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Herewith a copy of "Asbestos Dust Exposure During Brake Repair" by K. Rödelsperger et al, American Journal of Industrial Medicine 10: 63-72 (1986)

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Asbestos Dust Exposure During Brake Repair

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About 10,000 tons of chrysotile per year are used in the Federal Republic of Germany for the production of friction materials. During brake repair an unknown number of approximately 300,000 mechanics in automobile service stations are exposed to asbestos dust. In a field study, asbestos fiber concentrations during brake repair were measured. Occupational histories and chest X-rays of brake service mechanics are being examined. Ninety dust measurements in 76 service stations were made by phase contrast microscopy and by scanning transmission electron microscopy. By electron microscopy, extremely fine chrysotile fibers with lengths $< 5\ \mu m$ were identified in brake drum dust. Fibers with lengths $\geqslant 5\ \mu m$ constituted less than 1% of all chrysotile fibers counted in brake drum dust. Short-term asbestos dust exposures were measured by light microscopy in 101 personal samples during blowing out of brakes, and grinding and turning of brake linings. During blowing out of car brakes, as well as during grinding of brake linings, the product of fiber concentration with length $> 5\ \mu m$ and sampling time amounted to about 4-5 fibers/ml $\cdot$ min corresponding to a concentration of 10^6 fibers/m^3 over 4-5 min. For trucks and buses higher amounts of 5-10 $\cdot$ 10^6 fibers/m^3 $\cdot$ min were observed during these operations. From occupational histories of 210 vehicle mechanics, an average duration of employment of $\bar{x} \pm s = 21 \pm 10$ years and a mean cumulative fiber dose of $\bar{x} \pm s = (0.54 \pm 1.1) \cdot 10^6$ fibers/m^3 $\cdot$ years were calculated.

Key words: brake repair, auto mechanic, asbestos exposure, light and electron microscopy, occupational history, fiber dose

INTRODUCTION

The amount of brake lining material used during 1975 in the Federal Republic of Germany was estimated to be 26,000 tons [Ullman et al, 1978]. The asbestos content of brakes used in the FRG ranges from 10-70 weight-%, with an average of 35 weight-%. Infrared spectographic analysis of 18 samples of brake material resulted in the following reading of chrysotile [Jahn et al, 1985]: $\bar{x} \pm s = 30 \pm 11$ weight-%. In accordance with these data, it would appear that the asbestos content of brake material increased from 9,000 t/year in 1975 to about 12,000 t/year in 1980 and dropped to 10,000 t/year in 1983 [G Schmidt, 1984, personal communication].

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A large percentage of the approximately 300,000 car mechanics in the F.R.G. have been exposed to asbestos dust during the cleaning of brake systems and the machining of brake linings. It is the aim of this study to estimate the exposure to asbestos dust for this large group of persons.

Similar to earlier studies on the use of products containing asbestos [Heidermanns et al. 1978; Rödelsperger et al., 1980; Woitowitz and Rödelsperger, 1983], a risk assessment is made on the basis of 1) dust measurements during brake service, 2) screening for fibrogenic reactions by chest X-rays, and 3) evaluation of standardized work histories. Our intent is to examine a group of about 400 vehicle mechanics; to date, 210 have been examined.

MATERIALS AND METHODS

During the maintenance of automobile brake systems, 90 dust measurements in 76 garages were taken with static and personal samples. In general, personal sampling was extended over the whole service operation which lasted 1 h or more, but in some cases personal sampling was limited to certain dust-generating work operations. Therefore, depending on the duration of the work operation, sampling time varied from less than 3 min to more than 1 h.

Fiber concentrations were determined by light and electron microscopy. Fibers with lengths > 5 μm were counted with phase contrast light microscopy using the reference method of the AIA [Asbestos International Association, 1979]. In addition, counts of fibers of lengths ≧ 5 μm and fibers of all lengths were made by scanning transmission electron microscopy at magnifications of ×6,300 and ×29,000. Since it is suspected that the mineral structure of fibers is altered during the braking process, all fibers were examined by energy dispersive X-ray analysis and electron diffraction.

