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Assessment of airborne asbestos exposure during the servicing and handling of automobile asbestos-containing gaskets

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Abstract

Five test sessions were conducted to assess asbestos exposure during the removal or installation of asbestos-containing gaskets on vehicles. All testing took place within an operative automotive repair facility involving passenger cars and a pickup truck ranging in vintage from late 1960s through 1970s. A professional mechanic performed all shop work including engine disassembly and reassembly, gasket manipulation and parts cleaning. Bulk sample analysis of removed gaskets through polarized light microscopy (PLM) revealed asbestos fiber concentrations ranging between 0 and 75%. Personal and area air samples were collected and analyzed using National Institute of Occupational Safety Health (NIOSH) methods 7400 [phase contrast microscopy (PCM)] and 7402 [transmission electron microscopy (TEM)]. Among all air samples collected, approximately 21% ($n=11$) contained chrysotile fibers. The mean PCM and phase contrast microscopy equivalent (PCME) 8-h time weighted average (TWA) concentrations for these samples were 0.0031 fibers/cubic centimeters (f/cc) and 0.0017 f/cc, respectively. Based on these findings, automobile mechanics who worked with asbestos-containing gaskets may have been exposed to concentrations of airborne asbestos concentrations approximately 100 times lower than the current Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 0.1 f/cc.

Keywords: Asbestos; Automotive; Gaskets; Mechanics; Occupational; Exposure

1. Introduction

Asbestos-containing materials (ACMs) have been used in automobile brakes, gaskets, clutches, and some undercoating. The presence of asbestos in the workplace and the potential for fibers to be liberated during the servicing of vehicles has given rise to allegations of increased rates of asbestos-related diseases among automotive mechanics (Huncharek, 1990; Lemen, 2004). However, epidemiological studies attempting to elucidate the risk of lung cancer and mesothelioma within automobile mechanics report no increased risk of asbestos-related diseases within the occupational cohort (Agudo et al., 2000; Wong, 2001; Goodman et al., 2004; Hessel et al., 2004; Laden et al., 2004; Wong, 2006). Despite these findings, a debate continues about the deleterious effects of exposure to asbestos fibers in the automotive repair industry. There is little exposure data characterizing the airborne asbestos fiber levels that workers may encounter while performing maintenance activities on the various asbestos-containing parts found within automobiles. Each component is an independent point source of asbestos exposure and may constitute a unique occupational hazard for mechanics. Of the ACMs found in automobiles, brakes and brake components have been the primary source of interest. Several previously conducted exposure assessments report asbestos concentrations that do not exceed the current Occupational Safety and Health Administration's (OSHA) Permissible Exposure Limit (PEL) of 0.1 fibers per cubic centimeter (f/cc) (OSHA, 1997a; Weir et al., 2001; Blake et al., 2003; Paustenbach et al., 2003, 2004). Other asbestos-containing parts, such as gaskets, have not been studied in such detail.

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Asbestos-containing gaskets have historically been used in internal combustion engines as interfaces between solid components to prevent leakage. The asbestos content of gasket material provides additional flexibility, durability, and resistance against thermal and chemical degradation. During the servicing of vehicles containing these gaskets, the potential release of asbestos fibers and subsequent worker exposures raise occupational health concerns. Limited information is currently available that characterizes worker exposure to airborne asbestos fibers released during the servicing of vehicles assembled with asbestos-containing gaskets. A review of published literature identified three studies that examined the airborne fiber levels generated during the handling and replacement of automotive gasket materials containing asbestos. Yeung et al., investigated chrysotile exposure in garage workers using various control methods during the servicing and replacement of friction materials and gaskets (1999). The average phase contrast microscopy (PCM) fiber concentrations for personal and area air samples associated with the cutting and stamping of compressed sheet automotive gaskets were below the analytical level of detection (LOD) of 0.05 f/cc (Yeung et al., 1999). Liukonen and Weir assessed asbestos concentrations during the dismantling and cleaning of a medium-duty diesel engine containing asbestos gaskets (2005). Bulk sample analyses established the presence of asbestos fibers within 28 of the 33 removed gaskets in concentrations ranging from 15 to 70% (Liukonen and Weir, 2005). Airborne levels of asbestos fibers were reported to be approximately 10% of the OSHA PEL (Liukonen and Weir, 2005). Paustenbach et al., evaluated the exposure to asbestos during the removal of automotive exhaust systems containing asbestos gaskets (2005). Analysis of personal air samples were between 0.006 and 0.066 PCM f/cc (Paustenbach et al., 2005). The fiber concentrations reported in these studies indicate that automotive mechanics are exposed to limited, if any, levels of airborne asbestos fibers.

The purpose of this study was to characterize airborne asbestos exposure during vehicle servicing and handling of asbestos-containing gaskets. Data were collected during normal operational conditions within an active automotive service facility to ensure a valid assessment of worker exposure during the disassembly and reassembly of automotive engines containing asbestos gaskets. Personal and area air samples were analyzed for comparison against the OSHA PEL and with previous studies.

