Table 1

Chrysotile asbestos content of brake drum dusts

		X-ray diffraction (step-scan)			*Transmission electron microscopy*
	No. of samples	*No. positive*	*Weight percent Mean*	*Weight percent Range*	*No. positive*
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

● 1 sample possibly positive

properties consistent with chrysotile, been observed with this technique.

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 demonstrated 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

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