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TEXT

Asbestos Exposure during Brake Lining Maintenance and Repair¹

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Data obtained on asbestos exposure of garage mechanics during brake lining maintenance and repair work show that fiber concentrations frequently in excess of regulated limits are common. The presence of chrysotile, ranging from 2 to 15%, in brake drum dusts, was demonstrated by X-ray diffraction, transmission electron microscopy, selected area electron diffraction, and electron microprobe analyses. Unaltered chrysotile was found, both in fiber and fibril form, in air and brake drum dust samples. The chrysotile asbestos content of personal air samples, taken during automobile brake repair work, was measured both by optical and electron microscopic techniques. While a positive correlation exists between the types of measurements, the present technique of optically counting asbestos fibers may considerably underestimate the levels of total asbestos exposure.

INTRODUCTION

During the past decade, significant disease risk has been found associated with the inhalation of asbestos fibers in a number of occupational and environmental circumstances other than in asbestos mining, milling and manufacturing, where serious hazard was already known (Wagner *et al.*, 1960; Newhouse and Thompson, 1965; Selikoff *et al.*, 1964, 1965; Harries, 1968).

Such exposures were found in the construction industry and in shipbuilding, as well as in other industrial settings where asbestos products were used. More recently, asbestos exposure has been suggested to occur during automotive brake lining repair and installation work, and measurable concentrations of asbestos fiber were observed in the work environment of workmen involved in these operations (Hickish and Knight, 1970; Hatch, 1970; Boillat and Lob, 1973). With limited data available, however, uncertainty remained regarding the type and extent of asbestos exposure during this work. Some investigators have questioned whether free asbestos fibers survive the high temperatures produced during braking action (Lynch, 1968; Hickish and Knight, 1970; Hatch, 1970) contending that asbestos decomposes as a result of the high point contact temperatures produced at the interface of the brake drum or disc and brake lining.

We have sought to obtain information concerning asbestos exposure of workmen engaged in brake lining maintenance and brake shoe installation, by analysis of residual dusts recovered from brake linings and by direct measurement of the

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free asbestos fiber content of workroom air in areas where these operations take place. In the United States, an estimated work force of at least 900,000 auto mechanics and garage workers is potentially exposed to asbestos in the servicing of both brake and clutch linings. Furthermore, much brake dust enters the general environment during automobile use (Jacko and DuCharme, 1973), to add more to the burden of asbestos air pollution (Selikoff, Nicholson, and Langer, 1972).

Asbestos in Friction Materials

In the United States, an estimated 118 million pounds of asbestos is used annually for the production of brake friction materials (Jacko and DuCharme, 1973). After processing (cutting, grinding, punching), the asbestos in the material sold is approximately 103 million pounds per year. In addition, asbestos contained in automotive clutch friction materials amounts to 4.5 million pounds annually.

Major Constituents of Brake Linings

A number of materials is commonly used in the manufacture of the three major automotive brake lining components (binder, fiber reinforcer, and property modifier). These are listed in Table 1.

Binder. The binders used in the automotive industry today are primarily phenolic-type resins, which are noted for high binding efficiency and ability to withstand pyrolytic breakdown. Other materials have been used, in varying proportions and in addition to resins, for binder improvement (Table 1).

TABLE 1
COMMON COMPONENTS OF AUTOMOTIVE BRAKE LININGS*

Binder and organic friction modifiers	Fiber reinforcer	Property modifier
Phenolic-type resin	Chrysotile asbestos ^b	Lead compounds
Rubber	(grades 4-7)	Zinc compounds
Tire scrap	Unaltered	Antimony oxide
Pitch	Calcined	Iron oxide
Cork	Mixed fiber	Copper metal
Gilsonite		Brass chips
Cashew nutshell resin and particles		Clay minerals
		Barite (BaSO ₄)
Drying oils		Wollastonite (CaSiO ₃)
		Quartz (SiO ₂)
		Cryolite (Na ₃ AlF ₆)
		Rottenstone (SiO ₂)
		Coke (C)
		Coal (C)
		Gilsonite (C)
		Graphite (C)
		Carbon black (C)
		Molybdenum sulfide (MoS ₂)
		Fluorspar (CaF ₂)

* See Carroll, 1962; Anderson, 1969; Anderson, 1973; Jacko and DuCharme, 1973; Bark, *et al.*, 1975.

^b Chrysotile fiber constitutes about 50% by weight of most automotive brakes currently manufactured in the United States.

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Fiber. For fiber reinforcement of the friction product, chrysotile asbestos is used almost exclusively. The mineral typically comprises from 40 to 50% of the brake product. Fiber grades 4 through 7 are used, and occasionally, several sizes are admixed or even calcined to improve performance characteristics.

Modifiers. Perhaps the widest range of materials used in friction products are the property modifiers. Nineteen representative compounds are listed in Table 1. Modifiers are used for a number of purposes; they are included to increase brake shoe "density," making the brake surface able to withstand high pressures (e.g., barite); they are included as "lubricants" to reduce the coefficient of friction along the brake surface, and thereby prevent "grabbing" (e.g., lead compounds); they act as "friction agents" increasing the coefficient of friction and enhancing the braking action of the shoe (e.g., brass chips); they act as internal "abrasives," which help to "recondition" the braking surface and remove deposited decomposition products (e.g., rottenstone, quartz); they act as "heat sinks," reducing binder pyrolysis and fiber decomposition thereby extending the useful life of the lining (e.g., brass chips, metals, etc.).

It is important to note that one major purpose of the reconditioning agents is to retard the formation of forsterite (a mineral not originally present in the brake material, but created by dehydroxylation and recrystallization of chrysotile asbestos at high temperatures) which may accumulate on the surface of the brake lining. The hardness of the forsterite (Mohs, 6.5-7.0) is such that it tends to score and gouge brake drums and discs (hardness 3-3.5), degrading them prematurely. Therefore, recrystallization of chrysotile to forsterite is an unwanted effect, hindered insofar as possible by the modifiers present in the matrix.

Materials of Biological Interest

Asbestos, quartz, and heavy metals are constituents of automotive brake linings, each warranting special consideration from the viewpoint of biological activity. The focus of this report is limited to the problem of chrysotile asbestos exposure.

Mechanisms of Degradation of Brake Linings during Use

Brake wear is dependent upon many factors, such as the temperature generated at the surface of the brake shoe during braking operations. At any one time, only a small percentage of the rubbing area is in contact with the wheel, with "hot spots" generated, ranging up to 800 to 1000°C (Carroll, 1962; Anderson, 1969). It is not uncommon during moderate braking action, to attain temperatures as high as 500°C (Carroll, 1962). Some investigators have suggested that, in addition to binder pyrolysis, chrysotile completely dehydroxylates under these conditions and "reduces to powder" where it is swept off the brake facing (Carroll, 1962). However, this hypothesis is oversimplified, in that other important processes, besides thermal wear, contribute to shoe breakdown, and brake shoe degradation. (Burwell, 1957). For example, the effects of abrasive wear and macroshear have been investigated. When monitored by X-ray diffraction, chrysotile in brake materials displays structural strain and substructure fragmentation, caused by shear during braking processes (Mizutani *et al.*, 1973). This shear strain produces material fatigue which, with binder pyrolysis, can *cause brake lining disintegration at*

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temperatures far below those required for chrysotile dehydroxylation. Therefore, brake lining disintegration may liberate partially altered, or unaltered, chrysotile fibers.

Thermal Decomposition of Chrysotile

Differential thermal analysis indicates that chrysotile undergoes dehydroxylation at 650 to 680°C and recrystallizes (anhydrous magnesium silicate to forsterite) (Mg_2SiO_4) at about 810 to 820°C (e.g., Martinez, 1966; Daykin, 1971; Berry, 1971; Monkman, 1971; Harris, 1971). These temperature ranges are subject to great variation as a function of the chemistry of the fiber, particle size, instrumental variations, sample packing, etc. Also, forsterite has been noted to form, during prolonged static heating, at considerably lower temperatures (Bates and Comer, 1957; Martinez, 1966; Brindley and Hayami, 1965; Naumann and Drescher, 1966). In general, temperatures in excess of 570°C are required for dehydroxylation and incipient forsterite formation in chrysotile. Extensive study of both the thermal behavior of chrysotile and brake lining composition and design indicates that chrysotile fiber may survive in the decomposed lining dust.

METHODS

Analysis of Brake Drum Dust (Decomposed Lining)

Ten samples of automobile brake drum dusts were collected and examined by optical microscopy, X-ray diffraction, transmission electron microscopy and scanning electron microscopy with microchemical capability, for the purpose of determining the presence or absence of chrysotile.²

Optical microscopy, employing polarized light, was generally not useful for detecting asbestos in brake drum dust. A number of factors are considered responsible for this phenomenon including the low relief and birefringence of chrysotile and the nature of the matrix, consisting largely of road dust, resin binder, and pyrolyzed residue, which, in optical microscopic preparations, readily obscures the smaller asbestos fibers.

X-ray diffractometry, in the continuous and step-scan mode, was performed on all dusts. Chrysotile reflections ($hkl = 002; 020; 004$) were observed in all ten samples. Quantitative determination of chrysotile content was made by comparison of unknowns with calibrations of chrysotile dilution standards. The weight occurrence ranged from about 2–15%, with an average ranging from 3–6%. Lead compounds, quartz, calcite, mica, clays, barite, graphite, and alpha-iron particles were identified as well. In several samples, weak, diffuse reflections suggested the presence of forsterite, but positive identification could not be made using this technique.

Identification of Chrysotile by Electron Microscopy

Transmission electron microscopy, selected area electron diffraction, and elec-

²We acknowledge the cooperation of the United Automobile Workers, Local Union No. 259 and the Automobile Dealers Industrial Relations Association in helping us obtain these samples in auto maintenance shops in the New York area. Each sample was taken from "a typical job" under way at the time.

Iron microprobe analysis of the brake dusts were carried out on each of the ten samples after preparation by a technique which disperses the dust particles in a nitrocellulose film without altering particle size distribution. Free chrysotile fiber-bundles and fibrils were observed in all ten samples (Fig. 1). Selected area electron diffraction analysis of representative fibers demonstrated the preservation of the chrysotile structure (Figs. 2A, B). Some patterns displayed arcuate reflections suggestive of interfibril rotation and intrafibril displacement (Figs. 2A, B). Occasionally, fibers were observed without characteristic chrysotile morphology, with mottled surfaces and obliterated fibrils, indicating partial or complete recrystallization. Electron diffraction patterns obtained from these particles displayed



FIG. 1. Electronphotomicrograph of large chrysotile bundle in brake drum dust (38,000 $\times$ magnification). Other particles include phenol resin binder and road dust debris.

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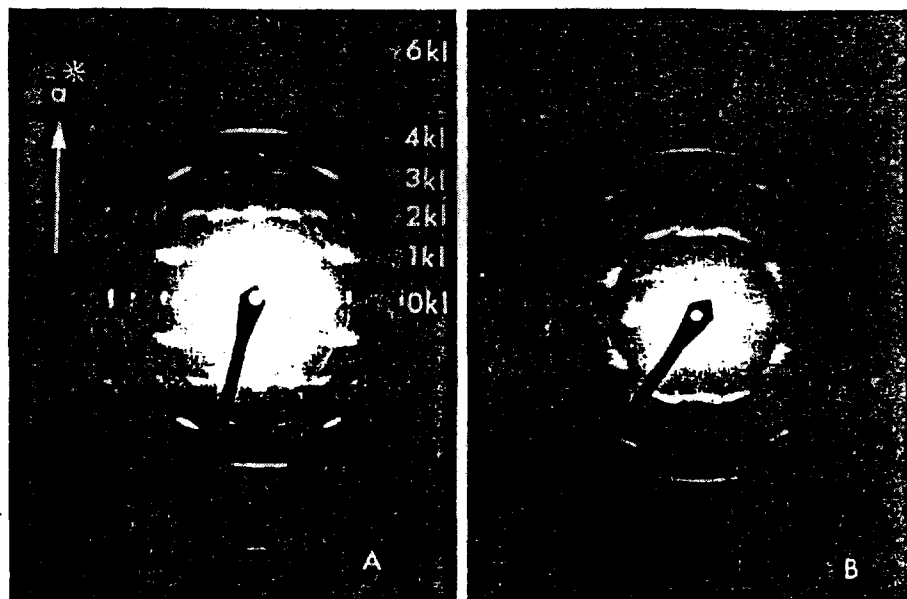


FIG. 2. Selected area electron diffraction patterns obtained on fibers of chrysotile obtained during air sampling at brake repair shops. In A, the reciprocal a axis is marked a^* as are the layer lines in the (OKI) series. Indexing of upper right quadrant yielded 16 reflections corresponding to single crystal X-ray diffraction analysis of Whittaker and Zussman, 1956. Pattern in (B) displays "smearing" of reflections in a "clockwise" manner suggesting interplanar rotation.

polycrystalline characteristics of multiple random reflections or Debye-Scherrer rings rather than the distinctive single fiber chrysotile pattern (Fig. 2B). Microchemical analysis with a probe technique on the unaltered fibers showed them to possess the usual Mg:Si ratio of chrysotile. In addition to free chrysotile fiber bundles and fibrils, chrysotile was also frequently observed projecting from the margins of binder fragments (Fig. 3).