In addition to the dust measurements, an epidemiological cross-sectional study was planned for a group of 400 car mechanics who have been involved in brake maintenance for at least 10 years. A standardized occupational history was administered to each individual and an extended medical examination made. To date, 210 occupational histories describing 459 different sets of working conditions under which brake maintenance is carried out have been evaluated.

RESULTS

Working Operations

The number of working operations which were registered in 76 automobile garages during dust sampling can be seen in Table I. The use of exhaust ventilation is also indicated.

Compressed air was used to blow out loose dust in 15 of 36 garages servicing cars and in 19 of 40 garages servicing trucks or buses. Special exhaust ventilation systems were used during blowing-out operations in 8 of the car garages and in 10 of the bus and truck garages. In addition to compressed air blowing, brushing and the use of solvents were observed. Only brake systems heavily contaminated with oil and dirt were cleaned with hot water.

Fitting of new brake linings for cars was done with special grinding machines in 20 garages. Although each grinding machine was combined with an exhaust ventilation, none of the filter bags were suitable for asbestos except in 3 garages.

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that concentration estimate seems to be at least four times higher than the concentration estimated in our study. Four cases of mesothelioma have been observed among brake repair workers seen as patients in our Polyclinic [Paur et al. 1985].

CONCLUSIONS

Asbestos dust measurements in garages during brake service operations show low fiber concentrations, typically about $0.1 \cdot 10^6$ fibers/m^3 average, and also low fiber doses.

The working conditions are generally characterized by short-term exposure. Blowing out and machine grinding take only min, and the time taken for turning is less than 1 h per vehicle.

All results are considerably below the existing German Technical Guiding Concentration (TRK) of $1 \cdot 10^6$ fibers/m^3 with lengths > 5 μm when a minimum sampling time of 1 h is taken.

Electron microscopy of brake drum dust does not indicate a high occurrence of fibers with lengths > 5 μm; however, there are very high concentrations of short fibers. Mass concentration of asbestos estimated from scanning transmission electron microscopy indicates the mass of fibers as < 1 weight-% [Rödelsperger et al, 1985].

Fiber concentrations for certain working operations are characterized by low fiber counts and therefore by a high uncertainty factor. Furthermore, there is a high uncertainty in the knowledge of the frequency of different working operations obtained using a standardized occupational history. However, the inconsistency in these data, inasmuch as it is measurable, has no great influence on the calculated size of the cumulative fiber dose. The data also allow the ranking of the workers according to the severity of exposure.

An average value of a cumulative fiber dose of $0.54 \cdot 10^6$ fibers/$m^3 \cdot$ years has been obtained. This dose is one order of magnitude lower than an estimate made for roofers cutting asbestos cement at building sites [Rödelsperger et al. 1980, Woitowitz and Rödelsperger, 1983]. It is about one order of magnitude above the environmental exposure which in the Federal Republic of Germany is usually less than 1,000 fibers/m^3 with lengths > 5 μm.

Some changes in working conditions have taken place. Nowadays, only precut and predrilled brake linings are used. Machine grinding is less frequent for cars and has been replaced by turning in the case of trucks and buses. Exhaust ventilation has been introduced almost universally during grinding and to some extent during blowing out and turning. These changes have to be mentioned when cumulative dose values are calculated from results of dust measurements and occupational history.

ACKNOWLEDGMENT

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TABLE I. The Number of Work Operations Releasing Dust Observed During Brake Repair in 76 Automobile Maintenance Shops

Operation	Passenger car (n = 36)	Truck, bus (n = 40)
Blowing out dust	15 (8)[a]	19 (10)[a]
Machine grinding of drum brake linings	20 (20)[a,b]	4 (3)[a]
Turning of drum brake linings	—	34 (11)[a]

[a]With exhaust ventilation

[b]For 17 of these systems, the filter bag was not suitable for asbestos.

TABLE II. Concentrations of Fibers With Lengths > 5 μm Determined by Phase Contrast Microscopy.