2. Materials and methods

2.1. Test location and environmental setting

This study was conducted in a fully equipped and functioning automobile service facility located in Detroit, Michigan. The specific workspace used for this testing was a two-bay automotive service garage with rollup doors on both ends of each bay. Interior dimensions of the service garage measured 37.5 feet (ft) by 29-ft with exposed roof decking at 17.8-ft. The general layout of this garage is shown in Fig. 1. The north wall of this garage angled into a hallway that lead to offices and the main shops located to the north. Barriers and isolation devices were not utilized to seal the test area from this section of the service facility due to its distance from the actual test area and to aid in maintaining standard environmental conditions. Area samples were collected from midway between the two shop areas which showed an absence of airborne fiber migration from shop-to-shop. A warehouse used for storage purposes was located adjacent to the north wall of the garage. Existing materials and equipment were left inside the automotive service facility and the connecting hallway during the testing. This included, but is not limited to, parts bins, used tires, compressed gas bottles, trash receptacles, a tire inflation safety cage and two fully functional hydraulically operated automobile lifts. Vehicles receiving service entered from the west side and exited from the east side or vice versa.

The ventilation system located within the two-bay automotive service garage was shut down during the three days of testing. Testing was performed in an unventilated facility to facilitate a "worse case" scenario. Also, the rollup vehicle doors remained closed during each test session. The four rollup doors were opened between test sessions to remove airborne particles generated during the previous test sessions.

2.2. Test vehicles

Vintage vehicles utilized in this experiment were selected based on (1) the likelihood of encountering asbestos-containing gaskets and, (2) the availability of new replacement asbestos-containing engine gaskets. The tested vehicles included a 1974 Chevrolet Malibu, 1978 Chevrolet pickup truck and a Ford 390 cubic inch V-8 engine. Table 1 contains a brief description of the vehicles and engines utilized in this study.

2.3. Mechanic's activities, equipment and tasks

The professional automotive mechanic was Automobile Service Excellence (ASE) certified, and was instructed to perform gasket removals or installations using his standard operating procedures (SOP). Thus, he was allowed to select all tools and equipment to ensure limited interference with his job practices. Tools utilized during this experiment included wrenches, screwdrivers, scrapers, and hammers, in addition to pneumatic powered ratchets for the removal of bolts and nuts. The mechanic was directed to wear a normal work uniform to further ensure realism and avoid use of cumbersome or uncomfortable garments which would have interfered with his normal activities or work habitats.

Five individual test sessions were conducted to assess the levels of airborne asbestos fiber generated during the servicing and handling of asbestos-containing gaskets. Three test sessions focused on the partial disassembly of engines and the removal of gasket remnants from engine receiving surfaces and loose parts. The two remaining test sessions involved engine reassembly and included installation of new asbestos-containing gaskets. Table 2 summarizes the individual activities performed during testing.

During the gasket removal test sessions, the mechanic first removed engine heads and manifolds components that covered or otherwise held the target gaskets. Many of these gaskets came off intact leaving gasket residue on the metal mating surface. Bulk samples of the removed gaskets were obtained for subsequent analysis. The mechanic next scraped away gasket residue using a wide blade putty knife, sometimes assisted with a rubber hammer. Loose parts, such as engine heads and manifolds, were next immersed into a water bath cleaner, a product of Safety Kleen, and washed using an Arm and Hammer brand Aqua Works Cold Cleaning Solution, before being burnished using a rotary 1-in. knot type wire end brush, NAPA service tools Part Number (P/N) 2312. The end brush was powered by a hand held drill motor, Ingersoll Rand model 7803R, operated from 90 PSI line pressure. To aid in the gasket and other residue removal process, the mechanic sprayed the parts with a non-chlorine containing solvent dispersed from an aerosol spray can, Aerosol Systems, Inc., P/N TM 3506. This solvent contained; xylenes, aliphatic petroleum distillates, and acetone, with a compressed carbon dioxide propellant. When cleaning the surfaces of fixed, non-transportable parts such as engine