Free asbestos fibers present in the decomposed lining dusts were sized at $42,000\times$ magnification. The results, seen in Table 2, show that most fibers are too small to be seen by optical microscopy; almost all of them are shorter than $0.4\text{ }\mu\text{m}$ in length; virtually all are of respirable size ($<5\text{ }\mu\text{m}$). Hatch (1970) in reporting on optical fiber counts obtained from brake cleaning operations with compressed air jet, found that 94% of the fibers fell in the $2\text{--}5\text{ }\mu\text{m}$ length category, while only 6% were longer than $5\text{ }\mu\text{m}$. Jacko and DuCharme (1973) made size distribution measurements of asbestos fibers in brake dusts generated during dynamometer tests, using both optical and electron microscopy. They found, at magnifications of $22,000\times$ that 30% of the fibers were from 0.25 to $0.50\text{ }\mu\text{m}$ in length and that 60% were longer than $0.5\text{ }\mu\text{m}$. Some discrepancies between our data and those of Jacko and DuCharme may be attributed to their use of the lower magnification ($22,000\times$ vs $42,000\times$), at which fibers shorter than $0.20\text{ }\mu\text{m}$ may not be easily seen or identified on the electron microscopic screen. Thus, both the optical fiber count data in other studies and the electron microscopic fiber size distribution data

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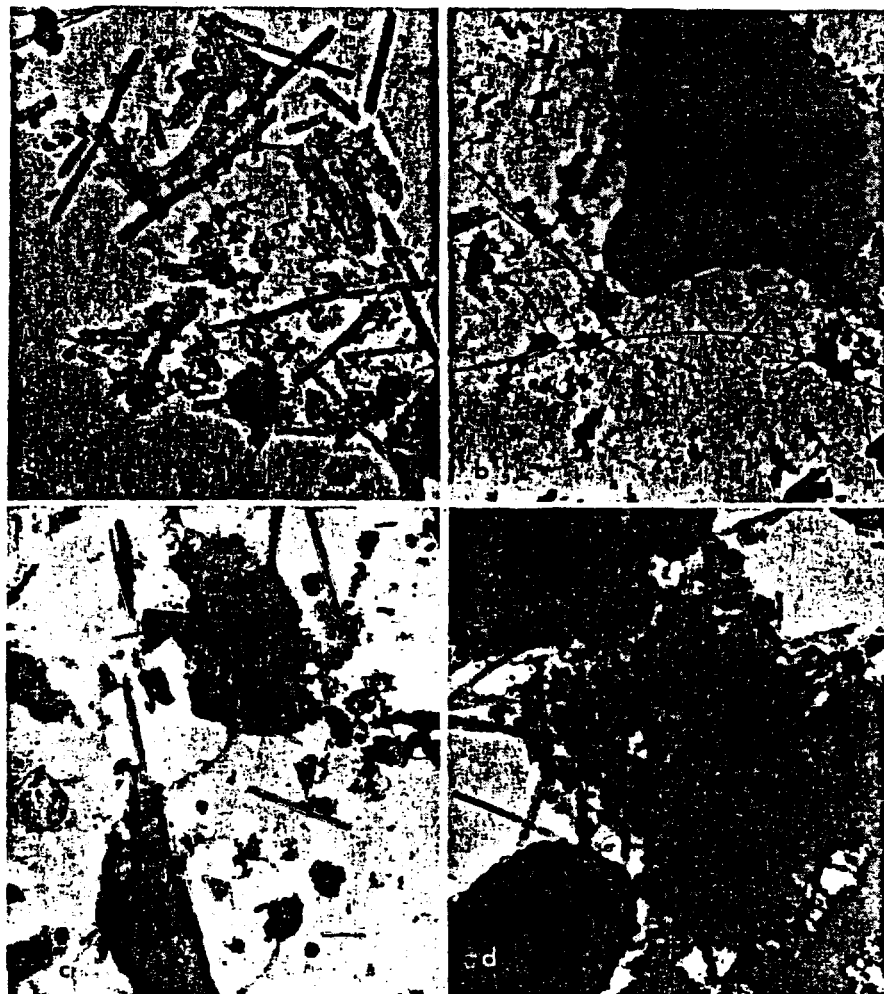


FIG. 3. Electron photomicrographs of brake drum dusts. Chrysotile is present in both free fiber and fibril form. Opaque granular material is road dust or phenolic binder. a. $\times 10,800$; b. $\times 9,300$; c. $\times 30,000$; d. $\times 30,000$.

indicate that the chrysotile fiber population generated by brake wear is a strongly skewed one, with almost all fibers concentrated in the smaller than $5 \mu\text{m}$ region. No attempt was made to size the asbestos-binder particulates.

Personal Air Sampling during Brake Repair Work

Personal air sampling for asbestos exposure during brake lining maintenance and repair was carried out at franchised auto dealer garages, taxi fleet repair shops, and a municipal truck repair shop, all located in New York City.³ Personal

³ Assistance in providing opportunity for sampling was given by the Department of Air Resources, New York City.

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TABLE 2
LENGTH DISTRIBUTION OF CHRYSOTILE FIBERS IN BRAKE DRUM DUST^a

Sample	750-1500Å N (%)	1500-2250Å N (%)	2250-3000Å N (%)	3000-3750Å N (%)	Total (%)
1	40	34	11	11	96
2	32	23	32	—	87
3	20	25	25	—	70
4	26	37	26	7	96
5	57	17	4	—	78
6	23	9	12	12	56
7	50	26	21	2	99
8	29	30	21	17	97
9	6	41	18	10	75
10	11	6	31	31	79

^a Fibers counted and sized at 42,000 $\times$; all fibers have diameters from 250 to 500Å.

air samples were taken during and after brake repair work and at varying distances from the work sites in other areas of the garages and shops. The latter samples were intended to provide information concerning levels of asbestos exposure which garage employees other than those doing brake work might experience.

Asbestos Exposure during Automobile Brake Repair Work

Air samples were first taken in the breathing zone of mechanics doing brake repair work. These peak exposure measurements were taken over periods of 3-8 minutes during which the workers were blowing dust from brake drums. The air samples, taken on membrane filters, were processed, and fiber counts made in accordance with the procedures which have been adopted by the Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor (Bayer, Brown, and Zumwalde, 1975). Essentially, the analysis consists of counting fibers 5 to 100 μ m, in a fixed area of a Porton graticule, using phase contrast microscopy at a magnification of 400 $\times$. This microscopic method enhances image contrast and allows large asbestos fibers to be readily seen and counted.

When a vehicle is brought into a repair shop for brake lining inspection or replacement, the wheel is removed and loose dust is removed from the drums and back plates, generally by means of a compressed air jet. A recent survey of brake repair establishments in Baltimore and Washington revealed that this is the standard method in those cities (Castleman *et al.*, 1975). A similar situation exists in New York City. The cloud of dust that is produced is visible for several minutes afterwards (Fig. 4). Table 3 shows that fiber concentrations are high in the operator's area under these conditions (an average concentration of 16 fibers/ml), and that there are significant concentrations at least 20 ft away. Background or area sampling during the same operation shows that, at least 14 minutes after jet air blowing and up to 75 ft away, asbestos concentrations are still measurable even by optical microscopy. The data in Table 3 indicate that an asbestos concentration gradient, dependent on distance and time, is associated with this operation. It is evident that any person 65-75 ft away can be exposed. Current (interim) regulations of OSHA prohibit concentrations of 5 fibers/ml or more, longer than 5 μ m, as

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FIG. 4. Removal of dust from brake drum and back plate by pneumatic air blowing at automobile garage.

a time-weighted average for workers, and concentrations above 2 fibers/ml will be illegal after 1976. Regulations set a peak concentration (maximum excursion) of 10 fibers/ml of air. Newly proposed standards are designed to set a limit of 0.5 fibers/ml (500,000 fibers/m³), with a maximum excursion of 5 fibers/ml.

It was generally found that there was minimal, if any, effort to control dust in most garages. Workmen do not use respiratory protection. There was little awareness of the potential hazard of brake dust.

In a single instance, brake drum cleaning was not done with a compressed air jet, but with a dry hand brush. Fiber concentrations were somewhat less (2.5 fibers/ml) at the operator level, but background levels 12 ft away were the same as with air jet cleaning.

Asbestos Exposure during Truck Brake Repair and Installation Work

Personal air sampling was also conducted at the New York Department of Sanitation truck repair shop, where various kinds of brake application and repair work are performed. Used truck brake linings are salvaged by grinding the surface to remove grease and dirt, and new linings are ground to expedite break-in. The edges of new linings are beveled on a grinding wheel or arcing machine to avoid noise problems. (Fig. 5). Holes are drilled or punched into the brake lining, which

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TABLE 3
ASBESTOS CONCENTRATIONS DURING AUTOMOBILE BRAKE SERVICE ^{a,b}

Operation	Distance (ft)	Number of samples	Fiber concentration (fibers/ml)	
			Mean	Range
Blowing dust out of brake drums with compressed air jet	3-5	4	16.0	6.6-29.8
	5-10	3	3.3	2.0-4.2
	10-20	2	2.6	0.4-4.8
	Distance from operation (ft)	Time lapse (min)	Concentration (fibers/ml)	
Background samples taken at varying distance and lapsed times, after brake drum blowing	10	0	0.3	
	20	0	0.8	
	12	5	0.2	
	50	5	0.1	
	65	7	0.1	
	75	14	0.1	
	Distance (ft)	Number of samples	Fiber concentration (fibers/ml)	
			Mean	Range
Cleaning brake drums with dry brush	1-3	2	2.5	1.3-3.6
Background samples taken 3 minutes after cleaning brake drums with dry brush	12	3	0.1	0-0.2

^a Fibers 5-100 μ m in length, counted by optical microscopy.

^b The new proposed Asbestos Standard of the U. S. Department of Labor records asbestos exposure in fibers/m³, noting that a workman might respire approximately 8 m³ of air per working day, retaining an unstudied proportion of inhaled fibers. The above table omits reference to air content of fibers < 5 μ m in length.

is then riveted onto a steel plate. Some of these operations are similar to those done during the manufacture of brake shoes. Table 4 summarizes the results of personal air sampling in the course of this work. During light grinding of truck brake shoes (Fig. 6), an average peak concentration of about 4 fibers/ml was found in the breathing zone of the operator. The data show that measurable fiber concentrations are found 25 ft or more away. At a distance of 25 ft, for example, a concentration of 1 fiber/ml (1,000,000 fibers/ml³) was found. Much larger numbers of shorter fibers would simultaneously be inhaled. During the beveling of truck brake shoes on a grinding machine, very high concentrations of fibers were found in the vicinity of the operator. The average of five air samples was about 37 fibers/ml. Area samples, taken up to 30 ft away from this operation, demonstrated the presence of airborne fibers. It was of interest to note that, at the time of this sampling, from eight to 15 other garage mechanics were working within this

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FIG. 5. Beveling of truck brake linings at municipal garage. Arrow indicates accumulation of asbestos dust.

perimeter and were exposed to asbestos. Fiber levels for other kinds of operations at the truck garage are given in Table 4.

Boillat and Lob (1973) have reported fiber concentrations measured during drilling holes for rivets and grinding. They found values ranging from 0.3 to 29.2 fibers/ml; four of the nine values exceeded 5 fibers/ml.

A Comparison of Fiber Levels Visible by Light Microscopy and Electron Microscopy

In the ten brake drum dust samples examined, it was found that asbestos fibers shorter than $0.4 \mu\text{m}$ predominated (Table 2). The OSHA Asbestos Standard does not require that short fibers ($< 5 \mu\text{m}$ in length) be counted or controlled. This oversight may have considerable biological significance in that small chrysotile fibers readily produce asbestos disease (Holt, Mills, and Young, 1964, 1965; Davis, 1965; Pott, Huth, and Friedrichs, 1972; Wagner, Berry and Timbrell, 1973;



FIG. 6. Renewing of municipal truck brake linings by light grinding to remove grease and dirt.

Hilscher *et al.*, 1970). Attention has recently been again called to the potential importance of this question (Bouhuys, 1975).

There is little published information on the numbers of, and sizes of, submicroscopic asbestos fibers in occupational exposures. The present study afforded an opportunity to collect data on the relationship between submicroscopically- and optically-visible fibers for this specific industrial exposure. Eight air samples were selected for both light and electron microscopic examination. Six of these were taken during brake drum dust removal operations with optical fiber counts recorded from 0.1 to 3.6 fibers/ml. The other two samples were taken during light grinding of automobile brake shoes.

Preparation and Analysis of Air Samples

One square centimeter sections of the eight membrane filters were mounted, dust side down, on microscopic slides and ashed in low temperature activated

TABLE 4
ASBESTOS CONCENTRATION DURING TRUCK BRAKE SERVICE^a

Operation	Distance (ft)	Number of samples	Fiber concentration (fibers/ml)	
			Mean	Range
Renewing used linings by grinding	3-5	10	3.8	1.7-7.0
Background to grinding used linings	10	2	1.5	1.2-1.7
	25	2	0.8	0.6-1.0
	60	1	0.2	—
Beveling new linings	3-5	5	37.3	23.7-72.0
Background to beveling new linings	8	1	0.6	—
	12	2	0.4	0.3-0.5
	30	1	0.3	—
Punching rivets into brake linings	3-5	2	1.5	1.9-2.0
Chipping rust off used brake linings	3-5	1	2.4	—
Sweeping floor around grinder	3-5	1	3.6	—
Background to sweeping floor around grinder	15	1	3.1	—

^a Fibers 5-100 μ m in length, counted by optical microscopy.

oxygen to remove organic materials. The ashed residue was dispersed in a drop of nitrocellulose solution. The dispersal was accomplished by a "rubout" technique using the edge of a watch glass (Nicholson, Rohl and Ferrand, 1971). By this method large asbestos fiber bundles are broken into their constituent smaller fibrils and large agglomerates of inorganic materials, which normally obscure the presence of asbestos fibers, are broken into particles small enough to allow virtually all asbestos to be seen. By placing a second slide over the ground residue and nitrocellulose solution and then gliding the two slides apart, a thin film is produced. The dried film is cut into segments which are then floated off in water. The film is mounted onto Formvar-coated electron microscopic grids. Typically, four grids are prepared from each sample and one square on each grid is scanned in the electron microscope at 42,000 $\times$ magnification to determine the quantity of chrysotile present. By estimating the length and diameter of each fiber, and assuming a cylindrical fiber geometry, the mass of chrysotile per grid square is determined. Representative electron photomicrographs of chrysotile fibers and fibrils are shown in Figs. 7 and 8.

