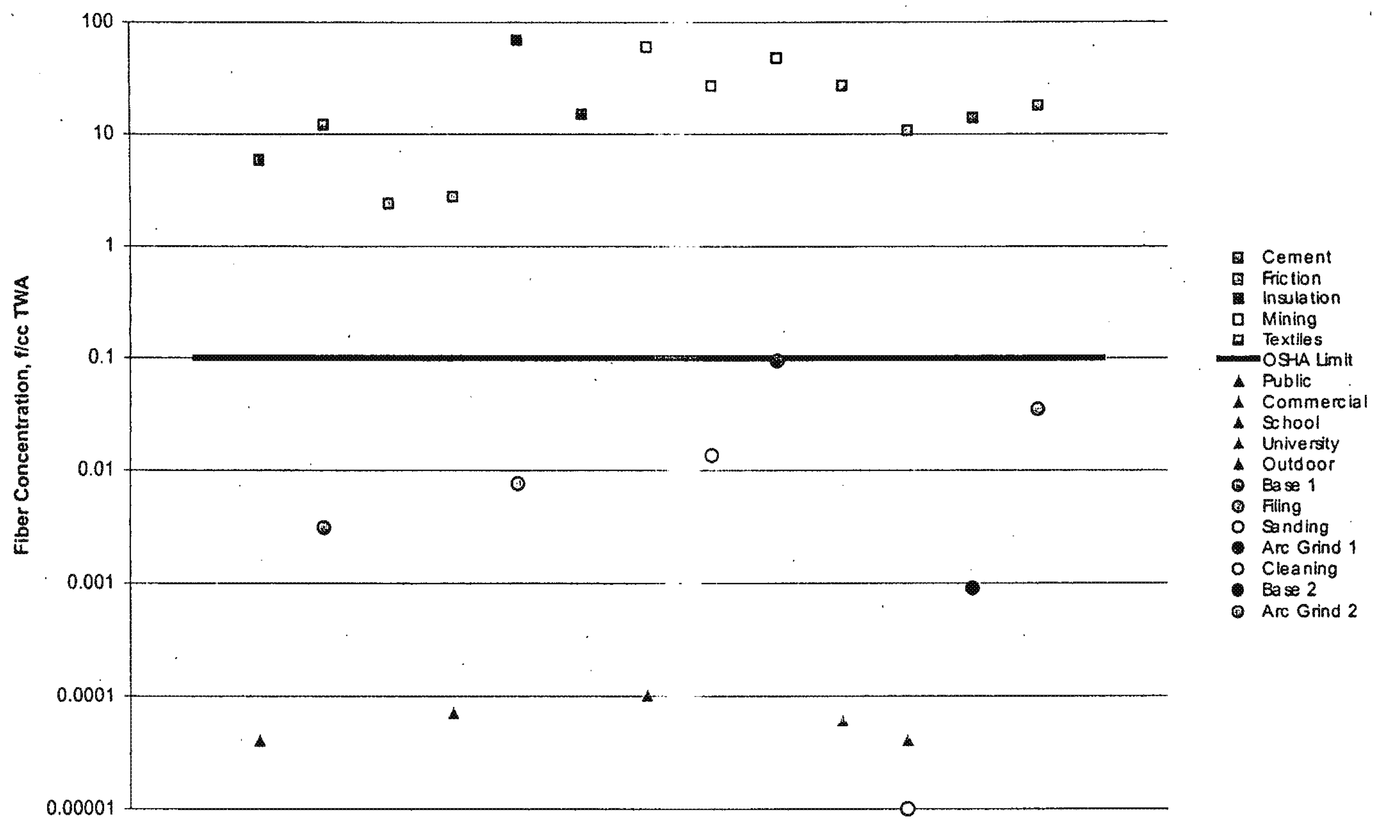

Figure 11. Graph showing the historical airborne fiber concentrations cited in the epidemiology studies used by OSHA in establishing the current exposure limit (0.1 f/ml). Also shown are typical airborne concentrations in buildings, as well as the mechanic exposures from the present study.