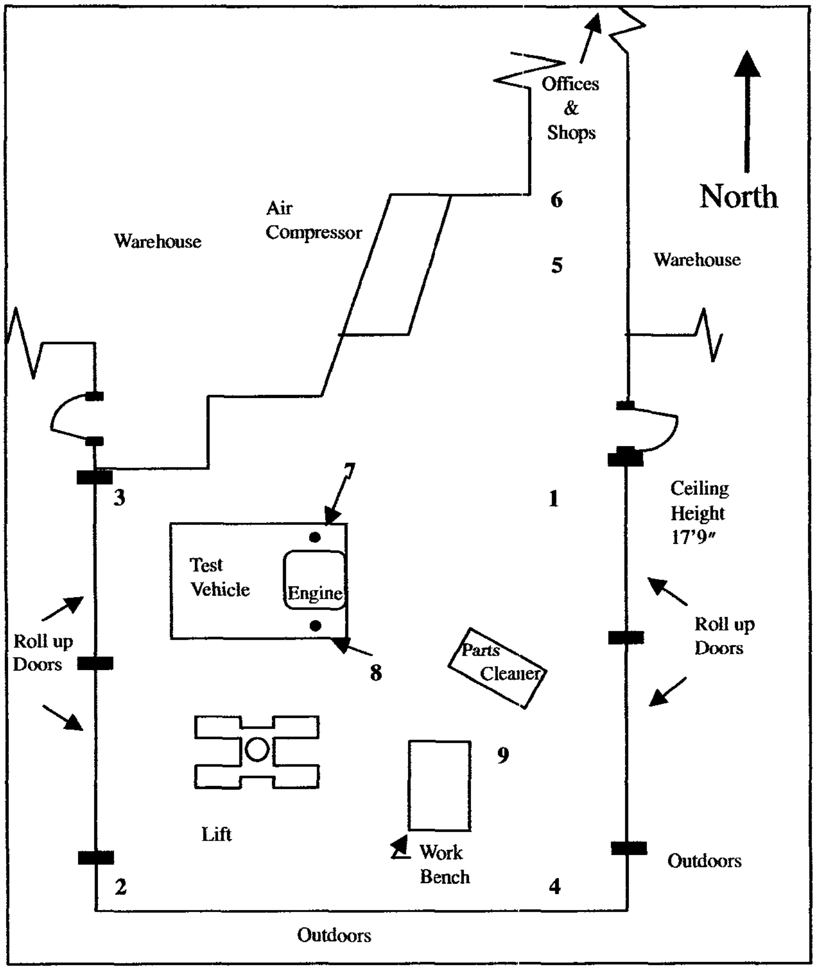

Fig. 1. Automotive servicing facility. Numerical values represent locations of area samples and correspond with Table 3.

Table 1
Make and model of vehicles and engines

Automobile/engine	Description of engines
1974 Chevrolet Malibu	Small Block Engine, 350 Cubic Inch V-8
1978 Chevrolet Pickup	In-line Engine, 250 Cubic Inch 6 Cylinder
Ford Thunderbird	390 Cubic Inch V-8 (Loose Engine)

blocks, the mechanic utilized scraping, powered wire brushing, and solvent spray, however no aqueous wash occurred with the fixed parts. This process continued until all gasket remnants were removed from the loose parts and engine blocks, and subject parts were sufficiently clean to allow reassembly.

Reassembly of the engines and installation of new asbestos-containing gaskets occurred in two test sessions. The mechanic chose to initially apply an adhesive glue strip to previously cleaned receiving surfaces on the engine blocks. This step ensured that the new gaskets would be securely held in place as the loose engine components were reattached. New asbestos-containing gaskets were laid on the engine receiving surfaces and the respective engine parts were lowered into place. Finally, bolts and other fasteners were tightened to specified torque limits.

The mechanic was responsible for cleaning the work area after each test session. When conducting cleanups, the mechanic utilized a hand held straw broom, a push broom and a dust pan. Debris on the work surfaces and floor was swept and disposed of into available trash containers. Air sampling continued during this time period and ended after the mechanic was satisfied with the conditions of the garage and work area.

Table 2
Activities associated with the removal and replacement of asbestos-containing gaskets

Task	Description
Engine disassembly and removal of asbestos-containing gaskets	1. Vehicle/engine moved into service facility 2. Vehicle placed on rack 3. Engine partially disassembled 4. Gaskets removed 5. Engine receiving surfaces dry scrapped and brushed to remove gasket remnants 6. Loose engine components placed in water bath; parts washed 7. Parts rotary brushed to remove gasket remnants
Engine reassembly and installation of asbestos-containing gaskets	1. Placement of adhesive on engine receiving surfaces 2. Placement of gaskets into position 3. Placement of loose engine components 4. Tighten fasteners; securing of loose parts to engine block
Cleanup of service facility	1. Sweeping of all debris into dust pan 2. Placement of debris into trash bin

2.4. Sampling and analysis of collected samples

Personal and area air samples were collected to estimate airborne fiber exposure levels that mechanic and hypothetical bystanders would encounter during the previously described work activities. The equipment utilized for collecting personal samples consisted of battery powered portable air pumps, Ametek Model ꝛl, that drew air at metered flowrates, nominally 2.0–2.4 liters per minute (lpm), through 25-mm diameter cassettes mounted mixed cellulose ester (MCE) membrane filters. The cassettes were placed within the mechanic's breathing zone. The membrane filters placed atop the mechanics right shoulder were of 0.8 micron (μm) pore size, while those placed atop his left shoulder were of 0.45 μm pore size.