RESULTS

A comparison of the optical microscopic fiber counts and the electron microscopic total asbestos mass calculations obtained from the eight samples is shown in Table 5. Figure 9, showing the same data, is plotted on logarithmic paper, and visual inspection indicates that a positive correlation exists between the optical and electron microscopic results, although the data are limited and the amount of

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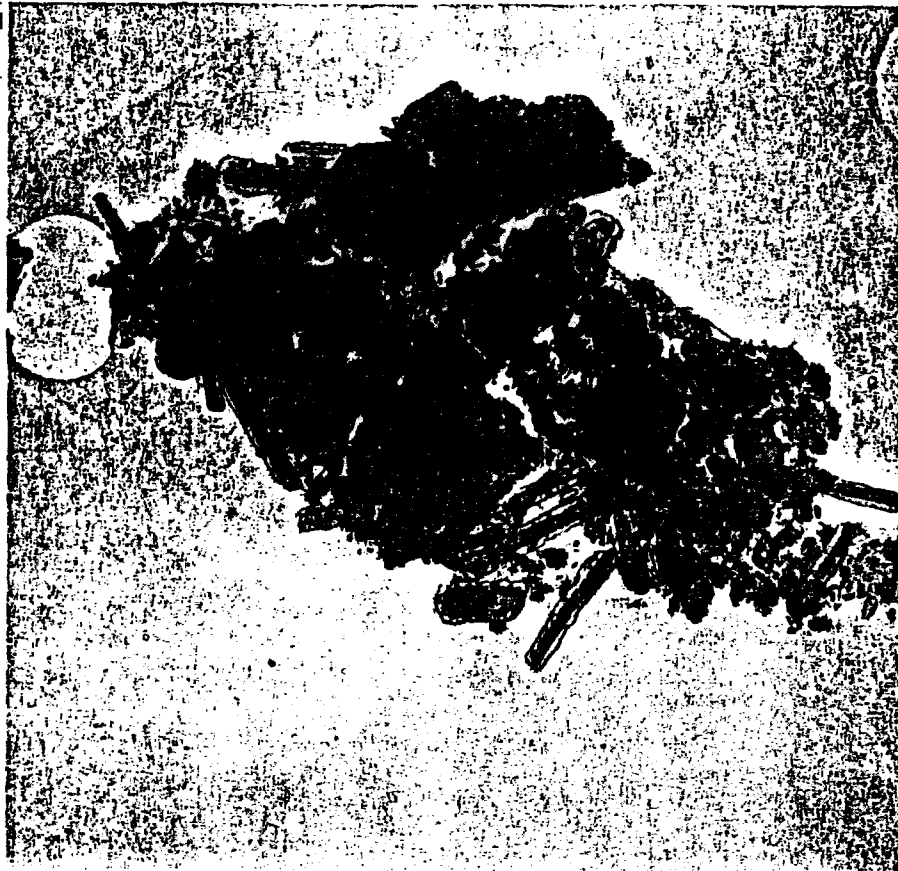


FIG. 7. Electron photomicrograph of air sample taken during brake drum blowing (sac sample No. 4, Table 5). Large numbers (70-100) of chrysotile, some of which are masked by granular particulates, presumably road dust (65,000 total magnification).

scattering precludes a regression analysis. For example, from these data it may be possible to predict that, during the grinding of new brake linings (Sample No. 8, Table 5), a worker could be exposed to about 0.5 mg of asbestos daily in circumstances in which the time-weighted TLV of 5 fibers/ml would not have been exceeded. Similarly, Fig. 9 shows that, since a microgram of asbestos represents on the order of 1 million fibers per cubic meter of air (of greatly varying diameters and lengths), extremely high concentrations of submicroscopic fibers are present up to 65 ft away from brake repair work (e.g., Sample No. 5, Table 5), even though fiber levels in such a case are barely detected, if at all, by the standard optical counting technique. These limited data indicate that the standard (OSHA) optical fiber counting method may be only a fractional indicator of total asbestos exposure, at least in the case of automobile repair work. They also indicate that the total exposure is much higher than the OSHA technique records, in terms of

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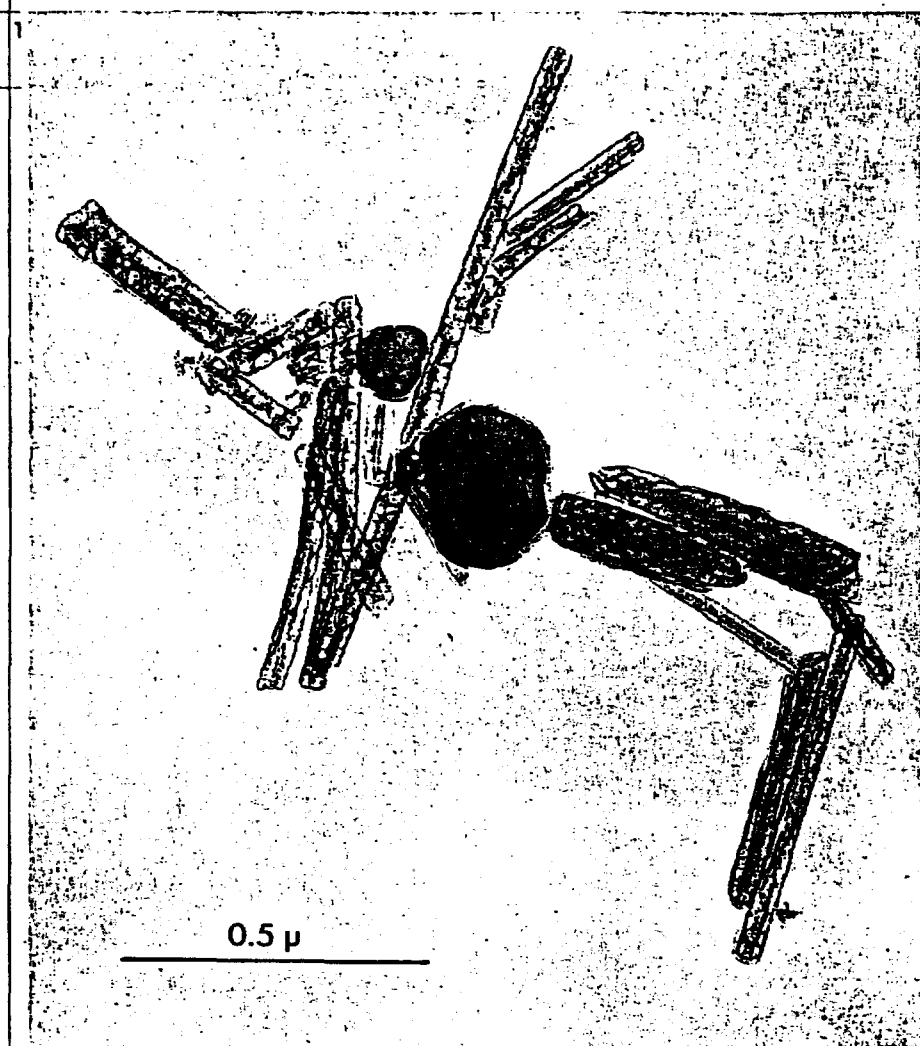


FIG. 8. Electronmicrograph of air sample of cluster of chrysotile fibrils in background sample (see sample No. 3, Table 5 (83,000 $\times$ magnification).

asbestos fiber number, mass, and surface area. Additional studies relevant to this and other kinds of asbestos exposure are needed to confirm and extend these findings. It is important to note that particles of asbestos-containing pulverized brake lining were not included in this mass determination. Their importance, in terms of biologic potential, is presently unknown.

SUMMARY AND CONCLUSIONS

(1) Chrysotile asbestos fiber is a major component of brake lining materials. Degradation of the lining is brought about by a combination of factors, which

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TABLE 5
COMPARISON OF OPTICAL AND ELECTRON MICROSCOPIC FIBER COUNTS

Operation	Optical microscopy (fibers/ml)	Electron microscopy ($\mu\text{g}/\text{m}^3$)
1. Blowing dust off drum with air jet (10 ft away)	2.0	1.27
2. Background to blowing out brake drum (10 ft away)	0.3	0.2
3. Blowing dust off drum with air jet (20 ft away)	0.4	1.1
4. Background to blowing out brake drum (20 ft away)	0.8	0.1
5. Background to blowing out brake drum (65 ft away—7 minutes after blowing stopped)	.1	0.2
6. Cleaning brake drum with hand brush	3.6	6.5
7. Light grindings of new linings before installation	4.7	53.0
8. Light grinding new linings before installation	2.7	66.0

include thermal stress, material fatigue, and shearing. Modifying agents are included in brake linings which lower the contact temperature between the lining and wheel interface; this, in turn, prevents binder pyrolysis and chrysotile fiber dehydroxylation. The amount of chrysotile fiber which survives the braking operation is related to a number of additional factors, including some which are external to the properties and quality of the lining itself. As a consequence, degradation may occur at temperatures significantly lower than that required for the dehydroxylation of chrysotile, with the persistence of fibers.

(2) Ten samples of dust were taken from automobile brake drums in New York City, and analyzed. Optical microscopy was of limited usefulness. X-ray diffraction analysis, using both continuous and step-scan modes demonstrated the presence of chrysotile in all dust samples. The proportion of chrysotile ranged from about 2–15%, and averaged about 3–6%. This included both free fibers and chrysotile which survived in pulverized binder as particulates. Forsterite, the

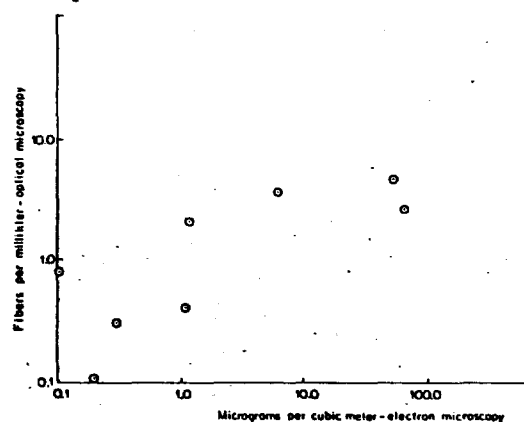


FIG. 9. Comparison of optical and electron microscopic fiber counts.

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thermal transformation product of chrysotile could not be unequivocally identified by continuous scan X-ray diffraction.

(3) The presence of chrysotile asbestos in the ten dust samples was further-verified by transmission electron microscopy, selected area electron diffraction and electron microprobe analyses. Chrysotile was found, both in fiber and fibril form, with unaltered structure and chemical composition. Its frequency of occurrence was consistent with, but lower than the quantitative determination made by X-ray diffraction analysis. However, it should be noted that X-ray diffraction analysis is based on both free fibers and fibers present in clumps; the latter would obscure the presence of discrete fibers on electron microscopic study. In addition to unaltered fiber, partially altered and completely recrystallized fibers were also seen.

(4) Size distribution analysis at 42,000 $\times$ magnification in the ten samples indicate that about four-fifths of all chrysotile, in fiber form, is shorter than 0.4 μ m in length. These fibers are too small to be seen by optical microscopic techniques.

(5) Personal air sampling was conducted during brake repair work in automobile garages in New York City. Standard optical microscopic procedures for fiber counting were used. In samples taken in the vicinity of repairmen blowing dust from automobile brake drums with compressed air, an average concentration of 16 fibers/ml was measured. Background and time-lapse samples indicate that measurable concentrations exist at least 75 ft from the work site and for at least 14 minutes after jet air blowing.

(6) Personal air samples were taken at a municipal truck repair facility where various brake fabrication and application operations are performed. Grinding of truck brake shoes resulted in an average concentration of about 4 fibers/ml (4,000,000/m³). During beveling, an average fiber count of 37 fibers/ml was measured. Exposure levels during drilling, punching rivets, and cleanup were also measured. Background measurements show that fiber concentration gradients are produced during truck brake repair and application work. During light grinding of truck brake shoes, measurable fiber concentrations were found 25 ft or more away, as well as up to 30 ft from brake beveling operations. The background measurements, during both automobile and truck brake work, indicate that many employees in garages other than brake lining workers are potentially exposed to asbestos, including other mechanics and shop management.

(7) Eight air samples taken during automobile brake repair work were analyzed by other optical and electron microscopy. A positive correlation was found to exist between optical fiber counts ($> 5 \mu$ m) and the total chrysotile mass calculations based on sizing all fibers at 42,000 $\times$ magnification. These data indicate that standard (OSHA) optical fiber counts may be a useful index of total free asbestos exposure during brake repair work. They also demonstrate that the total free asbestos exposure, in terms of fiber number, mass, and surface area is much greater than the optical counting techniques indicate.

(8) Attention is called to the fact that in addition to asbestos, other biologically active substances, including free silica and lead compounds, have been identified in brake lining dusts. Their concentrations in brake work environments are not known, and warrant investigation.

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- (9) Potentially hazardous asbestos exposure exists during automotive brake servicing. It has been reported that approximately 900,000 persons are employed in such work in the United States. It is recommended that stringent industrial hygiene measures to control exposure be implemented as rapidly as possible.

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irregular or nodular interstitial opacities of limited extent and intensity on their films. Silica or asbestos exposure had occurred in 22% of the work force examined. Such exposures had occurred in various job categories in the titanium facility as well as in prior occupations. Eight of the 26 workers with abnormal X-rays had had silica or asbestos exposure. No clear pattern of restrictive disease in relation to X-ray findings could be seen.