Brake service in automobile repair shops: Fiber concentration [$\cdot 10^6$ fibres/m^3][a]				
	Passenger car		Truck bus	
Operation	n = 31	$\bar{x}$	n = 36	$\bar{x}$
Blowing out	4	0.10	4	0.05
Dry brushing	4	0.09	1	0.15
Riveting off and on	—		7	0.10
Grinding by hand	7	0.12	—	—
Machine grinding	5	0.06	1	0.39
Turning	—	—	18	0.08
Combinations	11	0.04	5	0.08

[a]Phase contrast microscopy of fibers with length > 5 μm. Personal sampling for ≥ 30 min.
Sixty-seven measurements were made of personal air samples taken during brake service. Standard deviations approximately equal mean values.

Grinding of brake linings was only done in 4 out of 40 garages servicing trucks, and in one of these with exhaust ventilation. Thirty-four garages used a turning machine for fitting brake linings. In addition to the stationary machine, special movable equipment with a rotating cutting tool was used which could be mounted to the axle of the truck. Exhaust ventilation was also available for the turning machine in 11 garages servicing trucks. In general, blowing out and grinding only take a few min for each vehicle. On the average, the turning of brake linings takes about 30 min per vehicle.

Concentration of Asbestos Fibers

Light microscopy. Table II shows the results of 67 measurements of fiber concentrations during personal air sampling of brake repair work for periods of more than 30 min. Values are specified for different working operations involving emission of asbestos dust during the maintenance of cars compared with trucks, trailers, and buses.

Average fiber concentrations were about $0.1 \cdot 10^6$ fibers/m^3 [10^6 fibers/m^3 = 1 fiber/ml] of lengths > 5 μm for all but one of the working operations. A concentration of $0.39 \cdot 10^6$ fibers/m^3 of lengths > 5 μm was reached during machine grinding of brake drum linings in a truck garage. The sampling time for this measurement was about 1 h.

Because of the short duration of dust generation, sampling time is about 1 h or less. Therefore, the average fiber count for all measurements in Table II was only

TABLE III. Concentrations and Doses of Fibers With Lengths ≥ 5 μm

Brake Service in Automobile Repair Shops—Fiber Concentration and Fiber Dose[a]			
		Fiber concentration/dose ($\bar{x} \pm s$)	
Sampling time t (min)	n	[$\cdot 10^6$ fibers/m^3]	[$\cdot 10^6$ fibers/$m^3 \cdot$ min]
$t \leq 3$	14	5.5 ± 5.8	4.8 ± 4.8
$3 < t \leq 30$	20	0.47 ± 0.48	4.6 ± 4.9
$30 < t \leq 60$	24	0.09 ± 0.06	3.7 ± 2.5
$t > 60$	43	0.08 ± 0.07	7.4 ± 5.5

[a]Phase contrast microscopy of fibers with lengths > 5 μm. Analyses of 101 personal samples by phase contrast microscopy. The effect of different sampling times is shown. Personal sampling in the breathing zone

eight fibers per 100 fields. Because of this, the precision of measurement is very low and the detection limit corresponds to a count of about one fiber per 100 fields for an unused filter.

In Table III, 101 measurements with sampling times from ≤ 3 min to ≥ 60 min are compared. For all working operations, the average concentration decreased considerably as the sampling time increased. For 14 short-term measurements with sampling time ≤ 3 min, the maximum concentration was $20 \cdot 10^6$ fibers/m^3. The average reading was $5.5 \cdot 10^6$ fibers/m^3. Because of the generally short duration of dust emission, the average concentration decreased to less than $0.1 \cdot 10^6$ fibers/m^3, if the sampling time exceeded 30 min.

In addition, in Table III, fiber concentration is compared with fiber dose, which is calculated as the product of concentration and sampling time. In contrast to the fiber concentration, the fiber dose is generally independent of sampling time. Therefore, comparison of the emissions of asbestos (dust) during the different working operations is possible even if the sampling times are different. Moreover, fiber dose is a suitable parameter for estimating the exposure of workers during a short-term emission of asbestos fibers.