Area air samples were collected using line operated vacuum pumps, Gast Manufacturing, Inc., at metered flowrates, nominally 10 lpm. These pumps drew air through 25 millimeter (mm) diameter cassettes mounted with 0.45 μm pore size mixed cellulose ester (MCE) membrane filters. The flowrates for all air sampling systems were measured and documented prior to and after completion of each test. A primary standard airflow calibrator, Bios International Model DC-1, was used for these airflow measurements. Nine area air samples ($n = 9$) were collected during each test session at breathing zone heights (5-ft above floor) either being supported by portable stands, the automobile lift, or the test vehicles. Area samples were located; on either side of the test vehicles (or engine), at the four corners of the test garage, on the work bench used for wire brush cleaning and down the connecting hallway. These samples were placed at distances ranging from 0 to 50-ft from the test vehicle. Table 3 also summaries the location of area samples during each test session. Area samples locations are represented on Fig. 1.

Samples were analyzed using phase contrast microscopy (PCM) and transmission electron microscopy (TEM). PCM analysis followed the National Institute of Occupational Safety and Health (NIOSH) Method 7400 (NIOSH, 1994a). This analytical method is unable to distinguish between fibers of asbestos and non-asbestos origins, and provides an index of airborne fibers commonly used to estimate asbestos concentrations (NIOSH, 1994a). The optical limitations of the phase contract microscope restrict its resolution capabilities to fibers wider than 0.25 micrometer (μm) and longer than 5 μm in length. Additionally, fibers not exhibiting a three to one length to width ratio are excluded from the counting process. Use of this method satisfies requirements of the OSHA standards for asbestos specific air sampling.

PCM analysis of air samples counts all resolvable fibrous structures including non-asbestos fibers that meet the dimensional criteria. There exists the potential for such analysis to yield airborne fiber concentration data which exceed the actual airborne asbestos concentrations. In settings such as automobile repair shops, cellulose fibers, long thin metal fragments from power brushing activities and synthetic, and other fibers often appear in air samples taken during work of the type subject of this research. For this reason, additional analysis of air samples was done using TEM, following NIOSH Method 7402 (NIOSH, 1994b). This analytical method measures fibers longer than 5 μm and wider than 0.25 μm, and allows development of an asbestos-to-total fiber ratio. This ratio is then multiplied by the airborne fiber concentration generated using the PCM analysis, yielding an asbestos fiber count known as phase contrast microscopy equivalent (PCME). This asbestos fiber count may be used for comparison against occupational exposure limits (OEL) such as the OSHA PEL or NIOSH recommended exposure limits (REL).

Table 3
Location of area samples within service facility

Sample No.	Location
1	Southeast corner (SE corner); 22 feet SE of vehicle
2	Southwest corner (SW corner); 19 feet SW of vehicle
3	Northwest corner (NW corner); 15 feet NW of vehicle
4	Northeast corner (NE corner);18 feet NE of vehicle
5	Intermediate hallway; 30 feet NE of vehicle
6	Distant hallway; 50 NE of vehicle
7	Driver's side fender
8	Passenger's side fender
9	Work bench; 9 feet S of vehicle

Asbestos contents of gaskets were determined by polarized light microscopy (PLM) using the United States Environmental Protection Agency (USEPA) Method 600/R-93/116 (Perkins and Harvey, 1993). PLM is capable of identifying the individual components of a sample and estimating their relative concentration within the sample's matrix. Additionally, the specificity of the method allows for the differentiation between serpentine and amphibole asbestos fibers.

2.5. Statistical analysis

Descriptive statistics have been provided for personal and area samples collected during the five test sessions. Several of the samples collected ($n = 15$) were reported at the LOD for PCM. These unreported values are unusable for statistical analysis, and must be addressed to limit censorship of the data. The LOD for NIOSH Method 7400 is determined based on the number of optical fields and fibers counted and the volume of sampled air, and represents a dynamic value for each individual sample. For the purpose of statistical analysis, samples reported at the LOD have been counted as the full value. This method of analysis will skew the data towards an exaggerated mean fiber concentration, and provide a more conservative or "worse-case" scenario estimate of the airborne asbestos levels generated during this test.

The 8-Hour Time Weighted Average (8-HR TWA) for the individual samples and mean concentrations have been calculated based on the computation formula prescribed by OSHA (Occupational Safety and Health Administration, 1997b). Values of 0 f/cc were applied in the equation for the time period for which no work or sampling was performed. All reported values have been calculated by this method unless otherwise noted.

3. Results

3.1. Individual test sessions

A summary of the area airborne fiber levels generated during the removal and installment of asbestos-containing gaskets is presented in Table 4. During the three sessions associated with the disassembly of the test engines, the length of the tests ranged from 132 to 157 min. Installation of replacement gaskets in the Ford engine and Chevrolet Malibu required 122 and 150 min, respectively. Approximately 23% ($n = 10$) of the area samples were below the analytical LOD for PCM. The highest 8-HR TWA fiber concentration was 0.0079 f/cc, and occurred during the removal of gaskets from the Chevrolet Malibu. The relationship of the individual area air samples to the OSHA PEL is illustrated in Fig. 2. All area samples ($n = 43$) were approximately 100 times lower than the current PEL of 0.1 f/cc.