Summary and Conclusions

Clinically significant or symptomatic pulmonary disease was infrequent in a survey of 207 currently employed production workers in a plant producing titanium dioxide from ilmenite ore. Evidence of airways obstruction was found in 47% of all workers (including 38% of workers who had never smoked regularly). This abnormality was not frequently accompanied by disabling shortness of breath. Despite the fact that approximately 90% of the group of workers examined had worked for 20 years or more, radiological changes consistent with pneumoconiosis were relatively few, and unrelated to the respiratory abnormalities observed.

We conclude (with the caveats inherent in a prevalence study in which only half of the eligible long-term workers were examined) that occupational exposure associated with titanium production by the sulphate process may commonly cause undesirable irritation of the upper and lower respiratory tract and functional abnormalities of the lung, but does not result in an important incidence of serious occupational lung disease. Individual workers may, however, suffer unwanted abnormalities. These findings, of course, do not speak to the presence or absence of increased risk of malignant pulmonary disease. This is being separately studied.

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Asbestos Content of Dust Encountered in Brake Maintenance and Repair

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Asbestos in Brake Linings

The composition of automotive brake linings includes chrysotile asbestos fibre which comprises about 50% of the friction material. The exposure of garage workers to asbestos during brake lining maintenance and repair has recently been investigated (Rohl *et al.* 1976). This important issue was studied because a large labour force is potentially exposed (over one million people in the United States alone). Consequently it was thought essential to determine if chrysotile fibre survives braking, and to measure the amounts liberated as an aerosol during maintenance and repair operations.

Investigators in the past have expressed doubt as to whether chrysotile fibres can survive the high temperatures generated during braking (Lynch 1968, Hickish & Knight 1970, Hatch 1970). Chrysotile is alleged to be subjected to temperatures in excess of 800°C, which would cause its thermal transformation to forsterite or to an amorphous magnesium silicate phase. While 'hot spots' up to 1000°C may be attained (Carroll 1962), the heat distribution is nonuniform, and other processes, in addition to thermal wear, contribute to degradation of brake linings. For example, abrasion and macroshear may also cause physical breakdown (Burwell 1957, Mizutani *et al.* 1973). Accordingly, brake lining disintegration by these mechanisms may liberate partially altered or even unaltered chrysotile fibres.

Analysis of Brake Drum Dust

Initially, ten samples of automobile brake drum dusts from brake repair shops in New York City were collected and examined by optical microscopy, X-ray diffraction, transmission electron microscopy and energy dispersive X-ray spectroscopy, to determine the presence of chrysotile.

Optical microscopy: The detection of chrysotile in brake drum dust by optical microscopy is hindered by the nature of the debris matrix, consisting largely of opaque pyrolyzed phenolic-type resin binders and road dust. Chrysotile, particularly small fibres, has low optical relief and low birefringence, which further hinder its identification. Only in rare instances have large fibres, with optical

Table 1

Chrysotile asbestos content of brake drum dusts

	No. of samples	X-ray diffraction (step-scan)		Transmission electron microscopy No. positive
		No. positive	Weight percent Mean Range	
Great Britain	8	6	1.8 0.7-2.3	8
West Germany	8	5	2.4 0.5-3.2	8
France	1	1	2.5	1
United States of America	10	10	4.5 2.0-15.1	10
Finland	5	3	1.8 0.8-2.5	5
Western Australia	7	4	1.4 0.5-2.3	7
	39	29	$\bar{x}=2.4$ ± 1.1	39

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X-ray diffractometry: The ten brake dust samples were analysed by X-ray diffractometry, in both continuous and step-scan mode. The diagnostic reflection selected for chrysotile (3.66 Å; $hkl=(004)$) was step-scanned in the fixed-count mode. By comparison with external standards, the amount of chrysotile present can be determined. Chrysotile reflections were observed in all samples, with weight percentages estimated to range from 2 to 15 (average 4.5). Lead compounds, quartz, carbonate minerals, clays, halite (NaCl), graphite, micas and alpha-iron were also identified in various samples.

Twenty-nine additional brake drum dust samples were collected by colleagues in four European countries and Australia. The samples were obtained from areas representing variable circumstances, such as driving conditions, friction material composition, type of automobile and climate. The results of X-ray diffraction analyses are presented in Table 1. Of the 39 total samples analysed (including 10 United States samples) chrysotile was found in 29, or about three-fourths. The mean chrysotile content varied from 1.4% in the seven Australian samples to 4.5% in the New York City samples.

The thermal breakdown product of chrysotile, i.e., forsterite, which might be expected to form as a result of recrystallization, was not unambiguously detected in any sample.

Transmission electron microscopy (TEM): In order to verify the results of X-ray diffraction analysis, the brake dust samples were prepared for electron microscopic analysis by means of a technique which disperses the dust particles in a nitrocellulose film without altering particle sizes. Both free chrysotile fibre bundles and fibrils were observed in all 39 samples. Most of the chrysotile retained its characteristic morphology without significant alteration, and selected area electron diffraction patterns obtained on representative fibres dem-

onstrated the preservation of crystal structure as well (Fig 1).

Fibre size distribution: In ten brake dusts sampled in New York City, free asbestos fibres were sized by TEM at magnification 42 000. The results showed that about 80% of chrysotile is in free fibril form and is shorter than 0.4 µm in length. Over 57% have lengths of about 0.2 µm. At magnification 40 000, such a fibre would be about 1 cm long. If lower magnification were used to scan for asbestos, significant numbers of fibres might not be detected.

It is obvious that most fibres are too small to be seen by optical microscopy. The Asbestos Standard adopted by the Occupational Safety and Health Administration (OSHA) of the US Department of Labour is limited to optical microscopy and neglects to count or control fibres less than 5 µm long. On the other hand, accumulating evidence suggests that such small asbestos fibres may produce disease (Holt *et al.* 1964, Davis 1965, Pott *et al.* 1972, Wagner *et al.* 1973, Hilscher *et al.* 1970, Bouhuys 1975).

Air sampling: Eight personal air samples taken during brake repair work were selected for electron microscopic analysis. This was done in order to positively identify chrysotile in the samples and to determine whether a systematic relationship existed between optically and submicroscopically visible fibres for this type of exposure. The membrane filters were ashed in plasma oxygen to eliminate organic materials and the residue was prepared for electron microscopy by a 'rubout' technique (Nicholson *et al.* 1971), which comminutes large chrysotile fibre bundles into individual fibres and fibrils. Large inorganic particles are likewise reduced in size, permitting all chrysotile to be seen and measured. Chrysotile was identified in the eight samples, in both fibre and fibril form (Fig 2). By measuring a large number of fibres at magnification 42 000 and converting the volumetric data into mass, a concentration per volume of air is determined. Comparison of optical microscopic

fibre counts and the electron microscopic asbestos mass calculations indicates that a positive correlation exists between the two sets of data. These results show that the standard (OSHA) optical fibre counts may be only indicative of the total asbestos exposure.

Asbestos Exposure of Workmen

After the identification of chrysotile in the brake drum dusts, asbestos fibre exposure during maintenance and repair was determined by personal air sampling carried out at automobile repair shops,

taxi fleet repair shops and a municipal truck repair shop in New York City. Air sampling and analytical methods for the determination of fibre concentrations were in accordance with the OSHA techniques (Bayer *et al.* 1975). Present regulations of OSHA prohibit asbestos concentrations of 5 fibres per millilitre (f/ml) or greater, longer than $5\mu\text{m}$ as a time-weighted average, and concentrations above 2 f/ml will be illegal after July 1976. Peak concentrations or maximum excursions of 10 f/ml are permitted by the regulations.

In brake lining inspection and repair, the wheel

is removed from the vehicle and the brake is manually removed from the wheel by means of a jet of compressed air. This situation exists in the shops (Castle 1976). Table 2 shows that the breathing zone compressed air blow-off gradient, diminishes from the operation to 22 m from such a concentration

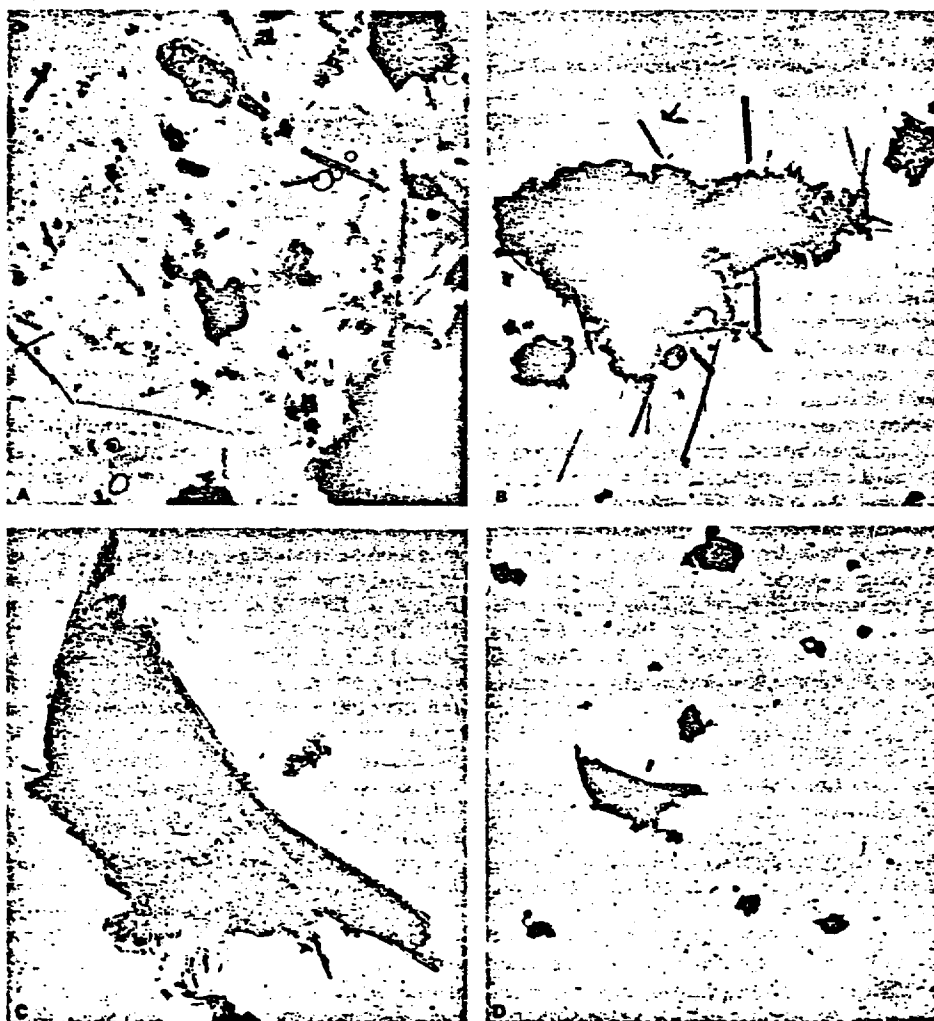


Fig 1 Electron photomicrographs of brake drum dusts, taken at various magnifications. A, the numerous chrysotile fibrils have average lengths of $0.4\mu\text{m}$ or less ($\times 30\,000$). B, large numbers of chrysotile fibres imbedded in, and protruding from, opaque particle, probably pyrolyzed phenolic resin binder ($\times 30\,000$). C, large chrysotile fibre bundle ($\times 45\,000$). D, large particle in left centre of photograph is the same as in C, but cannot be identified at low magnification ($\times 5400$).

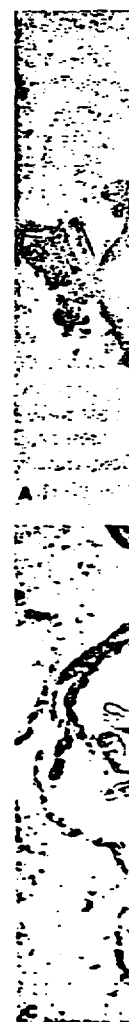


Fig 2 Electron photomicrograph associated with opaque particle.

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is removed from the axle and loose dust is commonly removed from the drum and back plates by means of a jet of compressed air. A survey of 220 garages in Baltimore and Washington, DC has shown that this is the method of choice in 80% of the shops (Castleman *et al.* 1975). A similar situation exists in New York City. The data in Table 2 show that fibre concentrations are high in the breathing zone of the operator during compressed air blowing. An asbestos concentration gradient, diminishing with time and distance away from the operation, appears to occur. Persons up to 22 m from such activity are exposed to measurable concentrations of asbestos.

