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An Australian Study to Evaluate Worker Exposure to Chrysotile in the Automotive Service Industry

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A study was conducted in Sydney, Australia, in 1996 to investigate the current exposure levels, control technologies, and work practices in five service garages (four car and one bus), three brake bonding workshops, and one gasket processing workshop. This study formed part of the assessment of chrysotile as a priority existing chemical under the Australian National Industrial Chemicals Notification and Assessment Scheme. A total of 68 (11 personal and 57 area) air samples were collected, in accordance with the Australian standard membrane filter method. Fiber concentrations were determined by the traditional phase contrast microscopy (PCM) method and 16 selected samples were analyzed by the more powerful transmission electron microscopy (TEM). Chrysotile exposure of car mechanics measured by PCM was typically below the reportable detection limit of 0.05 f/mL, irrespective of whether disc brake, drum brake, or clutch was being serviced. These low levels can be attributed to the wet cleaning or aerosol spray methods used in recent years to replace the traditional compressed air jet cleaning. In the three brake shoe relining workshops, task-specific exposure reached up to 0.16 f/mL in the processes of cutting and radius grinding. TEM results were generally higher, due to its higher resolution power. The median diameter on samples taken from the service garages (passenger cars), as determined by TEM, was 0.5–1.0 μm; and was between 0.2–0.5 μm for the brake bonding and gasket processing workshops, while that for the bus service depot was 0.1–0.2 μm. Most of the respirable fibers (84%, mainly forsterite) from the bus service depot were below 0.2 μm in diameter which is the resolution limit of PCM. In the brake bonding and gasket cutting workshops, 34 percent and 44 percent of the chrysotile fibers were below 0.2 μm in diameter.

Keywords Automotive Service, Brake Bonding, Brake Service, Chrysotile, Gasket Processing, Service Garage

In Australia, industrial chemicals are assessed for safety and registered under the National Industrial Chemicals Notification and Assessment Scheme. The use of chrysotile is being reviewed under the priority existing chemical assessment program. The review is a risk assessment process based on the inherent hazard of the material and its likely impact on occupational health and safety, the environment, and public health and safety. The assessment process will also make recommendations on measures to control these risks, investigate the present use of safe substitutes for chrysotile, and address the feasibility of phasing out the use of chrysotile in Australia.

Chrysotile is still used in the manufacture of motor vehicle brake and clutch materials in Australia, although increasingly other materials (for example, metal oxides, synthetic mineral and organic fibers) have been substituted for asbestos in the fabrication of friction materials. Friction materials commonly found in brake and clutch systems contain about 40–60 percent (drum brakes and clutches) and 20 percent (disc brakes) chrysotile asbestos (together with phenolic-type resins as binder and various other additives to improve performance). Amosite, crocidolite, or other amphibole asbestos varieties are not used because they are too harsh and tend to score the brake drums or discs.[1]

Many of the chrysotile fibers originally present in the brake and clutch materials can undergo thermal degradation to forsterite or to a non-fibrous silicate phase, due to the high temperature encountered in use.[2] Free chrysotile fibers can also be released because of abrasion and other shear processes. Unlike chrysotile, the health effects of exposure to forsterite, and to the transition series fibers (chrysotile/forsterite) with altered crystalline structures, are not well documented. The debris remaining in the brake and clutch assemblies and encountered in normal automotive service contains a combination of these fibers. Chrysotile fibers usually constitute less than 1 percent in weight of the debris.[1]

Asbestos-related diseases have attracted considerable attention in the Australian community. A study of the 16-year data from the Australian Mesothelioma Surveillance Program and

Register between 1979–1995 has indicated that the number of mesothelioma cases in Australia had increased in car mechanics (brake work) from 7 cases in 1979–1985, to 16 cases in 1986–1990, and to 24 cases in 1991–1995.[3,4] Although a link between garage work and cancer has not as yet been established by epidemiological study, the recently reported cases of mesothelioma strike a warning note.

Much is known about the risk of occupational exposure to raw asbestos fibers in mining, milling, and manufacturing[5] in Australia and elsewhere. The picture is less clear in Australia in work with asbestos-containing materials where the potential for fiber escape and associated airborne contamination is relatively low, as, for example, in motor vehicle repair and servicing. Earlier overseas studies of airborne asbestos exposure to car mechanics showed significant exposure to chrysotile during brake servicing, especially brake assembly cleaning.[1,6–10] However, to date, no similar exposure studies in Australia have been reported in literature.

Car mechanics are potentially exposed to asbestos dust during routine brake, clutch, and gasket maintenance service and repair. If the debris inside the brake and clutch assemblies is removed and disposed of using appropriate control equipment and work practices, the exposure can be minimized. The principal objective of this study was to determine the exposure to chrysotile of workers in the automotive service industry, particularly of automotive mechanics who may use various control techniques during maintenance and replacement of brakes, clutches, and gaskets.