Table IV specifies fiber doses for fiber lengths > 5 μm and for all sampling times. From 40 measurements made during the repair of cars, the average fiber doses are about $4 \cdot 10^6$ fibers/$m^3 \cdot$ min for dry brushing and grinding, and $5 \cdot 10^6$ fibers/$m^3 \cdot$ min for blowing out. Generally higher average values are obtained from 46 measurements during the repair of trucks and buses. For machine grinding, for example, they are about $10 \cdot 10^6$ fiber/$m^3 \cdot$ min.

The doses can be compared to the limit value of $1 \cdot 10^6$ fibers/m^3 with lengths > 5 μm which has been adopted in the Federal Republic of Germany which results in a maximum permissible dose of $480 \cdot 10^6$ fiber/$m^3 \cdot$ min for an 8-h shift.

Electron microscopy. Fibers with lengths of ≥ 5 μm on Nucleopore™ filters were counted at a magnification of ×6,300 in the scanning transmission microscope. In comparison to the results shown in Table IV, the dose of chrysotile fibers was considerably higher. For instance, an average reading of $20 \cdot 10^6$ fibers/$m^3 \cdot$ min was seen in three measurments made during blowing out of truck drum brakes. A

TABLE IV. Dose of Fibers With Lengths > 5 μm

	Brake service in automobile repair shops (fiber dose [$\cdot 10^6$ fibres/m^3 $\cdot$ min][a])			
	Passenger car		Truck, bus	
Operation	n = 40	$\bar{x}$	n = 46	$\bar{x}$
Blowing out	5	4.7	8	5.3
Dry brushing	6	4.0	1	9.3
Riveting off and on	—	—	7	9.0
Grinding by hand	5	3.9	—	—
Machine grinding	10	3.9	4	9.9
Turning	—	—	21	8.6
Combinations	14	3.8	5	4.4

[a]Phase contrast microscopy of fibers with length > 5 μm. Personal sampling for ≤ 3 to ≥ 60 min. Brake service was done most commonly for one car or one axis. Standard deviations approximately equal mean values.

reading of $\bar{x} \pm s = 35 \pm 45 \cdot 10^6$ fibers/m^3 $\cdot$ min was obtained in eight measurements made during turning of truck drum linings.

Static sampling away from the working operation was also evaluated by electron microscopy. Concentrations of less than $0.03 \cdot 10^6$ asbestos fibers/m^3 with lengths ≧ 5 μm were estimated from these background counts when sampling time was more than 1 h. Fiber counting by light microscopy is nonspecific for asbestos. Apart from chrysotile, metal fibers and other fibers may be released from brake linings. In this study, 1,219 fibers with lengths ≥ 5 μm from air samples in repair garages were examined by energy dispersive X-ray analysis and electron diffraction. Seventy-four percent of these fibers were identified as chrysotile.

Other studies have been reported on the chrysotile content of brake drum dust [Heidermanns et al. 1978; Jacko et al. 1973; Lorimer et al. 1976; Rödelsperger et al. 1985; Rohl et al. 1977; Williams and Muhlbaier, 1982; Rohl et al. 1976]. In several electron microscopic studies, brake drum dust showed an asbestos content of less than 1 weight-%, indicating a partial physical breakdown of chrysotile fibers during the braking operation, leading to a large number of short, thin fibers. These results are confirmed by our study. As shown in Figure 1, at a magnification of ×6,300 only a few fibers of lengths ≧ [illegible] μm are seen. After air sampling on Nucleopore™ filters of dust blown from brake drums, numerous fibers, usually of lengths < 2 μm were observed at a magnification of ×35,000, ×50,000, and ×60,000. Since alteration of the crystalline structure of these fibrils is possible, electron diffraction and energy dispersive X-ray analysis were also done. It was found that the thin fibers observed in brake drum dust did not differ from fibrils of UICC-chrysotile [Rödelsperger et al, 1985]. Therefore, in brake drum dust even under electron microscopy evaluation at a magnification of ×6,300, chrysotile fibers of lengths ≧ 5 μm only form ≦ 1% of chrysotile fibers of all lengths measured at a magnification of ×29,000.