Personal air sampling was also conducted at New York City Department of Sanitation where truck brakes are repaired. Used linings are salvaged by machine grinding to remove dirt and grease from the surface. New linings are bevelled by grinding to reduce noise and improve break-in. Accordingly, these studies relate to levels of asbestos exposure which may be experienced by workers engaged in brake lining manufacturing. Table 2 shows that fibre concentrations experienced during grinding ranged from 1.7 to 7.0 f/ml of air in the breathing zone of the operator. The background or area samples for this operation ranged from 1.2 to 0.2 f/ml, with a general decrease

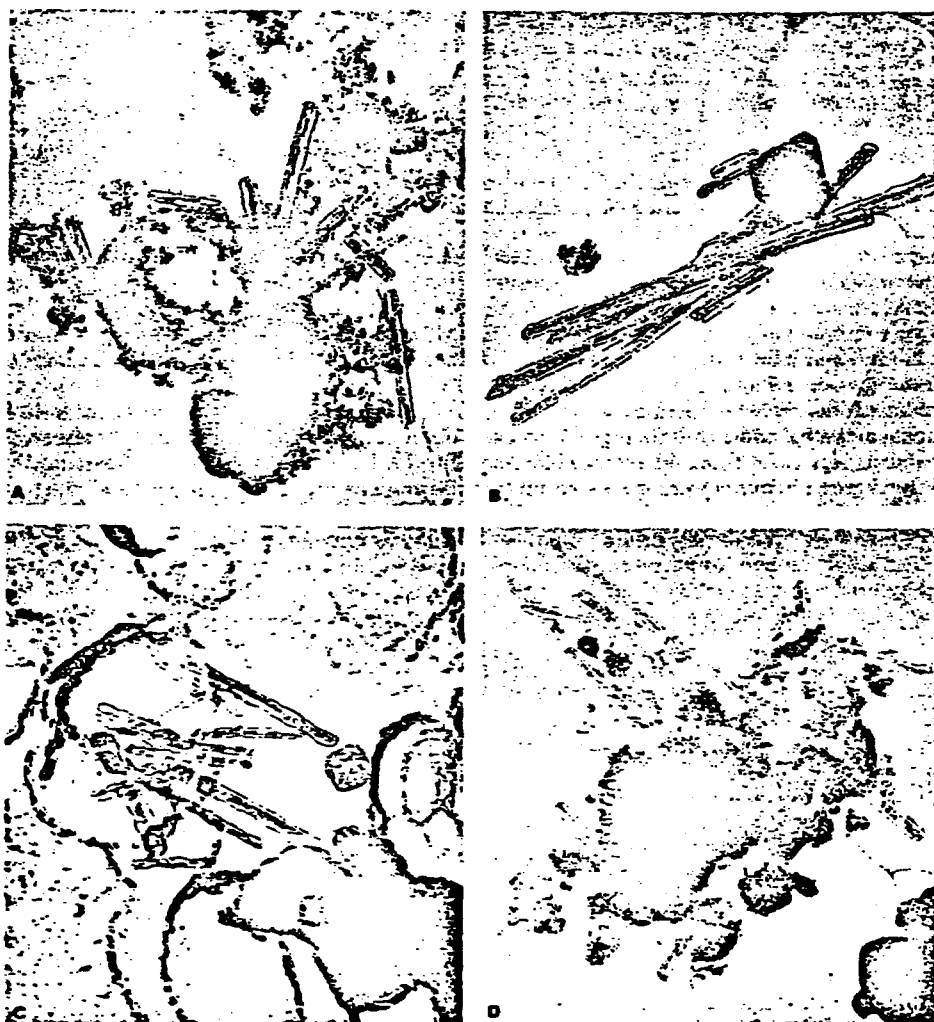


Fig 2 Electron photomicrographs of personal air samples taken during brake repair work. Clumps of chrysotile are associated with opaque particles of road dust and resin binders. A, B, $\times 60\ 000$. C, D, $\times 72\ 000$

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Table 2

Personal air samples, automobile and truck brake repair

	No. of samples	Peak fibre concentration (fibres per ml)	
		Mean	Range
<i>Automobile brake repair</i>			
Blowing dust from brake drums:			
Distance 1-1.5 m	4	15.0	6.6-29.4
Distance 1.5-3 m	3	3.3	2.0-4.2
Distance 3-6 m	2	1.6	0.3-4.8
Background (5 min after air jet blowing, distance 3.6-16 m)	2	0.2	0.1-0.2
Background (7-14 min after air jet blowing, distance 19.6-22.6 m)	2	0.1	0.1
	13		
<i>Truck brake repair</i>			
Renewing used linings by grinding (distance 1-1.5 m)	10	4.8	1.7-7.0
Background to grinding used linings:			
Distance 3.3 m	2	1.5	1.2-1.7
Distance 8.3 m	2	0.8	0.6-1.0
Distance 20.0 m	1		0.2
Bevelling new linings	4	37.3	23.7-72.0
Background to bevelling new linings:			
Distance 2.4 m	1		0.6
Distance 3.6 m	2	0.4	0.3-0.5
Distance 9.1 m	1		0.3
	23		

away from the operator. From six to ten other mechanics work within an area up to 20 m from this operation are exposed to asbestos as well. Since a person breathes about one cubic metre of air an hour, multiplication of the fibre concentrations by one million gives the number of fibres inhaled during this period. Fibre concentrations measured during bevelling of truck linings were as high as 72 f/ml and averaged about 37 f/ml. Background counts were measured up to 9.1 m away from this operation (0.3 f/ml). Fibre concentrations measured during drilling holes for rivets and grinding ranged from 0.3 to 29.2 f/ml, as reported by Boillat & Lob (1973). Four of the nine values exceeded 5 f/ml.

Conclusions

The existence of significant exposure during brake servicing operations necessitates the following measures:

- (1) Implementation of industrial hygiene procedures to control exposure.
- (2) Clinical studies of garage mechanics to determine evidence of asbestos-related disease.
- (3) Epidemiological studies of the mortality experience of exposed workers.

In addition, the entire variety of dusts and other materials present in brake repair work should be characterized in order to determine its disease potential, especially silica and lead compounds.

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Neurotoxic Potential of Certain Aliphatic Amines

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During the summer of 1972, a peripheral neuropathy group of employees at a printing plant in Ohio, USA, was characterized by sensory loss symmetrically in the feet (Allen et al, 1972). The affected individuals had worked in a solvent where colourants, were applied to coated fabrics. The process required the use of containing methyl isobutylketone (MIBK) was gradually replaced by 1972 to replace the solvent which was in its maximum first case of peripheral neuropathy thereafter. The solvent was replaced with other isolates and individuals chronically exposed suggested that this could be toxic. MBK produced

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Neurotoxic Properties of Certain Aliphatic Hexacarbons

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Bronx, New York 10461, USA)

During the summer of 1973 an outbreak of peripheral neuropathy developed among a large group of employees of a fabric manufacturing plant in Ohio, USA (Billmaier *et al.* 1974). The disease was characterized by distal weakness and sensory loss symmetrically in both the hands and the feet (Allen *et al.* 1975). The most severely affected individuals worked in the printing department where colouring inks, dissolved in volatile solvents, were applied to the surfaces of plastic coated fabrics. For several years the printing process required the use of a 9:1 solvent mixture containing methylethylketone (MEK) and methylisobutylketone (MIBK). Methyl-*n*-butylketone (MBK) was gradually introduced in the summer of 1972 to replace the MIBK. Methyl-*n*-butylketone was in its maximal use by December 1972 and the first case of peripheral neuropathy occurred shortly thereafter. The recent introduction of MBK into the printing department of the plant, coupled with other isolated outbreaks of neuropathy in individuals chronically exposed to MBK, suggested that this compound had neurotoxic properties. MBK produced peripheral neuropathy in

several species of experimental animal (Duckett *et al.* 1974, Mendell *et al.* 1974, Spencer, Schaumburg, Raleigh & Terhaar 1975). These studies demonstrated that prolonged intoxication by inhalation or subcutaneous injection caused the insidious development of symmetrical weakness first in the hindlimbs and later in the forelimbs. The first signs of peripheral neuropathy developed after 4 to 12 weeks of continuous inhalation of 200-600 parts/10⁶ of MBK, and after 12 to 16 weeks of intermittent inhalation of 1300 parts/10⁶ of MBK. The onset of MBK neuropathy was associated with a reduction in the sciatic nerve conduction velocity (Mendell *et al.* 1974), an indication of nerve damage also found in rats and monkeys inhaling 1000 or 100 parts/10⁶ MBK intermittently for periods of 3 and 8 months respectively (Johnson 1975), the figure of 100 parts/10⁶ being the recommended Threshold Limit Value in the United States. Recent studies have suggested that concurrent exposure to MEK and MBK will produce neuropathy more rapidly than in animals exposed to MBK alone (Saida *et al.* 1976). Methyl-ethylketone alone or MBK alone produce no neurotoxic effects (Spencer & Schaumburg 1976).

The purpose of the present paper is to emphasize the importance of chronic testing of potentially neurotoxic compounds in experimental animals, to describe the range of hexacarbon compounds which have been identified as neurotoxic agents and, finally, to characterize and illustrate the pathological basis for the onset of the nervous system disease. A total of seven hexacarbon compounds have been tested in this study (Table 1).

Table 1
Hexacarbon compounds tested

- (1) *n*-hexane CH₃CH₂CH₂CH₂CH₂CH₃
- (2) methyl-*n*-butylketone CH₃COCH₂CH₂CH₂CH₃
- (3) 2,5-hexanedione CH₃COCH₂CH₂COCH₃
- (4) 2,5-hexanediol CH₃CHOHCH₂CH₂CHOHCH₃
- (5) 2,4-hexanedione CH₃COCH₂COCH₂CH₃
- (6) 2,3-hexanedione CH₃COCOCH₂CH₂CH₃
- (7) 1,6-hexanediol HOCH₂CH₂CH₂CH₂CH₂CH₂OH

The first compound, *n*-hexane, an important solvent and a minor component of petrol, was indicted in several reports as a possible neurotoxic agent (Herskowitz *et al.* 1971, Korobkin *et al.* 1975). Rats were exposed continuously to atmospheric levels of 400 to 600 parts/10⁶ of *n*-hexane for up to five months, 500 parts/10⁶ being the US Threshold Limit Value for *n*-hexane (see also Schaumburg & Spencer 1976). The second compound, methyl-*n*-butylketone, the solvent implicated in the outbreak of neuropathy, was administered to cats by subcutaneous injection of 150 mg/kg twice daily for periods up to six months (see also Spencer & Schaumburg 1976). The third compound, 2,5-

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AIRBORNE ASBESTOS IN THE VICINITY OF A FREEWAY

J. ALSTE*, D. WATSON† and J. BAGG

Department of Industrial Science, University of Melbourne, Parkville, Victoria 3052, Australia

(First received 22 December 1975 and in final form 16 February 1976)

Abstract—Asbestos fibres taken from fresh or worn brake linings or collected from the atmosphere near a freeway were examined by electron microscopy and electron diffraction. The major effect of braking appears to be in separating bunches of fibres and reducing their average length but not in altering their crystal structure. The suggestion that gross changes in the crystal structure are brought about by heat generated during braking is not supported by this work. Airborne samples were collected at points where there was considerable braking and where there was only slight braking. At the point where slight braking took place the airborne concentration was very low and could not be satisfactorily measured. At the point where considerable braking occurred an estimate of $5 \times 10^5 \text{ m}^{-3}$ particles was determined, each particle consisting of a small bundle of fibres. The majority of particles had a maximum linear dimension $\leq 2 \mu\text{m}$.

INTRODUCTION

The concentration of asbestos fibres in the atmosphere may reach high levels in the immediate vicinity of mining the asbestos mineral or manufacturing asbestos products. It has been known for a long time that the inhalation of fibres at these concentrations is injurious to both man and animals (Merewether, 1930). A qualitative standard which has been proposed by the E.P.A. (*News Focus*, 1973) is that there should be no visible emissions during the handling and manufacture of asbestos products. One criterion for a recommended quantitative standard is that the concentration should not exceed $5 \times 10^6 \text{ fibres m}^{-3}$ of length $\leq 5 \mu\text{m}$ for a 30 y exposure and that this standard should become more rigorous after July 1976 becoming $2 \times 10^6 \text{ fibres m}^{-3}$ (NIOSH, 1972; U.S. Dept. Labor, 1972). British and West German proposals agree with the more rigorous standard suggested above (Schutz and Weitowitz, 1973). Extensive work has been carried out on the health of workers exposed in the industries producing airborne asbestos. Much less work has been carried out on the presence of asbestos in the atmosphere far away from any such industry. Asbestos was found in all samples taken from the atmosphere of several cities in Europe which did have an asbestos industry (Holt and Young, 1973). The asbestos was present chiefly as single fibres but a small fraction occurred as agglomerates. No quantitative estimate of concentration was made but compared to other suspended particulates it was small. Preliminary results for New York city showed concentrations ranging from 11 to 60 ng m^{-3} with dupli-

cate samples differing by a factor of 2-3 (Selikoff, 1972; Nicholson *et al.*, 1973). Asbestos was also found to be present in all 200 samples taken from the atmosphere of 49 cities in the U.S.A. (Selikoff, 1972).

The source of asbestos emissions in the absence of asbestos mining and industry is a matter of speculation but one strong possibility is from the brake linings of automobiles. These linings are subjected to considerable wear leading to the release of asbestos dust. In one careful study the release of asbestos was measured by surrounding the brake drum with a collector and capturing the total emission (Jacko *et al.*, 1973). A total emission of $17.8 \mu\text{g km}^{-1}$ for passenger vehicles and $54.8 \mu\text{g km}^{-1}$ travelled for light trucks were quoted as typical values. Not all this emission reached the atmosphere, some depositing upon the ground and some being retained by the brake drum. The fraction which became airborne was estimated to be 3.7% for passenger vehicles and 2.9% for trucks. This research also gave the expected result that heavy braking produced more emission than light braking. Although it is very difficult to convert these results into atmospheric concentrations clearly only very low concentrations would be anticipated.

Lynch (1968) examined the dust from brake linings and from the appearance of the fibres suggested that the crystal structure of the fibre was degraded by heat released during braking. Holt and Young (1973) found that fibres collected by them from the atmosphere showed very little evidence of loss of crystallinity, and, therefore, following Lynch's suggestion, concluded that building materials were a more likely source than brake linings.