BRAKE AND CLUTCH SERVICE OPERATIONS

Repair facilities ranging from small service stations to bus depots follow similar service procedures. The vehicle is driven into a repair stall or bay, sometimes elevated, wheels are removed, and the brakes or clutch are inspected. Traditionally, brake dust was often cleaned from brake assemblies by blowing with compressed air. At the time of this study, however, most brake servicing facilities we observed used wet/dry wiping, squirt bottle wash-off, or aerosol can organic cleaner. After cleaning, parts are replaced or repaired as needed, and the brake or clutch system is reassembled and adjusted. Dust arising from the work was obviously a possible source of asbestos exposure. The debris accumulated in the brake housing, and when it was cleaned out by one of the above methods, could liberate asbestos fibers into the ambient air.

With the introduction of bonded linings and factory-made disc pads in recent years, the need for drilling, facing, or grinding operations during installation has decreased significantly.

BRAKE BONDING OPERATIONS

Worn drum brake shoes collected from brake service stations are re-processed in specialized brake bonding establishments. The metal shoes are stripped of the worn asbestos linings, then cleaned, glued to precut replacement linings, and finally cured in an oven at a temperature of 200–300°C. Machine sa[illegible] and leveling of the new brake lining surface (commonly called "radius grinding") is routinely required and is the most likely source of fiber generation. Cutting of new linings is also sometimes performed.

GASKET PROCESSING

Asbestos-free gaskets are widely used in the automotive industry and for other purposes. However, asbestos gaskets are still found in older models of passenger cars and heavy vehicles, although nowadays they are more commonly used in high-temperature and high-pressure applications (for example, in oil refineries and chemical plants). In asbestos gasket production operations, articles are cut off from compressed asbestos fiber sheets by hand-held electric saws, and are then cut to the desired shapes by a powered stamping machine. Process workers are potentially exposed to asbestos dust during the cutting and powered stamping process.

METHODS AND MATERIALS

Nine typical establishments in the Sydney metropolitan area, including five service garages (four for passenger and light commercial vehicles, one for buses and coaches), three brake bonding workshops, and one gasket processing workshop participated in this study. The three brake bonding workshops and one g[illegible] processing workshop were the only workshops in the indus[illegible] that still processed asbestos-containing products and were located in the Sydney metropolitan area.

The study methodology involved air monitoring to estimate exposure to chrysotile at work when chrysotile-containing friction materials were worked on, in relation to the type of control measures used, and sizing of airborne fibers by transmission electron microscopy (TEM). In this study, the dust control techniques were also assessed, and the work practices and the use of personal protective equipment were evaluated by the use of a standardized questionnaire.

Monitoring of Airborne Asbestos Fibers

Task-specific personal and area air samples were collected at a flowrate of 2 liters per minute on 25-mm-diameter 0.8 μm pore size Millipore mixed cellulose ester membrane filters housed in anti-static cowls, in accordance with the Australian standard membrane filter method.[11] Area samples were taken at fixed locations in the vicinity of the work tasks, and between one and two meters above floor level. Single sample durations were selected not to exceed two hours, such that only a maximum of 240 liters of air would be collected. This approach has resulted in a practical detection limit of around 0.05 f/mL (or 10 fibers/100 graticule areas) by phase contrast microscopy (PCM).

Filter sections were cleared by acetone-triacetin and the fibers were sized and counted under a phase contrast optical m[illegible]scope at 400–450× magnification. Fibers with an aspect ra[illegible]

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exceeding 3, with length greater than 5 μm, and diameter under 3 μm, were counted to a minimum of 100 fibers in 20 fields or 100 random fields. The limit of resolution of PCM is about 0.2 μm.

In addition to PCM analysis, 16 samples in half filters were selected for TEM analysis on a Phillips CM12 at 8800× magnification. These 16 samples included all personal samples and some area samples with relatively high PCM fiber readings. TEM analysis was performed to identify asbestos fibers too small to be detected by PCM. Fibrous minerals were identified by selected area electron diffraction (SAED) and energy-dispersive X-ray analysis (EDAX), and sized by length and diameter. The grid openings used in TEM were sized by optical microscopy so that the TEM results could be reported in fibers per equivalent Walton Beckett graticule area and directly compared to the PCM results. Due to the higher resolution power of TEM, respirable fibers of all dimensions were recorded (resolution limit was about 0.02 μm in diameter).

Survey by Questionnaire

In addition, the nine establishments were surveyed through a standardized questionnaire designed to obtain information about work practices, the use of dust control measures and personal protective equipment, the use of asbestos products and substitutes, the current practices of risk management including training of workers, and provision of safety information in the form of proper labelling and material safety data sheets (MSDS). The questionnaire was completed in consultation with the employer and the relevant workers at each establishment.