Among the nine area sampling locations, only slight variations in the fiber concentrations were observed throughout the automotive service facility during the removal and replacement of asbestos-containing gaskets. The highest fiber concentrations observed during the removal of gaskets from the three test vehicles did not occur in the immediate test area. Background levels of fibers ranged from 8-HR TWA of 0.0005–0.0015 f/cc. A summary of the mean fiber levels relative to sampling location is provided in Table 5.

3.2. Personal samples

Table 6 provides a descriptive summary of the personal samples. Results from personal samples are

Table 4
PCM fiber concentrations for the individual test sessions

Test	Vehicle/engine	Session description	Sample No.	Duration (min)	Mean PCM[a] Concentration 8-HR TWA[b] (f/cc)[c]	Range
1	Chevrolet Malibu	Engine disassembly gaskets removed	8[d]	151	0.002	0.0017–0.0026
2	Chevrolet Malibu	Engine reassembly; gaskets installed	8[d]	157	0.0015	0.0012–0.0017
3	Chevrolet Pickup Truck	Engine disassembly; gaskets removed	9	132	0.0002	0.0002–0.0003
4	Ford 390 Engine	Engine disassembly; gaskets removed	9	122	0.0009	0.0007–0.0011
5	Ford 390 Engine	Engine reassembly; gaskets installed	9	150	0.0006	0.0003–0.0009

[a] PCM, phase contrast microscopy.
[b] 8-HR TWA, eight hour time weighted average.
[c] f/cc, fibers per cubic centimeter.
[d] Indicates test with one sample overloaded.

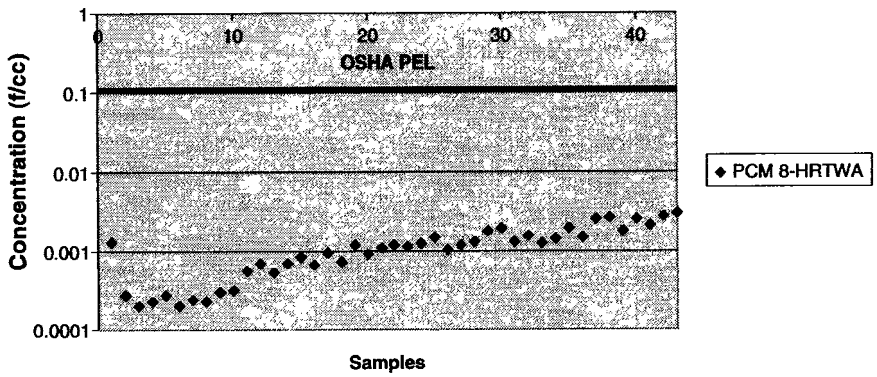

Fig. 2. Distribution of area samples.

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

Task	Location	Mean PCM[a] (f/cc)[b]	Mean PCM 8-HR TWA[c] (f/cc)
Gasket removal	Bench	0.0069	0.0019
	Driver side	0.0028	0.0005
	Passenger side	0.0049[d]	0.0013
	Northeast corner	0.0035	0.001
	Northwest corner	0.0061	0.002
	Southeast corner	0.0062	0.0018
	Southwest corner	0.0078	0.0022
	Distant hallway	0.0049	0.0013
	Intermediate hallway	0.0051[d]	0.0015
Gasket installment	Bench	0.0021[d]	0.0036
	Driver side	0.0023[d]	0.0007
	Passenger side	0.0078[d]	0.0024
	Northeast corner	0.0019[d]	0.0006
	Northwest corner	0.0036[d]	0.0011
	Southeast corner	0.003[d]	0.0009
	Southwest corner	0.0023[d]	0.0007
	Distant hallway	0.0015[d]	0.0005
	Intermediate hallway	0.0015[d]	0.0005

[a] PCM, phase contrast microscopy.
[b] f/cc, fibers per cubic centimeter.
[c] 8-HR TWA, average eight hour time weighted.
[d] Indicates location with one or more samples reported below the LOD.

presented as 8-HR TWA PCM and PCME fiber concentrations for comparison purposes against the OSHA PEL. The PCM 8-HR TWA fiber concentrations ranged from 0.001 to 0.0079 f/cc. Only 3 of the 10 personal samples were identified through TEM to contain chrysotile fibers. Additionally, 50% ($n = 5$) of these samples were below the LOD. The highest PCME fiber concentration was 0.0044 f/cc.