The aim of the work reported here was to examine more closely the possible contribution that brake linings could make to the asbestos concentration in the atmosphere

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EXPERIMENTAL

A number of methods have been proposed for the estimation of asbestos particles in the atmosphere (Keenan and Kupel, 1968; Lane *et al.*, 1968; Gadsden *et al.*, 1970) but at the present time the only method of sufficient sensitivity and selectivity for the very low concentrations involved is the electron microscopy of samples collected on suitable filters. Atmospheric samples were collected on a Millipore filter (VSWP 047, 0.025 μm pore dia.) at an average flow rate of 0.6 l min^{-1} . A High-Volume sampler was modified by placing an aluminium face-plate containing a small tube over the inlet to the sampler. A Millipore filter holder was connected by a plastic tube with a rotameter interposed to the small tube on the face plate. Samples were taken at three locations, (i) on the roof of the Department of Industrial Science, University of Melbourne, 10 m above street level and 30 m from the nearest traffic, (ii) outside the same building 0.8 m above street level, (iii) at the exit of the S.E. end of the Tullamarine freeway, 0.8 m above ground level. This last sampling point was 30 m from the position where brakes were applied to reduce the speed of vehicles from approx. 100 to 60 km h^{-1} . The total number of vehicles passing all three locations during the total sampling period was very similar and the major difference was the absence, locations (i and ii), or presence, Location (iii), of extensive braking. The sampling period was from 08:00–17:00 h during November 1973; the weather was fine with only light winds over this period. After the samples had been collected the Millipore filters were coated with a carbon film, approx. 20 nm thickness, and then five small pieces (1.5 $\times$ 1.5 mm) cut out at random. Each small section was placed on a copper grid, carbon film facing down, and the membrane material removed by dissolution in acetone. Electron micrographs and diffraction patterns were obtained from these specimens using a Phillips EM 200 microscope at 50 kV. The electron diffraction patterns were calibrated by evaporating aluminium on to the copper grid and by comparison interplanar spacings, $d(hkl)$, could be deter-

mined. Samples of fresh and worn brake drum linings were obtained from an automobile repair shop and were crushed gently in a mortar and pestle with a few ml of chloroform. An electron microscope grid covered with a smooth film of evaporated carbon was then dipped into this suspension and the chloroform allowed to evaporate.

RESULTS AND DISCUSSION

Figures 1 and 2 show electron micrographs and diffraction patterns from a sample prepared from a fresh brake lining. The characteristic structure of chrysotile asbestos, long filaments each of which is a hollow cylinder (McCrone and Delly, 1973), is clearly visible in this micrograph. The electron diffraction patterns of chrysotile have been determined and indexed by Yada (1967, 1971). In Table 1 the interplanar spacings determined from the pattern of fresh brake linings are compared to Yada's values and the agreement is seen to be excellent.

Figures 3 and 4 show results for the dust from worn brake linings. The average length appears to be shorter than in the fresh lining but the hollow cylindrical structure is still obvious. The diffraction pattern still consists of well-defined rings and the interplanar spacings derived from these rings are in good agreement with Yada's values (see Table 1). There was no indication from the diffraction pattern of the presence of forsterite, the name given to thermally-degraded asbestos. It appears that for the wear this lining had received no significant changes in the crystal structure due to excessive heating had taken place. Temperatures within brake drums may reach 873 K under racing conditions with severe and repeated braking

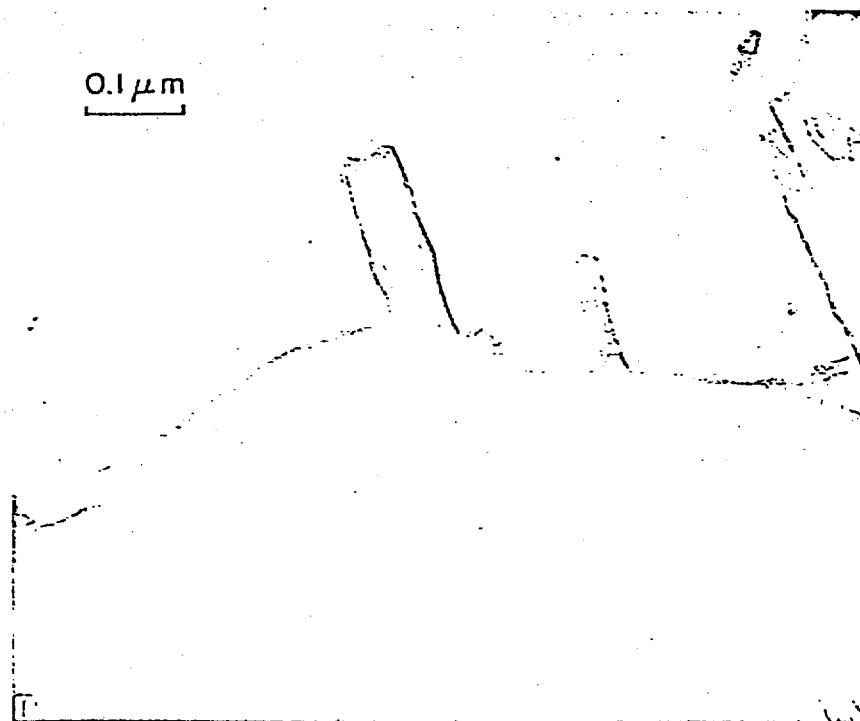


Fig. 1. Dust sample from crushed new brake linings.

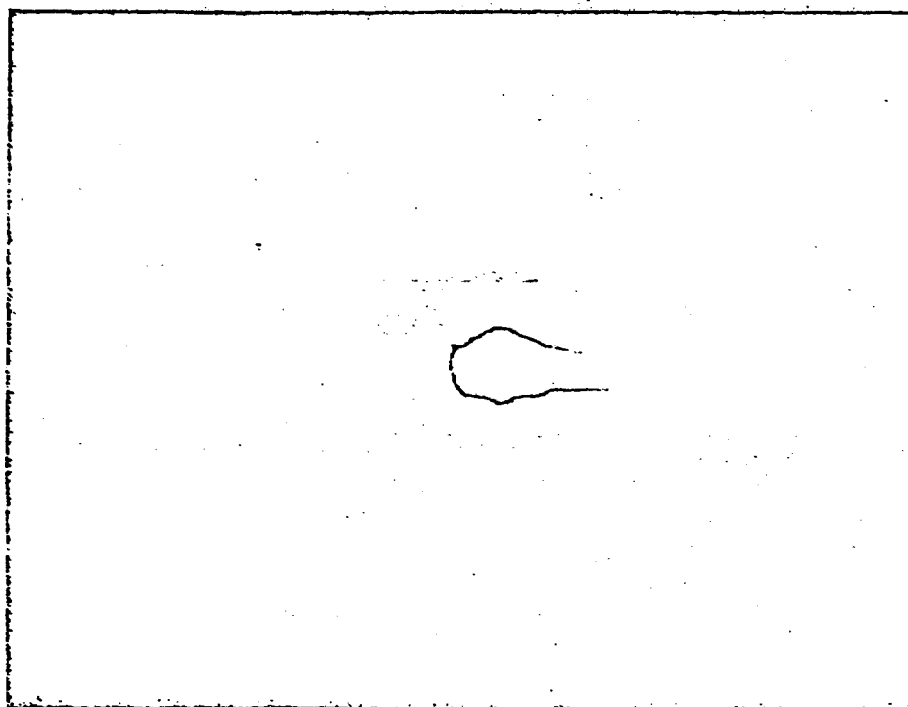


Fig. 2. Diffraction pattern from sample in Fig. 1.

but would be expected to be very much lower under normal city driving. Chrysotile has been shown to maintain its crystal structure until temperatures in excess of 800 K are reached (Yada, 1971; Robock and Klosterkotter, 1973). The observations on the worn brake drums are then consistent with the likely temperatures reached and the known thermal behaviour of chrysotile. Yada (1967, 1971) has shown that electron bombardment inside the electron microscope can lead to production of amorphous material in the fibres and, therefore, excessive exposure during examination should be avoided.

Table 1. Values of $d(hkl)$ for chrysotile and brake linings. $\text{nm} \times 10^{-1}$

Values for chrysotile (Yada, 1967, 1971)	Fresh brake lining	Worn brake lining	Plane (hkl)
7.30	7.30	7.21	(001)
4.69		4.60	(110)
4.50	4.48		(020)
3.65	3.62	3.67	(002)
2.70		2.67	(200)
2.60	2.62		(130)
2.51	2.52	2.56	(201)
2.43	2.45	2.47	(003)
2.30			(220)
2.25	2.24	2.26	(040)
2.15	2.13	2.10	(202)
1.82			(004)
1.80	1.79	1.75	(050)
1.53	1.54	1.55	(330)
1.46			(005)
1.35	1.32	1.33	(400)
1.21	1.21	1.19	(060)

Samples taken either on the roof or at ground level near the Department of Industrial Science contained very low concentrations of asbestos fibres (Fig. 5). Although the rings in the diffraction pattern (Fig. 6) are more diffuse than from fresh linings the interplanar spacings, shown in Table 2, again match both the values for fresh linings and Yada's values. Although the comparison in Table 2 enabled the presence of asbestos to be deduced, no attempt was made to estimate the atmospheric concentration because of its very low value.

Samples taken at the exit from the freeway, however, contained a much higher concentration of asbestos particles (Figs. 7 and 8) estimated at an average of 5×10^5 particles m^{-3} over the 9 h sampling period. The general appearance of the fibre clusters and the presence of other material is very similar to that observed for the worn brake lining dust. Again the diffraction patterns do not show significant amounts of amorphous material and match Yada's values (Table 2).

Table 2. Values of $d(hkl)$ for chrysotile and airborne asbestos. $\text{nm} \times 10^{-1}$

Values for chrysotile (Yada, 1967, 1971) (hkl)	Dept. Industrial Science	Tullamarine freeway exit
3.65 (002)	3.65	3.60
2.15 (202)	2.20	2.15
1.80 (50)	1.80	1.75
1.21 (060)	1.28	1.18

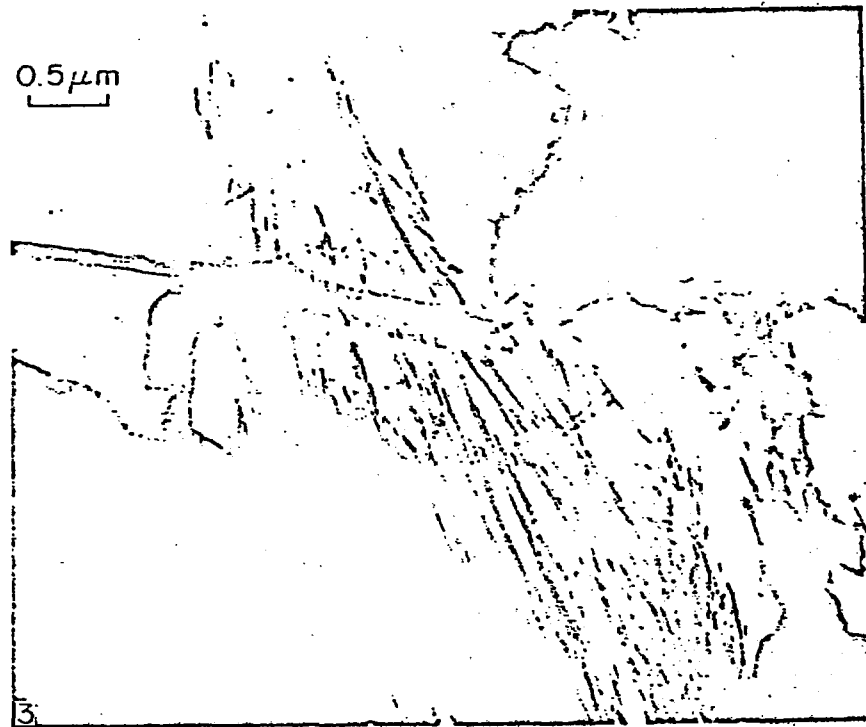


Fig. 3. Dust sample from worn brake lining.

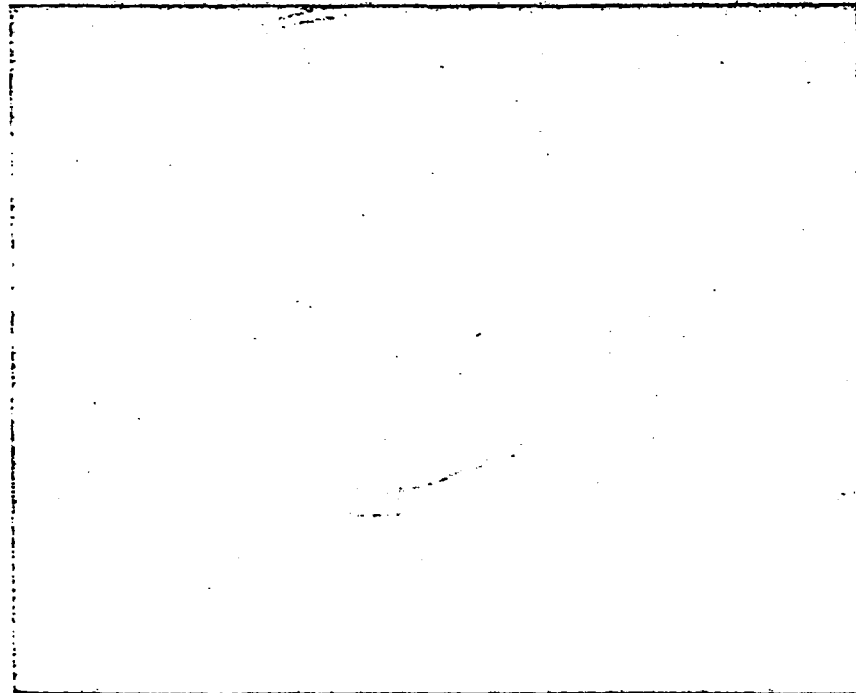


Fig. 4. Diffraction pattern from sample in Fig. 3.