RESULTS

This small-scaled cross-sectional survey indicated that both chrysotile-containing products and substitutes were widely used in the nine workshops. However, there was an increasing tendency for them to lean toward the use of non-asbestos products where possible, apparently driven by the market supply situation and the health concern of the community and the workforce. The substitutes used in the brake friction materials encountered in these workshops included metallic oxides and synthetic mineral and organic fibers including fiberglass, wollastonite, graphite fibers, carbon fibers, kevlar, and steel fibers.

The survey also revealed that all replacement clutches and gaskets, and most disc brake pads were asbestos-free and supplied to the automotive service industry in the form of factory-made order parts. However, the majority of replacement drum brake linings, still used in cars of older models and in buses and coaches, were still chrysotile products.

The five service garages in this study did not conduct any brake re-lining or re-bonding work. According to them, it is already an industry-wide practice that worn drum brake shoes and clutch discs were collected, distributed to, and re-processed by specialized brake bonding establishments. Garage workers rarely need to undertake activities such as cutting, grinding, and drilling which may release fibers to the ambient air.

Waste friction materials generated in these workshops (e.g., worn brake discs in garages, asbestos-containing debris in brake bonding workshops) were kept in special closed bins and disposed of by licensed waste contractors. Only some asbestos-containing products were labelled with the appropriate hazard warning and safe handling instructions. However, none of these products was provided with MSDS.

Work Practice and Control Techniques

Work activities in these nine establishments at the time of air sampling, the dust control techniques, and standard of ventilation are summarized in Table I. In the service garages, specialization was not a feature and tasks were allotted as the mechanic became available with each spending about 10–75 percent of his time on brake work. Dust control technologies in brake and clutch work included wet and dry wiping, and the use of a squirt water bottle or aerosol can organic solvent. Garage C used a combination of squirt water bottle, wet wiping, and then compressed air stream for drying. However, three workshops (A, D, and I) did not provide any form of dust control measures. Traditional compressed air jet cleaning has long been abandoned at these workplaces. Most younger workers stated that this is due to the proper automotive trade training provided by technical colleges in Sydney.

Among the three brake bonding workshops, shops G and H are specialized businesses working full-time in the activities of cutting, radius grinding, curing, and packing. Radius grinding and cutting which would potentially release asbestos-containing dust were performed for about one to two hours every day. Although both processes were provided with local exhaust ventilation, area contamination with asbestos dust was easily discernible. Some exposed workers in these workshops were provided with regular health surveillance (chest x-ray and lung function tests). Approved disposable-type dust respirators were worn by some workers during cutting and radius grinding.

PCM Results

A total of 68 (11 personal, 57 area) samples were collected. All the results were below the current Australian occupational exposure standard of 1.0 f/mL for chrysotile (under review, see reference [5]) and the exposure standard of 0.5 f/mL in the State of New South Wales.

Details of the air sampling results determined by PCM, the types of sample, and the work activity are presented in Table II. Respirable fibers were present in most (25 out of 36) air samples from the service garages. The task-specific fiber concentrations were all below the reportable detection limit of 0.05 f/mL. The highest short-term exposure levels (geometric mean = 0.11 f/mL) were found in a brake bonding workshop (shop G) which is an old-fashioned workplace specializing only in the reprocessing of asbestos drum brakes. Although

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TABLE I
Work activities and control measures

Establishment	Work activities[A]	Frequency	Control techniques	Ventilation standard
Service garages for passenger and light commercial vehicles				
A	Replaced BM & BD	6 h/day	None	Natural, good
B	Replaced BD & checked BM	6 h/week	Aerosol spray	Natural, good
C	Replaced BM & BD	6 h/week	Squirt water bottle + compressed air drying	Natural, good
D	Replaced clutch	Occasionally	None	Natural, poor
Service depot for buses				
E	Replaced BM	3 h/week	Dry wiping, respirators	Natural, good
Brake bonding workshops				
F	Bonding & RG	1 h/day	Respirator	LEV, good
G	Bonding, cutting, RG & packing	8 h/day	Respirator	LEV, good
H	Cutting, RG & packing	8 h/day	None	LEV, good
Gasket processing workshop				
I	Machine cutting & stamping	2 h/day	None	Natural, fair

[A]BM = drum brake; BD = disc brake; RG = radius grinding; LEV = local exhaust ventilation.