Table 6
Personal samples

Test session	Description	Location	Time (min)[a]	Volume (L)[b]	PCM[c] (f/cc)[d]	PCM 8-HR TWA[e] (f/cc)	Asbestos fiber ratio[f]	PCME[g] 8-HR TWA (f/cc)
1	Engine disassembly; gaskets removed-Chevrolet Malibu	Left shoulder	141	320	0.023	0.0068	0.381	0.0026
1	Engine disassembly; gaskets removed-Chevrolet Malibu	Right shoulder	140	348	0.027	0.0079	0.556	0.0044
2	Engine reassembly; gaskets installed-Chevrolet Malibu	Left shoulder	156	345	0.0058	0.0019	0	0
2	Engine reassembly; gaskets installed-Chevrolet Malibu	Right shoulder	155	371	0.005[h]	0.0016	0	0
3	Engine disassembly; gaskets removed-Chevrolet Truck	Left shoulder	124	242	0.012	0.0031	0	0
3	Engine disassembly; gaskets removed-Chevrolet Truck	Right shoulder	60	131	0.01[h]	0.0013	0	0
4	Engine disassembly; gaskets removed-Ford 390 Engine	Left shoulder	119	285	0.007[h]	0.0017	0	0
4	Engine disassembly; gaskets removed-Ford 390 Engine	Right shoulder	119	262	0.01	0.0025	0.333	0.0018
5	Engine reassembly; gaskets installed-Ford 390 Engine	Left shoulder	151	335	0.0032	0.0010	0	0
5	Engine reassembly; gaskets installed-Ford 390 Engine	Right shoulder	151	371	0.005	0.0016	0	0

[a] Min, minutes.
[b] L, liters.
[c] PCM, phase contrast microscopy.
[d] f/cc, fibers per cubic centimeter.
[e] 8-HR TWA, eight hour time weighted average.
[f] Asbestos fiber ratio is defined as the number of asbestos fibers detected via transmission electron microscopy (TEM) divided by the total number of all fibers detected via TEM.
[g] PCME, phase contrast microscopy equivalent.
[h] Indicates samples below the LOD.

3.3. Samples identified to contain asbestos

Approximately 21% ($n = 11$) of all samples were determined through TEM analysis to contain chrysotile fibers. A summary of the individual air samples is presented in Table 7. The majority of the air samples determined to contain asbestos fibers were collected during the removal of gaskets from the 1974 Chevrolet Malibu. Asbestos fibers were not detected in samples associated with the installation of new asbestos-containing gaskets in the Malibu or the Ford engine. Table 8 provides descriptive statistics for these samples. The average 8-HR TWA PCM and PCME

Table 7
Samples containing asbestos fibers

Description	Location	Time (min)[a]	Volume (L)[b]	PCM[c] 8-HR TWA[d] (f/cc)[e]	Asbestos fiber ratio[f]	PCME[g] 8-HR TWA (f/cc)
Gaskets removed; Chevy Malibu	Personal: right	140	348	0.0079	0.556	0.0044
Gaskets installed; Chevrolet Malibu	Area: southeast corner	151	1498	0.0026	0.4	0.0010
Gaskets removed; Chevy Malibu	Area: southwest corner	151	1505	0.0031	0.833	0.0026
Gaskets removed; Chevy Malibu	Area: northeast corner	148	1471	0.0014	0.757	0.0011
Gaskets removed; Chevy Malibu	Area: northwest corner	151	1144	0.0026	0.487	0.0013
Gaskets removed; Chevy Malibu	Area: driver side	151	1495	0.0009	0.762	0.0007
Gaskets removed; Chevy Malibu	Area: bench	148	1463	0.0029	0.596	0.0017
Gaskets removed; Chevy Malibu	Area: hall intermediate	148	1048	0.0026	0.622	0.0017
Gaskets removed; Chevy Malibu	Personal: left	141	320	0.0068	0.381	0.0026
Gaskets removed; Ford Engine	Personal: right	119	262	0.0025	0.333	0.0008
Gaskets removed; Ford Engine	Area: southwest corner	120	1017	0.13	0.7	0.0009

[a] Min, minutes.
[b] L, liters.
[c] PCM, phase contrast microscopy.
[d] f/cc, fibers per cubic centimeter.
[e] 8-HR TWA, eight hour time weighted average.
[f] Asbestos fiber ratio is defined as the number of asbestos fibers detected via transmission electron microscopy (TEM) divided by the total number of all fibers detected via TEM.
[g] PCME, phase contrast microscopy equivalent.

Table 8
PCM and PCME fiber concentrations for samples containing asbestos

Sample type	No. of samples	PCM[a] mean concentration (f/cc)[b]	SD[c]	Range	PCME[d] Mean concentration (f/cc)	SD	Range
Personal	3	0.0018	0.0011	0.0007–0.0044	0.0026	0.0018	0.0008–0.0044
Area	8	0.0022	0.0008	0.0009–0.0031	0.0014	0.0006	0.0007–0.0026
All	11	0.0031	0.0022	0.0009–0.0079	0.0017	0.0011	0.0007–0.0043

[a] PCM, phase contrast microscopy.
[b] f/cc, fibers per cubic centimeter.
[c] SD, standard deviation.
[d] PCME, phase contrast microscopy equivalent.