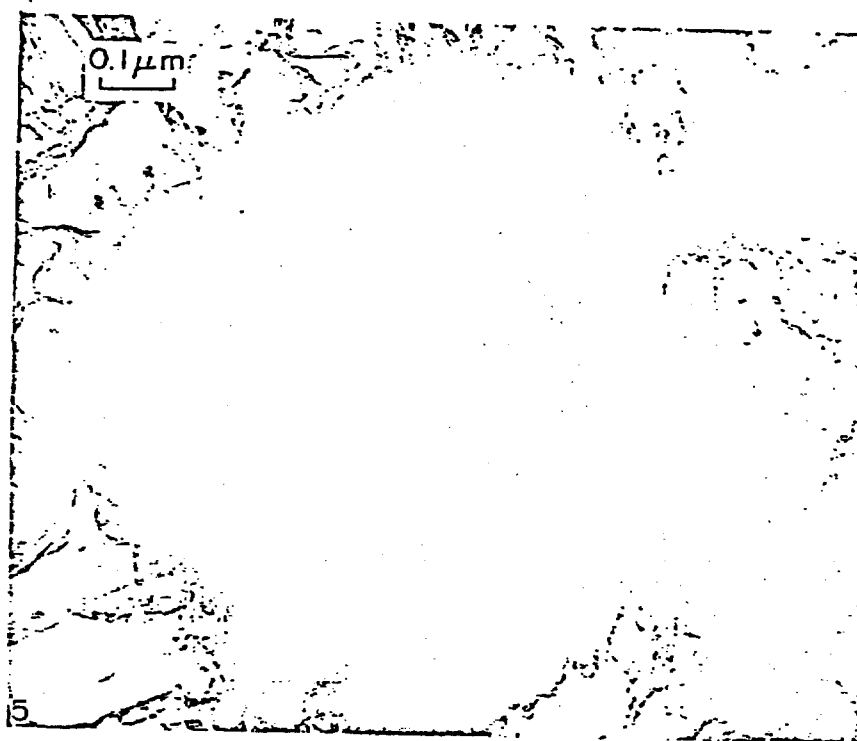


Fig. 5. Atmospheric sample collected 0.8 m above ground level at Melbourne University.

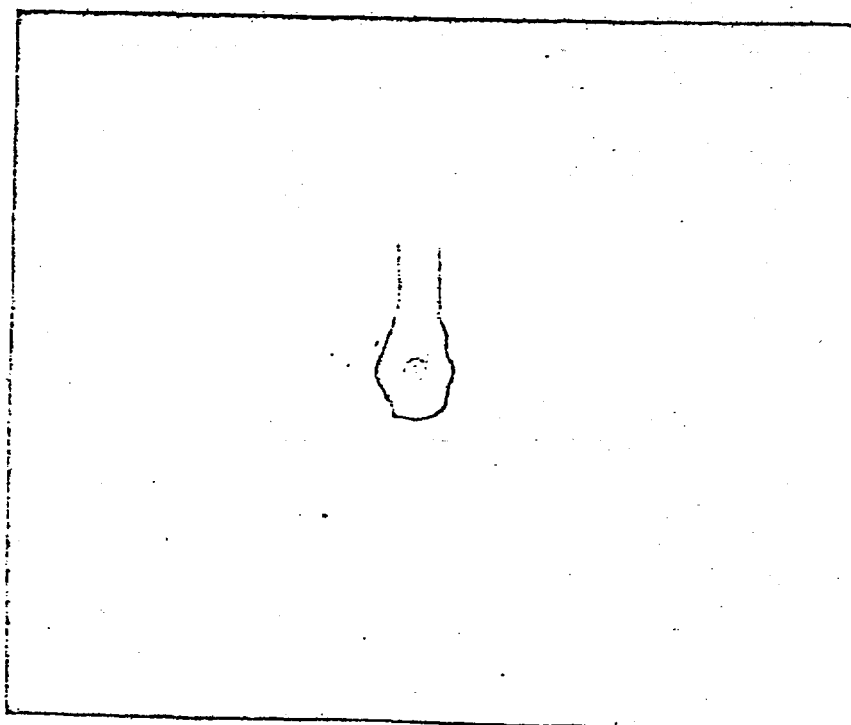


Fig. 6. Diffraction pattern from sample in Fig. 5.

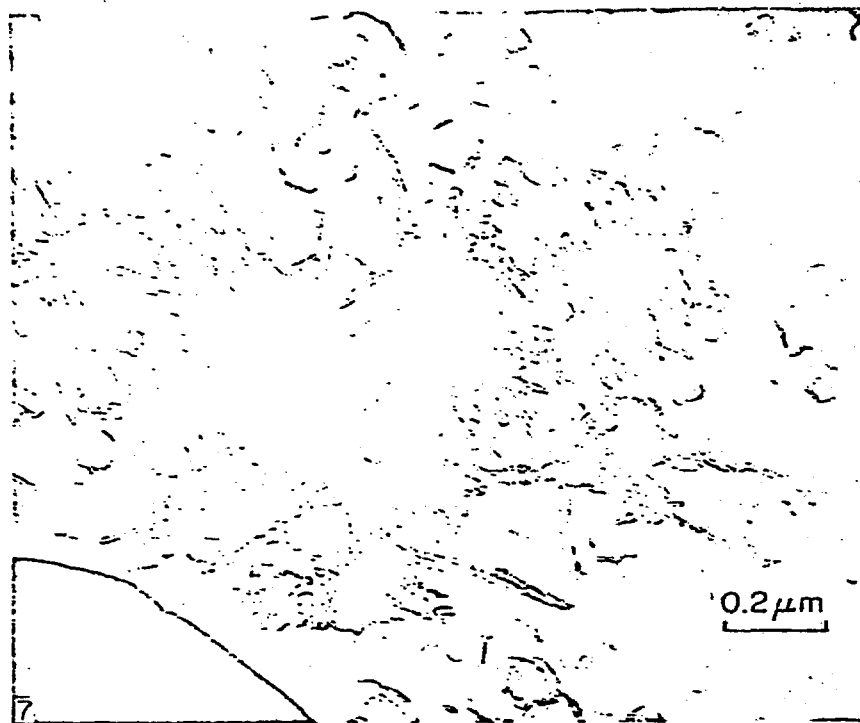


Fig. 7. Atmospheric sample collected 0.8 m above ground level at the exit of Tullamarine Freeway.

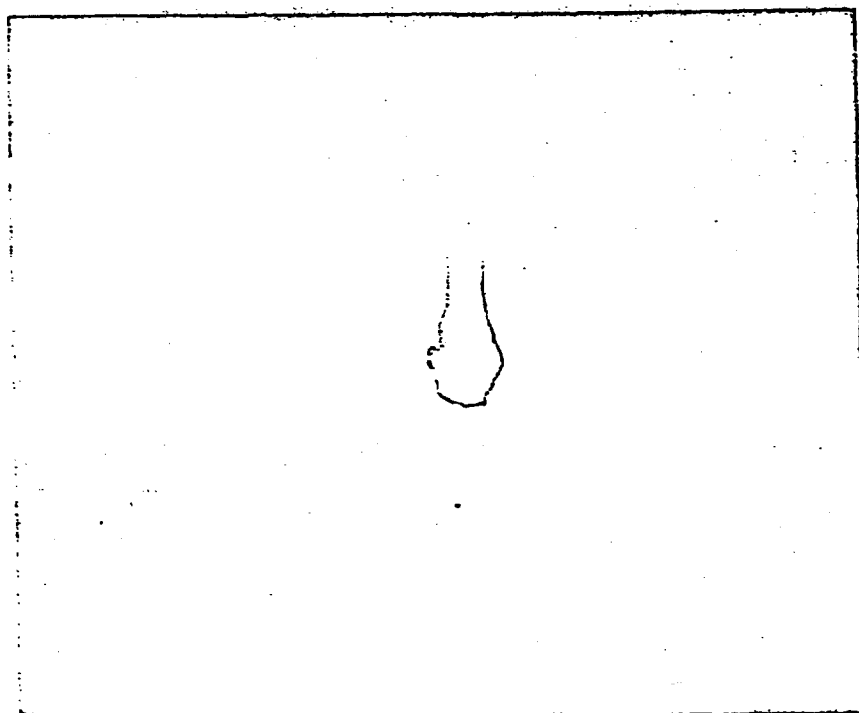


Fig. 8. Diffraction pattern from sample in Fig. 7.

The particles consisted of small bundles of fibres together with other material which may have contained binder present in brake linings. Another possible source for this amorphous material consistent with a location where braking occurred is wear from tyres. Measurements by other workers (Pierson and Brachaczek, 1975) have shown concentrations of airborne debris from tyre wear from 0.05 to $2.2 \mu\text{g m}^{-3}$. The number of fibres in the bundle and their size varied considerably and no attempt was made to count individual number of fibres. The majority of bundles did have a maximum dimension $\leq 2 \mu\text{m}$. Although these results are limited and of a preliminary nature the following points can be made:

(i) Electron diffraction has proved to be a method of great sensitivity in the identification of asbestos particles suitable for the low concentrations found in atmospheric samples.

(ii) Asbestos fibres from brake linings operated under normal conditions have the same crystal structure as asbestos from other sources. The absence of thermally-degraded material cannot, therefore, be taken as evidence that brakes have not contributed to a particular sample.

(iii) The results from the samples collected at the freeway exit suggest that emissions from brakes can become airborne. The concentrations reached are very low, below the recommended exposure standard (NIOSH, 1972; U.S. Dept. Labor, 1972), and consistent with the prediction by other workers that only a small fraction of the total dust formed becomes airborne (Jacko, *et al.*, 1973).

Acknowledgements—The authors would like to thank Dr. J. V. Sanders, C.S.I.R.O., Division of Tribophysics, University of Melbourne, for considerable assistance and use of electron microscope facilities. One of us, J. Alste, wishes to thank A.C.I. Fibreglass for support during this work.

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NILFISK
OF AMERICA, INC.

201 KING MANOR DRIVE, KING OF PRUSSIA, PA 19406 (215) 277-3900



April 20, 1979

Mr. I. H. Weaver
Corporate Director Envir. Control
RAYBESTOS-MANHATTAN
123 E. Stiegel St.
Manheim PA 17545

Dear Ike:

I thought you would be interested in the enclosed report
from Dr. Arthur Rohl of Mt. Sinai Hospital Medical Center.

We have been anxiously awaiting the results of Dr. Rohl's
tests and needless to say, are very pleased with the report
and what he has to say about NILFISK'S ASBESTO-CLENE systems.

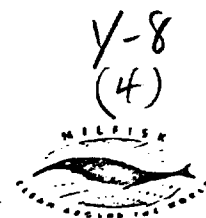
Sincerely,

NILFISK OF AMERICA, INC.

Robert S. Magdelain
Robert S. Magdelain
President

RSM:ds

Enclosure



FMSI 04756



IN THE CITY OF NEW YORK
COUNTY OF NEW YORK

THE MOUNT SINAI MEDICAL CENTER

ONE GUSTAVE L. LEVY PLACE • NEW YORK, N.Y. 10029

RECEIVED

APR 16 1979

NILFISK OF AMERICA, INC.

Mount Sinai School of Medicine • The Mount Sinai Hospital PER _____

April 11, 1979

The Mount Sinai School of Medicine
Cummings Basic Sciences Building
1275 York Ave.
New York, N.Y. 10021
(212) 241-6171

Mr. Robert S. Magdelain, President
Nilfisk of America, Inc.
201 King Manor Drive
King of Prussia, Pennsylvania 19406

Dear Mr. Magdelain:

This will report the results of air sampling tests conducted, in October 1978, to determine chrysotile asbestos concentrations during brake repair work.

Our major objective was to determine the efficiency of the Nilfisk Asbestos System utilizing HEPA filters, particularly with regard to submicroscopic asbestos fibers. Studies conducted in our Laboratory and elsewhere have demonstrated that free asbestos fibers present in brake drum dusts are predominantly shorter than 5µm in length. In particular, it was found that about 75% of the fibers in such dusts were less than 0.3µm in length, as determined by transmission electron microscopy. Thus, the optical microscopic technique used by OSHA for determining asbestos levels in workplaces (in which only fibers 5µm or longer are counted) would overlook a large number of asbestos fibers in air samples. That is, the total asbestos exposure in terms of fiber number, mass and surface area would be significantly greater than the levels determined using the OSHA fiber-counting method.

Therefore, it was of considerable interest to us to have an opportunity to test the efficiency of the Nilfisk Asbesto-Clene System. To do this personal air sampling was carried out on the exhaust of a HEPA-filtered vacuum dust collector and, simultaneously, on a garage mechanic cleaning a brake drum with the Nilfisk brake encapsulation cylinder. Three such tests were made. Background air samples, also using personal air pumps, were taken.

For each of the tests, a sample of settled dust was taken from the brake drum. The dusts were analyzed by x-ray diffraction in the step-scan mode to quantitatively determine asbestos contents, using a technique previously published. Asbestos was found in all three samples, ranging from 2.5% to 4.5% by weight.