TABLE II
Air sampling results by phase-contrast microscopy (PCM)

Establishment	Sample type[A]	Work activity	Sampling time (min)	No. of samples	Fiber concentration (f/mL) GM	Fiber concentration (f/mL) Range
Service garages for passenger and light commercial vehicles						
A	P	BM & BD	77	1	<0.05	<0.05
	A		77	5	<0.05	<0.05
B	P	BM & BD	80	1	<0.05	<0.05
	A		75	6	<0.05	<0.05
C	P	BM & BD	135	1	<0.05	<0.05
	A		135	6	<0.05	<0.05
D	P	Clutch	125	1	<0.05	<0.05
	A		125	7	<0.05	<0.05
Service depot for buses						
E	P	BM	125	1	<0.05	<0.05
	A		125	7	<0.05	<0.05
Brake bonding workshops						
F	P	Bonding & RG	80	1	<0.05	<0.05
	A		80	8[B]	<0.05–<0.17	<0.05–<0.17
G	P	Bonding, cutting, RG & packing	~130	2	0.11	0.07–0.16
	A		~125	6	<0.05	<0.05–0.04
H	P	Packing	125	1	<0.05	<0.05
	A	Cutting & RG	120	6	0.04	0.03–0.07
Gasket processing workshop						
I	P	Cutting & stamping	~100	2	<0.05	<0.05
	A		~100	6	<0.05	<0.05

[A]P = personal sample; A = area sample; GM = geometric mean; see Table I for other abbreviations.
[B]Three samples were taken for only 20 minutes.

respirable fibers were found in all the air samples from the gasket processing workshop (shop I), the fibre concentrations were all below the reportable detection limit of 0.05 f/mL.

Personal or area sampling apparently did not cause a major difference in results, probably due to the very low level of exposure in most of the workshops. However, in shop G, personal exposures ($n = 2$, concentration = 0.07–0.16 f/mL) were obviously higher than the area sampling results (all below 0.05 f/mL) which were taken for the same processes and for the same sampling duration.

It is important to note that the fiber levels reported in this study were all short-term task-specific exposures (less than two hours) which covered only periods of work where peaks of exposure were expected. The time-weighted average (TWA) daily or weekly exposures would be many times lower, as indicated by the frequency of particular work activities.

TEM versus PCM Results

Due to its higher resolution and analytical power, TEM could indicate the presence of fine fibers not detected by PCM, and identify different types of fibers: chrysotile, organic, or mineral. In the 16 samples selected for TEM analysis, the TEM results were generally higher than the corresponding PCM counts because high energy shearing processes (e.g., cutting and grinding) tend to liberate finer particles and fibers. A comparison of the TEM and PCM results is given in Table III. For the purposes of comparison, the actual calculated PCM results are used in this table.

Chrysotile fibers were only detected by TEM in one (in Garage C) of the seven air samples collected from the service garages, resulting in a chrysotile fiber concentration of 0.004 f/mL for that sample. The other fibers found were mostly organic fibers (e.g., calcium sulphate) which presumably were sourced from general pollution. In the two samples collected from the bus depot (Garage E) during drum brake maintenance, the fibers were mostly very fine forsterite and amorphous silica which are the thermal degradation products of chrysotile. These fibers would have been too fine to be counted under PCM (i.e., diameter <0.2 μm).

In brake bonding work, 88 percent of the fibers from the six samples were chrysotile (range = 63–100 percent). In gasket processing, 78 percent of the fibers were chrysotile (range = 70–93%, $n = 3$).

Despite the difference in resolution power, the PCM and TEM data (for all fibers) show a positive correlation ($r = 0.79$) (see Figure 1). When the diameter differences of the two sets of data (for all fibers) are adjusted, it is shown in Figure 2 that a very strong positive correlation exists between the two methods ($r = 0.90$).

Fiber Dimensions

All the countable fibers were less than 50 μm in length. The percentage diameter distributions as measured by TEM are shown in Table IV. The median diameter on samples taken from the service garages (passenger cars) was 0.5–1.0 μm, and was 0.2–0.5 μm for brake bonding and gasket processing workshops, while that for the bus service depot was 0.1–0.2 μm. Most of the respirable fibers (84%, mainly forsterite) from the bus service depot were below 0.2 μm in diameter which is the practical resolution limit of PCM. It is also important to note that 34 percent and 44 percent of the respirable chrysotile fibers taken from the brake bonding and gasket cutting workshops were below 0.2 μm in diameter.

The actual size distributions of the fibers sampled from the four types of establishment, as determined by TEM, are presented in Figures 3–6.

TABLE III
A comparison of PCM and transmission electron microscopy (TEM) results

Type of establishment	Work type/ activities	No. of samples	GM-fiber concentration (f/mL) PCM[A] (all fibers)	TEM (chrysotile)	TEM (all fibers)
Service garages for cars	Brakes	4	0.006	<0.01[B]	<0.01–0.01
	Clutch	1	0.003	<0.01	<0.01
Service depot for buses	Brakes	2	0.009	<0.01	0.11[C]
Brake bonding	P	3	0.06	0.07	0.09
	A	3	0.05	0.05	0.05
	Total (brake bonding)	6	0.05	0.05	0.07
Gasket processing		3	0.01	0.02	0.02
All processes		16	0.01	0.02	0.03

[A]"Actual" PCM airborne concentration (not reported as <LOD).
[B]One sample contained chrysotile (conc. = 0.004 f/mL).
[C]Most are forsterite.
See Tables I and II for abbreviations.