Table 9
Asbestos and non-asbestos components of removed gaskets

Gasket description	Asbestos content	Non-asbestos fibrous materials	Non-fibrous materials
390 Ford exhaust manifold gasket	70% Chrysotile	Cellulose fiber; Fibrous glass	Oil/grease; metallic sheet
390 Ford intake manifold gasket	70% Chrysotile	Cellulose fiber	Oil/grease, Metallic sheet
390 Ford head gasket	70% Chrysotile	Cellulose fiber	Oil/grease; Metallic sheet
1978 Chevy head gasket	70% Chrysotile	Cellulose fiber	Oil/grease; metallic sheet; paint
Thermostat gasket	ND	Cellulose fiber	Binder/filler; mastic; paint
1978 Chevrolet carburetor space	14% Chrysotile	Cellulose fiber	Binder/filler; mastic
Exhaust donut	ND	No fibers detected	Binder/filler; metallic rust
350 Chevrolet V-8 intake gasket	75% Chrysotile	Cellulose fiber	Oil/grease; metallic sheet
350 Chevrolet V-8 carburetor gasket	ND	Cellulose fiber; fibrous glass	Oil/grease

ND, none detected.

concentrations were 0.0022 fibers/cc and 0.0017 fibers/cc, respectively. It should be noted no amphibole fibers were identified within any sample.

3.4. Bulk sample analysis

Bulk sample analysis of the removed gaskets was performed to provide evidence of the presence of asbestos fibers in the gaskets and the workplace. A total of nine gaskets were removed from the three test engines, and analyzed via polarized light microscopy (PLM). The results and the descriptions of the gaskets can be found in Table 9. Asbestos concentrations ranged from 0 to 75% of the gasket matrices with five of the gaskets identified to contain more than 70% asbestos. Amphibole asbestos fibers were not identified in any of the samples, but chrysotile fibers were present in six of the removed gaskets. Non-asbestos fibrous materials, including cellulose fiber and fibrous glass, were present in all gaskets except the donut gasket removed from the Chevrolet Malibu.

4. Discussion

Previous assessments of asbestos exposure during the servicing of asbestos-containing materials in the automotive repair industry predominantly report fiber levels at or below the current OSHA PEL (Yeung et al., 1999; Weir et al., 2001; Blake et al., 2003; Paustenbach et al., 2003, 2004, 2005; Liukonen and Weir, 2005). Yeung et al., evaluated the concentrations of chrysotile fibers mechanic were exposed during the maintenance of vehicles assembled with asbestos-containing brakes and gaskets (1999). Nine automotive service facilities were utilized in this assessment, and a total of 68 air samples were collected (Yeung et al., 1999). Transmission electron microscopy (TEM) analysis of the samples revealed a range of <0.01–0.07 chrysotile fibers per cubic centimeter (Yeung et al., 1999). The authors note that the majority of particulates identified in the air samples were foresterite, a non-asbestiform silicate mineral produced when chrysotile fibers are exposed to high temperatures (Yeung et al., 1999). Weir et al., conducted an exposure assessment aimed at determining the airborne asbestos concentrations and total particulate matter associated with the replacement of brake drums and the arc grinding of asbestos brake pads (Weir et al., 2001). The majority of samples contained non-fibrous material with little, if any, asbestos or non-asbestos fibers being detected (Weir et al., 2001). The highest PCM TWA observed in area samples was 0.02 f/cc (Weir et al., 2001). Blake et al., characterized the airborne asbestos fibers generated during the maintenance of asbestos-containing brakes (Blake et al., 2003). Six independent test sessions were conducted in which one of the following tasks were performed: (1) the repair and replacement of brake shoes, (2) filing of new replacement asbestos-containing shoes for installation purposes, (3) sanding of new shoes to remove the outermost wear surfaces or (4) arc grinding of new shoes to match companion brake drum's circumstance (Blake et al., 2003). The 8-HR TWA PCM fibers concentrations reported for the personal air samples collected during the six test sessions ranged from 0.008 to 0.0937 f/cc (Blake et al., 2003). Ten previously published asbestos monitoring studies were identified and assembled to characterize retrospective asbestos exposures for brake mechanics under various working conditions (Paustenbach et al., 2003). A total of 162 8-HR time weighted average (TWA) asbestos concentrations from the late 1960s to 2003 where identified from the 10 original studies. Airborne asbestos levels were evaluated and compared based on the location and time period of sampling, servicing methodology and type of vehicle receiving brake maintenance (Paustenbach et al., 2003). Analysis of a subset of 141 samples collected during the servicing of light trucks and automobiles between 1968 and 1996 reported an average TWA of 0.05 f/cc with a range of 0.004–0.28 f/cc with the overall 8-HR TWA for all identified air samples ($n = 162$) being 0.04 f/cc (Paustenbach et al., 2003).

The airborne asbestos levels detected during our assessment, in most cases, are lower than the concentrations observed in the previously discussed studies, and present additional evidence against excessive exposure to airborne asbestos fibers associated with the maintenance of vehicles assembled with parts containing asbestos using standard workplace practices. Additionally, the current investigation provides support to epidemiological studies that have reported no association between the servicing and handling of asbestos-containing materials and increased rates of mesothelioma and lung cancer among automotive mechanics (Agudo et al., 2000; Wong, 2001; Goodman et al., 2004; Hessel et al., 2004; Laden et al., 2004; Wong, 2006). The findings of this study are consistent with previous exposure assessments and workplace simulations, and add evidence to the position that asbestos exposure among mechanics does not increase the risk of developing pulmonary cancer.