The membrane filters were analyzed by both transmission electron microscopy (X25,000) and by the standard OSHA fiber-counting technique, employing phase contrast optical microscopy. The results are as follows:

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Mr. Robert S. Magdelain, President
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<u>Sample</u>	<u>Description</u>	<u>Nanograms/cu meter</u> <u>(electron microscopy)</u>	<u>Fibers/milliliter</u> <u>(optical microscopy)</u>
<u>TEST #1</u>			
N-1	Background (70 feet from operator)	400	0
N-2	Operator (breathing zone - 6 ft. from dust collector)	0	0
N-3	Dust collector (HEPA-filtered vacuum)	0	0
<u>TEST #2</u>			
N-4	Background (70 feet from operator)	615	0.12
N-5	Dust collector (HEPA-filtered vacuum)	0	0
N-6	Operator (breathing zone - 6 ft. from dust collector)	59,000	0.5
<u>TEST #3</u>			
N-4	Background (same as in Test #2)	615	0.12
N-7	Operator (breathing zone - 6 ft. from dust collector)	0	0
N-8	Dust collector (HEPA-filtered vacuum)	0	0

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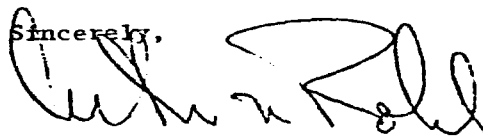
Remarks and Conclusions:

The tests demonstrate that asbestos levels are virtually eliminated by the use of a system employing brake encapsulation device connected to a HEPA-filtered vacuum dust collector. Without the use of such equipment, fiber concentrations during compressed air jet-blowing of brake drums ranged from 6.6 to 29.8 fibers/milliliter. However, when the Asbesto-Clene System was used, fiber concentrations on both the mechanic and dust collector exhaust were not detected, as verified by transmission electron microscopy. An important exception to this is observed in Test #2, the sample taken on the operator. Prior to this test, this mechanic had worked on brake jobs without using the Asbesto-Clene System and without changing his work clothes. This exposure had resulted in contamination of his clothes, reflected in the high residual asbestos concentration of 59,000 nanograms/cubic meter and 0.5 fibers/milliliter. In contrast, the operator in Test #1 and Test #3 wore clean coveralls. This points up the need to adhere to the OSHA regulations concerning special clothing, change rooms, etc. to minimize contamination.

The background asbestos measurements, of 400 and 615 nanograms/cubic meter, are consistent with other background measurements taken during brake repair work. They are the result of residual contamination of the garage by asbestos.

This study has been unique and fortunate in two respects; first because of the great interest and importance of determining chrysotile asbestos levels in such circumstances. The data indicate that the Asbesto-Clene System represents an outstanding advancement in industrial hygiene procedures to control asbestos exposure. It has also been a pleasure to work with you in preparing and conducting these tests. If there are any questions regarding the results or conclusions in this report, please do not hesitate to contact me.

Sincerely,



Arthur N. Rohl, Ph.D.
Environmental Sciences Laboratory

ANR:jm

FMSI 04759

Technical Correspondence

Asbestos Health Hazards

There have been a lot of stories lately about the hazards of breathing airborne asbestos fibers. Is asbestos still used in brake linings? It is common practice to blow the brake dust out with compressed air to clean the brakes. Does this present a health hazard? Is there a risk to motorists from brake dust in the air near streets and highways?

Ken Bohn
Louisville, Kentucky

Asbestos is the name for a family of silicate minerals that occur in nature in the form of ultra-fine, brittle fibers. Asbestos has a high resistance to heat and is still commonly used as insulation or molded (with other materials) into clutch and brake linings. In molded form asbestos is safe but when the fibers are released (from wear or from cutting or sanding the molded material), they present

an insidious health hazard. The fibers are so brittle that when they are broken, they tend to disintegrate into particles too small to be seen (an electron microscope is needed to see the smallest, most harmful particles). According to current medical research, usually there is no sign of asbestos-related disease for 10-35 years after the first exposure to asbestos particles. After this incubation period, the fibers can cause asbestosis, a disease characterized by severe scarring of the lung tissue, and mesothelioma, a cancer of the lining of the chest and abdomen. Asbestosis usually doesn't kill directly. Its victims generally succumb to related respiratory infections such as bronchitis or pneumonia. Exposure to asbestos fibers also greatly increases the risk of cancer of the lungs and esophagus, stomach, kidneys and larynx. Cases have been found where family members of workers exposed to asbestos fibers developed asbestos-related diseases just

from exposure to asbestos fibers on the worker's shoes and clothing.

Motorists and pedestrians have little to fear from inhaling brake dust. There is some brake dust in the air near streets and highways, but the number of particles is very small and they tend to settle out of the air, so the overall risk is virtually nonexistent.

To reduce the risk of asbestos-related diseases, avoid contact with asbestos particles, especially airborne particles. It's usually a good practice to clean any component before reassembly, but with brakes and clutches, it's better to leave the brake or clutch dust in place, where it does no harm, rather than to use compressed air to blow it out and risk inhaling the asbestos fibers. If you must clean the parts, use a vacuum system or rinse the parts in solvent and wear disposable gloves. Clutch or brake linings shouldn't be allowed to soak in the solvent, as this can damage the lining material. Discard the used solvent and wash your hands immediately so you don't spread the particles around. To cut or sand clutch or brake linings, use a ventilation system designed to suck in the asbestos dust before it can be inhaled and wear a dust or paint mask. To clean brake dust from the wheels, use a detergent solution and rinse with a hose or use a high-pressure cleaner at a self-service car wash.

Information on health risks associated with asbestos exposure is available from
NATIONAL CANCER INSTITUTE
BETHESDA MD 20014.

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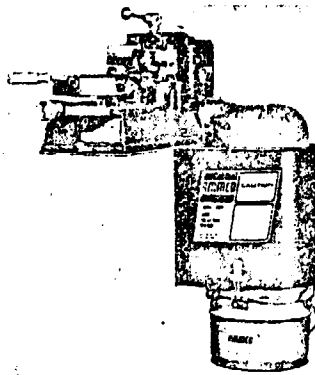
Know and understand the law - OSHA will soon be around

... asbestos is a danger to your employees

Last month, we introduced the proposed changes in the asbestos regulations and briefly outlined some of the standards your shop must meet to obey them. This month, we will take a closer look at some of the specific standards affecting your business, show how much danger is involved in handling asbestos and present some of the solutions parts and equipment manufacturers have developed.

When the 1974 asbestos inhalation law went into effect, most of the concern was for those employees involved in milling, fabrication and construction

A dust collection system designed for use with Ammco Tools, Inc.'s brake shoe grinders (Model 8925) efficiently collects, contains and disposes of asbestos dust ground off brake shoes, according to the company. No external power source is required, as a built-in suction fan pulls dust from the surface of the brake shoe and deposits it in a sealable disposable plastic bag. Once installed, the brake shoe grinder is said to meet or exceed Federal Clean Air Standards set by the OSHA Act of 1970.



industries (the miners were under another law). Of the nearly one million

Use of the common sense NIOSH guidelines will mean greater shop safety and could help you pass OSHA industrial hygiene inspection.

tons of asbestos "consumed" in the United States in 1972, approximately 77% was used in the construction industry.

However, further statistics reveal that only 500,000 workers are exposed to asbestos in mining, milling, fabrication and construction. Compare that number with the nearly one million American workers exposed to asbestos while installing and/or maintaining clutch and brake linings! A smaller percentage of the total asbestos is consumed but a larger percentage of America's work force is exposed.

But how serious is the exposure? A 1975 study done by Dr. W.J. Nicholson of Mt. Sinai Hospital detailed in a paper entitled "Asbestos Exposure During Brake Lining Maintenance and Repair" reveals some interesting statistics.

Before studies were undertaken, it was thought that the heat involved during the use of brakes caused a chemical breakdown, transforming the asbestos in the linings into a relatively harmless dust. The data presented in the paper indicates that workers engaged in car and truck brake service are exposed to potentially hazardous levels of airborne asbestos dust.

Specific brake servicing operations studied included blow-out of automobile brake assemblies, grinding of used truck brake linings and bevelling of new truck brake linings. Average peak asbestos air concentrations for these three activities based on personal samples taken within 10 feet of the operator were, respectively, 10.5, 3.75 and 37.3 fibers (greater than five microns in length) per cubic centimeter, up to 19 times worse than the recommended limit.

The study concluded that "during brake lining maintenance and repair, workmen in garages, service stations and brake repair shops are exposed to asbestos and thus may be subject to serious cancer risk. Others, at some distance from the repair work, (including those who are within 75 feet) are perhaps subject to the same hazard."

This study, and others that have been undertaken, has established in the scientific community a basis for studying the extent of asbestos-related disease in brake servicing personnel. A recent review of scientific literature, quoted in an ASIA news bulletin, states that "the association between asbestos exposure and [tumors of the chest and abdominal membranes] has revealed at least four cases of these rare tumors in persons who were employed in jobs involving automobile brake servicing." (Researchers have just begun to pinpoint this industry. Other related cases are expected to be found.)

Now that the scientific community and the federal government are convinced of the risk involved in brake servicing, it is time for the individual shop owner to comply with the standards established by the Dept. of HEW and stated in the Airborne Asbestos regulations.

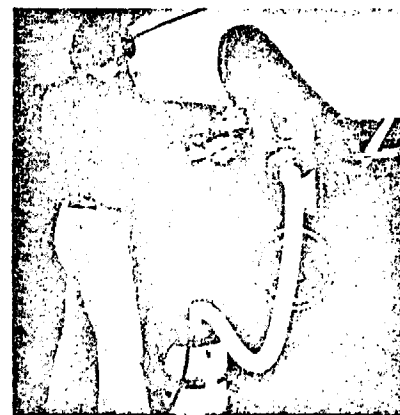
The law states that airborne asbestos fibers must be below a certain count

per cubic centimeter. Specifically, the Federal Register states "The 8-hour time-weighted average airborne concentrations of asbestos fibers to which any employee may be exposed shall not exceed two fibers, longer than five micron, per cubic centimeter of air."

The measurement is done by using a membrane filter method with an electronic microscope costing between \$500-\$1,000. Obviously, this is too costly for most brake shops. Some insurance companies will undertake this measurement for their accounts, providing the insurance company has an industrial hygiene division. Also, some state OSHA offices will help.

Regardless who does it, the employer is responsible for taking the measurement. An explanation of the membrane filter method (which is the only acceptable method according to OSHA) can be found in the Asbestos Information

The Brake-O-Vac brake assembly cleaner has been redesigned by Per-Lux, Inc., to meet OSHA requirements by attaching the unit to an approved shop vacuum. When attached to a standard air hose, dust, asbestos and other foreign matter can be vacuumed off brake assemblies in seconds. Automatic or manual models, plus quick-change adapters from 9 in. to 12 in., are available.

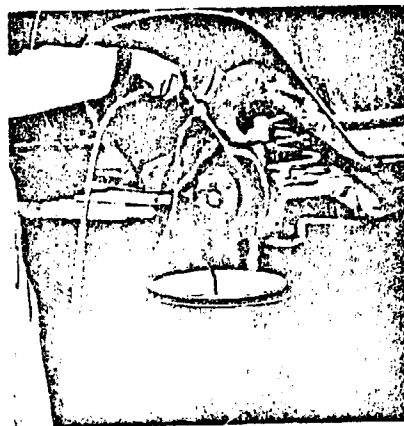


Association's "Recommended Work Practices: Fabrication and Use of Asbestos Friction Materials." It takes 11 complicated pages to explain the procedure.

A toll-free call to OSHA's Chicago office revealed that the industrial hygiene inspectors will look favorably on indications of voluntary compliance. (The Chicago office is quite willing to answer any questions on this and any other OSHA regulations. The toll-free number is: 1-800-621-0523).

The National Institute for Occupational Safety and Health has suggested the following procedures for asbestos brake and clutch servicing in order to reduce exposures:

Model 1250 brake assembly washer introduced by Ammco permits solvent washing of brake assemblies and eliminates the practice of air-blasting asbestos particles and dust around the shop. The specially designed gun, which requires shop air pressure, delivers a properly atomized stream of solvent without misting or waste. The solvent returns to the sump through the perforated parts pan for recirculation. As parts are removed from the brake assembly, they are allowed to drop into the perforated parts pan where they are retained until reused or discarded.



- If possible, an area should be designated for all brake and clutch repairs. Entrances should be posted with warning sign saying: "Asbestos dust hazard. Avoid breathing dust. Wear assigned protective equipment. Do not remain in area unless your work requires it. Breathing asbestos dust may cause asbestosis and cancer."

- During brake servicing, an air purifying respirator, either single use or with replaceable particulate filter(s), as approved by the Mining Enforcement and Safety Administration of NIOSH, will be worn during all procedures starting with the removal of the wheels and including reassembly. Such a respirator should also be worn during all clutch procedures from removal to installation

Tempo Products Co. offers this brake/clutch service vacuum (Model AB-7515) for dry recovery of asbestos fibers. The vacuum is equipped with a four-stage filtration system with secondary fail-safe protection that is said to assure maximum asbestos filter entrapment. Each unit includes complete instructions and all elements necessary for the safe collection and disposal of asbestos fibers. According to the manufacturer, it has been certified to comply with current regulations by an environmental laboratory when used as instructed.



BRAKE AND FRONT END

of a new assembly.

- Dust should first be cleaned from brake drums, brake backing plates, brake assemblies and clutch assemblies using an industrial type vacuum cleaner equipped with a high efficiency filter system. After vacuum cleaning, any remaining dust shall be removed using a rag soaked in water and wrung until nearly dry. Under no circumstances should compressed air or dry brushing be used for cleaning.

- During arcing and riveting operations, respirator should also be worn. Grinding (arcing) machines should be provided with local exhaust ventilation such that worker exposures maintained at least below the 1976 asbestos standard.

- Industrial vacuum cleaner bags containing asbestos dust and cloths used for wiping brake and clutch assemblies should be sealed in plastic bags and labeled with the following warning label printed in letters of sufficient size and contrast to be readily visible and legible, "Caution, contains asbestos fibers. Avoid breathing dust. Breathing asbestos dust may cause asbestosis and cancer."

- All floor cleaning in areas where brakes and clutches are repaired should be done with a high efficiency industrial vacuum cleaner.

- Although adherence to the above procedures should minimize any contamination of work clothing, appropriate portions of the OSHA asbestos regulations concerning special clothing, change rooms, etc. should be followed.

Compliance to this law will mean not only a safer shop for your employees but it will mean a cleaner and neater shop. Also, be sure your employees understand the severity of this problem so that compliance procedures become standard operating methods in your shop.

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