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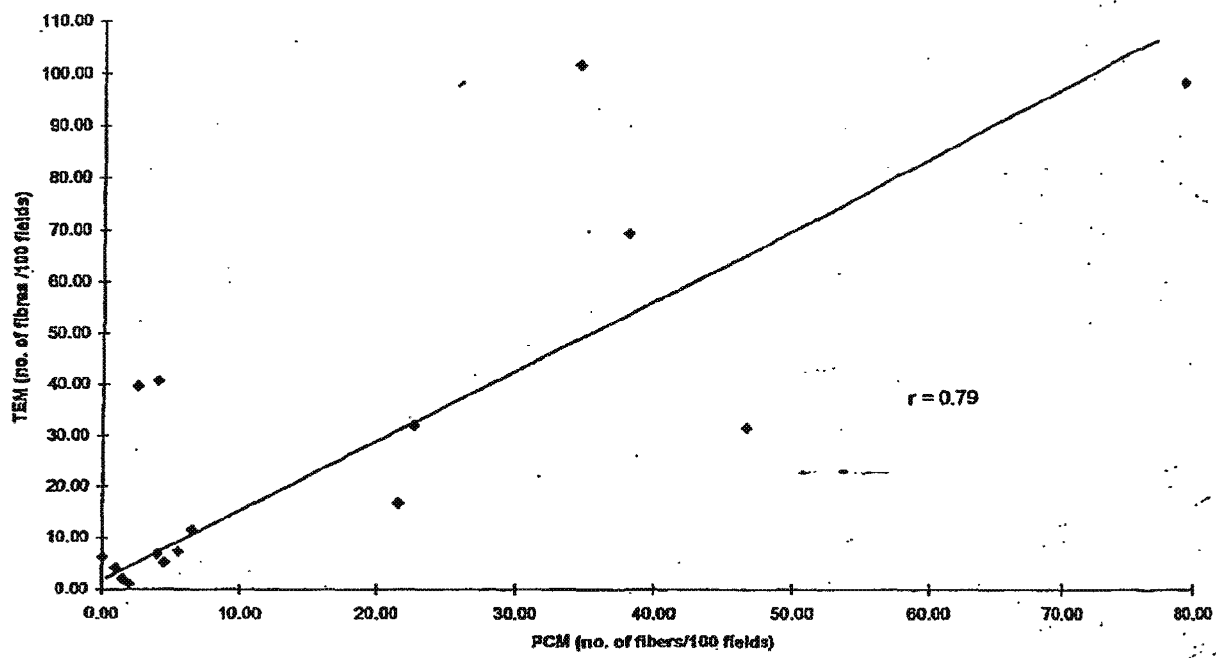

FIGURE 1

PCM versus TEM data (not adjusted for fiber diameter).