Approximately 21% of all samples collected during the five test sessions were identified to contain asbestos through TEM. No amphibole fibers were found in any sample, and chrysotile fibers were detected only in samples associated with the removal of gaskets from the Chevrolet Malibu and Ford engine. Six gaskets were removed from the two engines with asbestos concentrations determined via PLM to range from 0 to 75%. Several of these gaskets were extracted intact with small amounts of residue remaining on metal mating surfaces. Torn gaskets and remnants found on the surfaces of the engine components can be attributed to heat produced by the normal operations of internal combustion engines. Thermal stress is capable of degrading the gasket matrices over time, and results in the "baking" of gaskets onto engine mating surfaces. No asbestos fibers were found in the samples collected during the installation of new asbestos gaskets. Replacement gaskets have no discernible ability to release fibers when installed using standard operating procedures due to the gasket being precut and sprayed with adhesive sealant.

Criticism of the use of phase contrast microscopy and transmission electron microscopy focuses on the exclusion of short (<5 μm long) and long, but thin (<0.25 μm wide) asbestos fibers (Atkinson et al., 2004; Lemen, 2004). Those who oppose the use of NIOSH Methods 7400 and 7402 state that the elimination of short and thin structures from the data set underestimates the risk that exposed workers encounter. Recent committee findings released by the Agency for Toxic Substances and Disease Registry (ATSDR) report limited or no human cancer risk from fibers fitting the previous descriptions (ATSDR, 2003). Research has demonstrated that the pathogenesis of asbestos-related diseases is directly influenced by the physical dimensions of asbestos fibers (Stanton et al., 1981). The length and width of fibers determine their ability to be deposited within the lungs, and subsequently affect the onset of malignant and non-malignant diseases (Lippmann, 1990; ATSDR, 2003). Fibers longer than 10 μm are not easily phagocytized, and tend to remain in the lower respiratory tract or penetrate the pleural membrane (Hume and Rimstidt, 1992). Shorter fibers, including the fiber populations (<5 μm in length and <0.25 μm in width) excluded from consideration by NIOSH Methods 7400 and 7402, are arguably of less significance in terms of the development of asbestos-related cancers. In addition, the debate regarding dimension based fiber exclusion distracts attention from the real benefit these methods offer. NIOSH Methods 7400/7402 data can be directly compared against established health risk databases. No such databases exist for the asbestos structure data for short (<5 μm long) and long but thin (<0.25 μm wide) asbestos fibers. Despite the limitations associated with these NIOSH Methods 7400 and 7402, the advantages of their use exceed their disadvantages.

Use of the water bath cleaner may have had some asbestos fiber suppression effect. Despite the argument that the wetting of loose parts may potentially prevent the liberation of fibers during the cleaning process and subsequently reduce the concentration of airborne asbestos fibers, the water bath cleaner is commonly used in the automotive repair industry and conforms to the study design's aim of applying actual work practices. Additionally, the water wash periods were brief and power wire brushing was performed without aqueous wash on the engine blocks. For these reasons, the fiber suppression effect attributed to the use of the water bath cleaner was minimal.

NIOSH Method 7400 recommends fiber loading concentrations at or above 100 fibers/mm^2 (f/mm^2) to avoid inaccuracies during the counting process (1994a). In situations, such as the current study, where airborne fibers concentrations remain extremely low or below the analytical level of detection, compliance with the recommendation is difficult. Several methods have been suggested to offset the effects of low fiber densities including decreasing the surface area of the filter or increasing the sampling flowrates (Cherrie et al., 1986). During the current study, the range of applied flowrates varied from 2 to 10 lpm. The fiber concentrations determined through PCM and TEM analysis for air samples collected at the different flowrates did not noticeably differ, and indicate the absence of airborne fibers, both asbestos and non-asbestos, within the automotive repair facility. The potential error associated with low fiber densities has been demonstrated to result in high fiber counts and frequently yield overestimated airborne fiber concentrations (Cherrie et al., 1986).

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5. Conclusion

The airborne asbestos concentrations observed during the removal and replacement of asbestos-containing automotive gaskets remained well below the occupational exposure limit currently enforced by OSHA. The average PCM fiber concentrations for all air samples ($n = 53$) and samples identified through TEM to contain asbestos fiber ($n = 11$), were 0.0015 and 0.0031 f/cc, respectively. In conclusion, the findings of the current study indicate that:

1. The use of standard workplace practices produces limited fiber release during the handling and removal of asbestos-containing gaskets, and workers receive only a minimal exposure under these conditions.
2. Airborne asbestos levels observed in exposure assessments are predominantly lower than the OSHA PEL, and support the claim of no relationship between employment in the automotive repair industry and increased rates of cancers (Yeung et al., 1999; Weir et al., 2001; Blake et al., 2003; Paustenbach et al., 2003; Paustenbach et al., 2004; Paustenbach et al., 2005; Liukonen and Weir, 2005). The fiber levels reported in the current study are, in most cases, lower than the concentrations observed in previously reported studies.

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