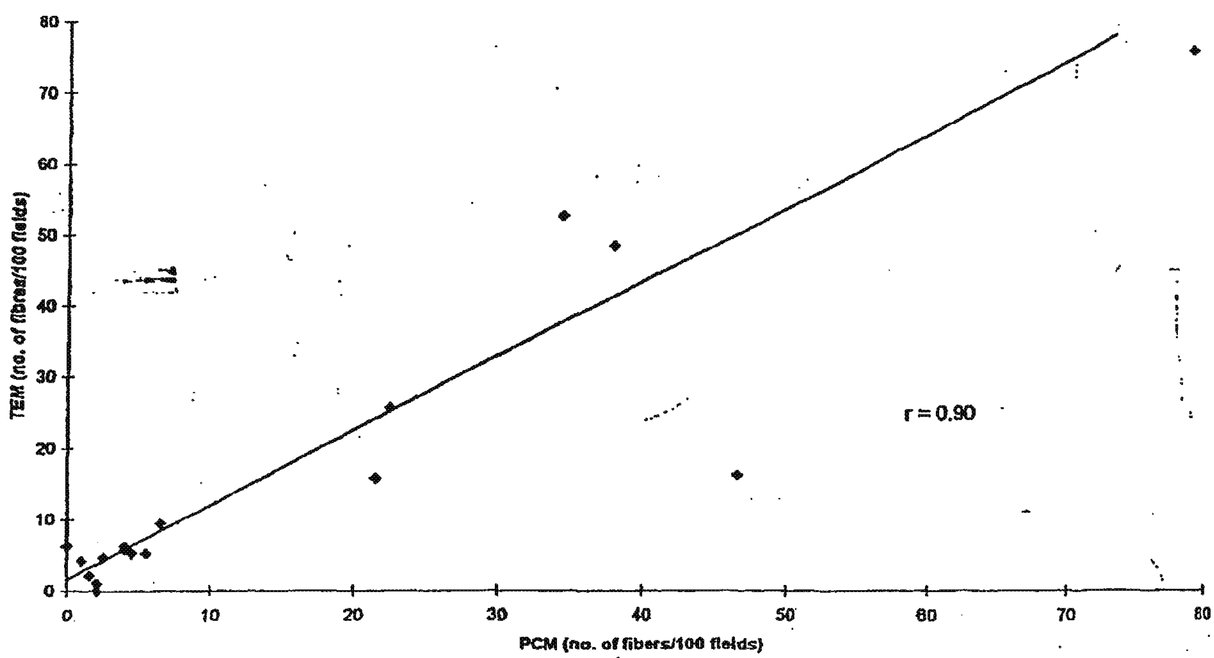

FIGURE 2

PCM versus TEM data (adjusted for fiber diameter).

TABLE IV
Percentage size distribution by TEM

Type of establishment	# fibers counted	Fiber diameter (μm) distribution in percent				
			0.2–0.5	0.5–1.0	1.0–2.0	2.0–3.0
Service garages—car (all fibers)	17		29	59	6	6
Service depot—bus (all fibers)	79		11	0	0	5
Brake bonding (chrysotile only)	291.5		28	24	4	10
Gasket processing (chrysotile only)	37.5		32	21	3	0

Shaded area represents the proportions of fibers not 'countable' by PCM.

DISCUSSION

This small study suggests that there is widespread replacement of chrysotile in friction materials used in the Australian automotive industry. The use of substitutes for chrysotile is most evident in brake disc pads and clutches. However, chrysotile-containing drum brake linings continue to be manufactured and imported into Australia in large quantities, predominantly for use in the aftermarket industry for older model passenger cars and heavy vehicles.

The three brake bonding workshops participating in this study collectively indicated that the great majority of work in the industry involved the use of chrysotile-containing products. However, due to the continuously increased introduction into the market of asbestos-free clutch kits and disc brake pads, business activities in the rebonding industry are rapidly decreasing.

As shown by the air samples taken from the four service garages (passenger cars), the respirable fiber concentrations were very low and all below 0.05 f/mL (the detection limit of

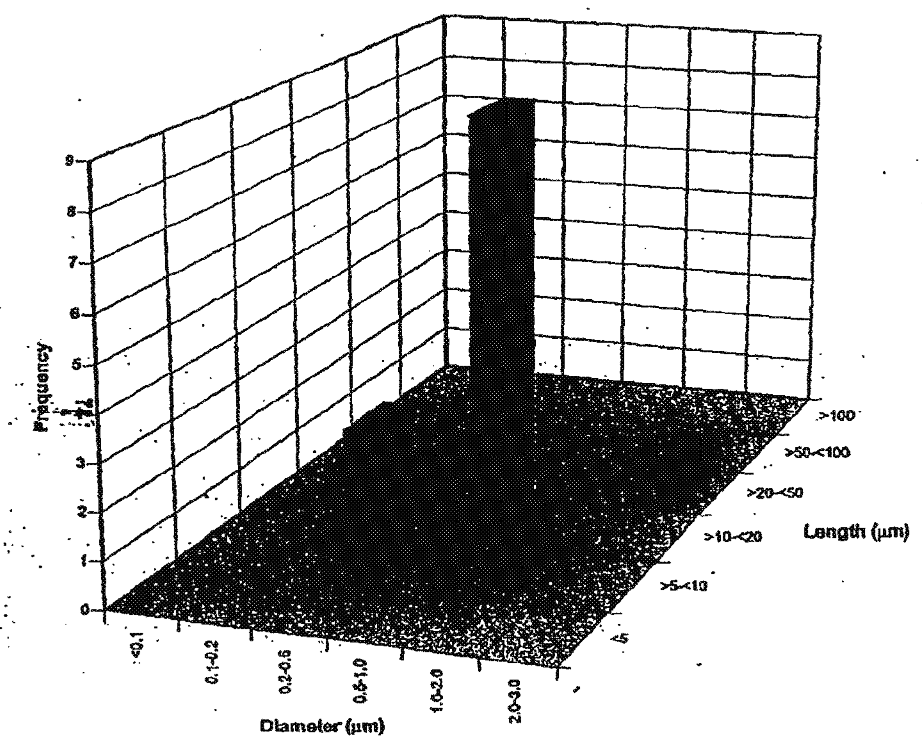

FIGURE 3
Fiber size distribution (all fibers)—Service garages (cars).

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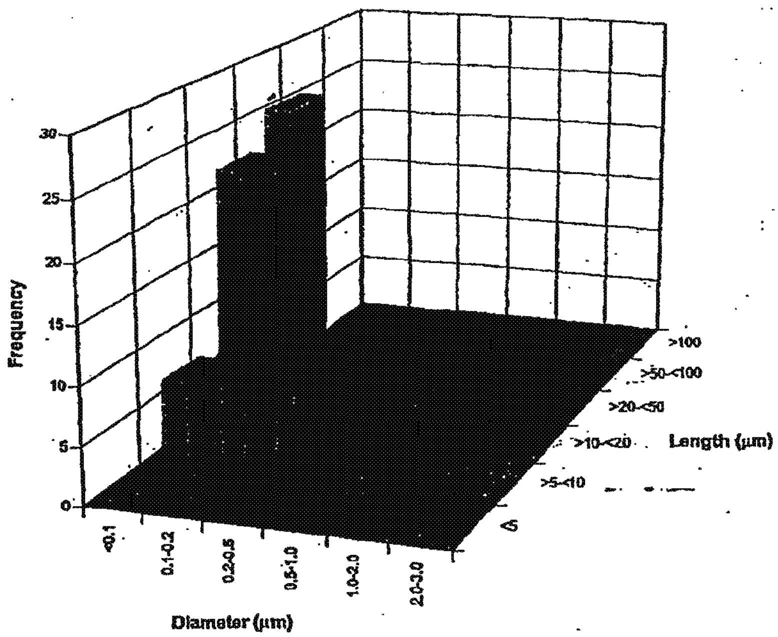
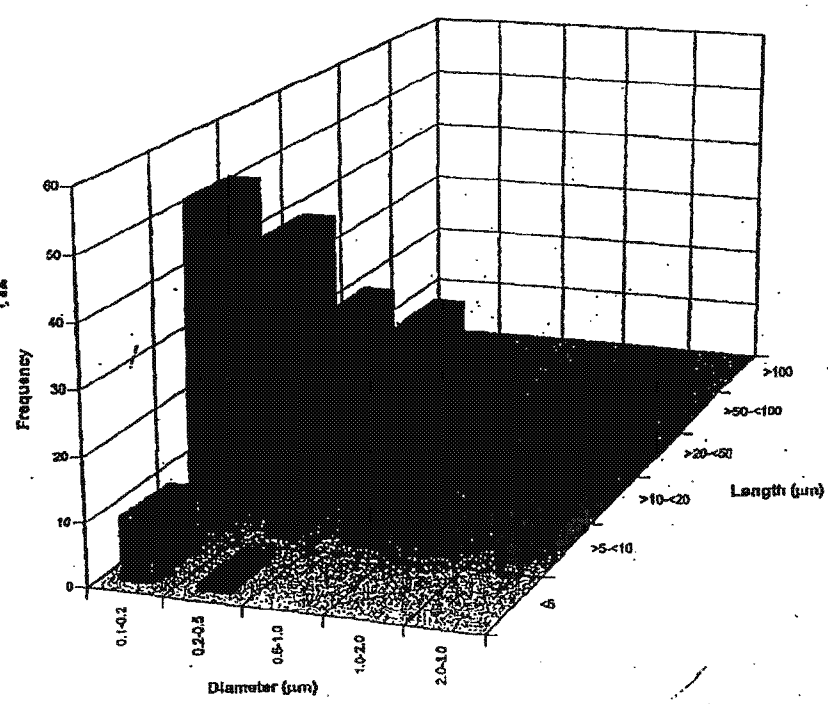


*Shaded Area = Fibers not countable by PCM

FIGURE 4
Fiber size distribution (all fibers)—Bus service depot.



*Shaded Area = Fibers not countable by PCM

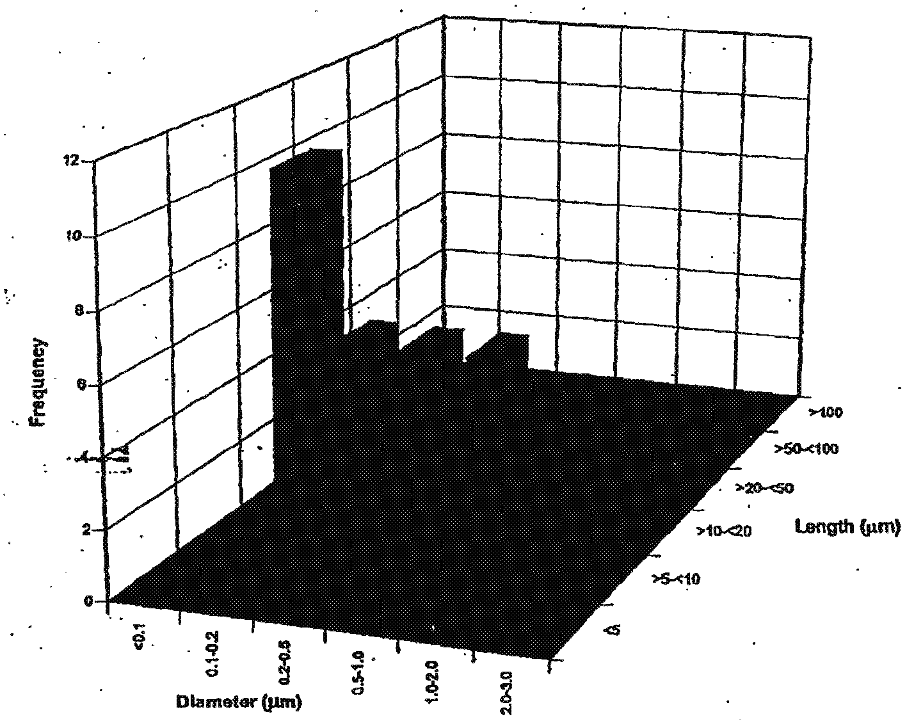
FIGURE 5
Fiber size distribution (chrysotile)—Brake bonding.

PCM). These findings, contrary to those of many previous overseas exposure studies that indicated significant exposures, may be attributed to garage workers' increasing awareness of the hazards of asbestos, which has led to the use of wet methods to replace the traditional compressed air jet. The interpretation is reinforced by the observation that chrysotile fibers were identified by TEM only in the personal sample from Garage C where compressed air was used for drying after some wet cleaning processes. No asbestos fibers were detected in any of the samples taken from Garages A, B, and D where only a wet cleaning method was used.

Although there was no practical difference in PCM results between servicing bus and passenger cars, fiber concentrations as determined by TEM for servicing buses were an order of magnitude greater than for passenger cars. TEM analysis shows that 84 percent of the fibers found in the samples taken from the bus service depot (Garage E) were too fine (less than 0.2 μm in diameter and between 5–20 μm in length) to be detected by PCM. The fibers were mainly forsterite which is a thermal degradation product of chrysotile. These findings can possibly be explained by the greater extent of wear and tear in the friction material during braking of heavy vehicles, and the failure of Garage E to use wet cleaning methods during brake service. The findings raise concerns about the likely higher exposure to chrysotile, particularly to the very fine fibers not detected by PCM, during brake service to other types of large vehicles (e.g., coaches, trucks). More studies may be needed before a valid conclusion can be reached on the likely exposure levels for the service of heavy vehicles.

In brake bonding, exposure to chrysotile was demonstrated. Although the exposure level may still be low (especially after adjustment for a 8-hour workday), the possibility of area contamination has caused health and environmental concerns. In these workplaces, improvements to control measures and personal protection and housekeeping practices are necessary to reduce the health risk and possible contamination of the environment.

PCM is the international regulatory method for the determination of airborne asbestos fiber concentrations. However, as shown in this study, PCM is not able to detect the very many small fibers (<0.2 μm in diameter) generated by high-energy shearing processes (e.g., cutting, grinding, and sanding) of asbestos-containing materials. For this type of processes, PCM may underestimate exposure and thus the health risk; and TEM should be used as an adjunct to PCM in any regular air monitoring program.



Shaded Area = Fibers not countable by PCM

FIGURE 6
Fiber size distribution (chrysotile)—Gasket processing.

CONCLUSION AND RECOMMENDATIONS

Although it was a small scale cross-sectional study, the following conclusions can be drawn from the results:

- The use of substitutes for chrysotile is quite common for brake disc pads, clutches, and gaskets in Australia. However, chrysotile-containing drum brake linings continue to be manufactured and imported into Australia, predominantly for use in the aftermarket industry for older model passenger cars and heavy vehicles.
- All the air sampling results from this study (service garages, brake bonding, and gasket processing) were below the current Australian occupational exposure standard of 1.0 f/mL for chrysotile and the New South Wales State's exposure standard of 0.5 f/mL.
- Task-specific exposures of car mechanics to chrysotile during service of brakes and clutches were typically less than the PCM detection limit of 0.05 f/mL. These low levels can be attributed to the use of wet cleaning or aerosol spray methods in recent years to replace the traditional compressed air jet cleaning.
- Brake service to heavy vehicles can generate substantial number of very fine fibers which are not detectable by PCM. More studies are needed to quantify the likely exposure in brake work for heavy vehicles.
- Area contamination by asbestos debris in brake bonding workshops raises health and environmental concerns. The use of asbestos in these workshops should be better controlled. An improved control program should include education of exposed persons, isolation of asbestos work, control by ventilation and personal protection, maintenance of ventilation system, and good housekeeping measures necessary to reduce the inhalation of dust.

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DISCLAIMER

The conclusions reached and scientific views expressed in this article are the authors' and do not necessarily reflect those of the organizations in which they work.

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