Occupational Histories

The occupational histories of 210 car mechanics were evaluated. These mechanics had been engaged in brake maintenance for at least 10 years. The average duration of employment as a car mechanic was $\bar{x} \pm s = 21 \pm 10$ years.

Fig. 1. Asbestos fibers in brake drum dust. Scanning transmission electron microscopy at different magnifications: Upper left, ×6,300; upper right, ×35,000; lower left, ×50,000; lower right, ×60,000. Whereas at a magnification of ×6,300 (lower borderline = 14 μm) only a few fibers are visible, at higher magnifications numerous unit fibrils are observed.

Since most of the mechanics had more than one employment position, altogether 459 job profiles were described. Nine car mechanics gave descriptions of jobs where they had not repaired brakes themselves but had been exposed to asbestos dust generated by others.

Table V shows the percentage of job profiles that involved brake maintenance work and the number of vehicles with brake repairs per week, classified according to type of vehicle. The average number of clutch repairs per year is also shown. In 60% of the job profiles, mechanics repaired car brakes, averaging 4.6 jobs per week. In these cases the duration of repair work was approximately 2 h. On average, the brakes of trucks or buses were repaired 2.6 times per week by those who did such work. The average duration was approximately 4 h. The duration was about 2 h for all other vehicles, e.g., fork-lift trucks. Clutch repair also took an average of 2 h.

Mechanic work activities during brake and clutch repair, specified according to type of vehicle, are shown in Table VI. In almost all repairs, either blowing out (75–83%) or dry brushing (54–59%) of drum brakes took place. Machine grinding of drum brakes is described in 25–36% and grinding by hand in 55–75% of the jobs for trucks, buses, and cars, whereas turning (6–64%) was mainly restricted to trucks and buses. The cutting and drilling of brake linings, reported in 11–26% of the jobs, mainly occurred before 1960. Since then, precut and predrilled brake linings have been used.

From dust measurements and occupational histories as shown in Tables IV–VI, dust exposures, expressed as a cumulative fiber dose, can be calculated as follows: A dose value as shown in Table VI is equivalent to the dose for the maintenance of one car. Dose values per car can be calculated if the frequency of work operations described in Tables IV and VI are known for a particular job. Taking the number of cars repaired per year (Table V) and the duration of employment, the cumulative fiber dose per job can be calculated. All jobs of the car mechanics are taken into account. The unit of measurement, fibers/m^3 · min, is converted into fibers/m^3 · year assuming 240 working shifts per year, each of 480 min duration.

The cumulative probability distribution function of cumulative fiber dose for fibers with lengths > 5 μm is shown in Figure 2. For 7% of the 210 workers, there was no measurable fiber dose since they were only indirectly exposed as bystanders. The median value is 0.3 · 10^6 fibers/m^3 · years; for about 13% of the vehicle mechanics, the cumulative fiber dose exceeds 1 · 10^6 fibers/m^3 · years. Thus, the

TABLE V. Occupational Histories of 210 Vehicle Mechanics With Potential Exposure to Abestos Dust

Brake repair	No. of employment histories reporting brake or clutch repair work by vehicle: n	%[a]	No. of vehicles repaired per week ($\bar{x} \pm s$)
Passenger car	275	60	4.6 ± 4.6
Truck, bus	209	46	2.6 ± 3.9
Other vehicles	32	7	3.7 ± 5.0
Clutch repair	278	61	1.8 ± 2.0

[a]Percentage of 459 employment histories of 210 vehicle mechanics. In 33 histories, mechanics were exposed only as bystanders.

TABLE VI. Occupational History of 210 Vehicle Mechanics With Potential Exposure to Abestos Dust

Operation	Passenger cars	Trucks, buses (No. of jobs = 100%)	Mixed
	198	133	78
		Percentage of job profiles that involved indicated operation	
Blowing out	76	75	83
Dry brushing	59	54	59
Riveting off and on	86	93	87
Grinding by hand	75	56	55
Machine grinding	32	25	36
Turning	6	64	42
Cutting and drilling	14	11	26

*Four hundred nine jobs of 210 car mechanics. In 50 other jobs the mechanics did not perform brake repairs of passenger cars, trucks, or buses.

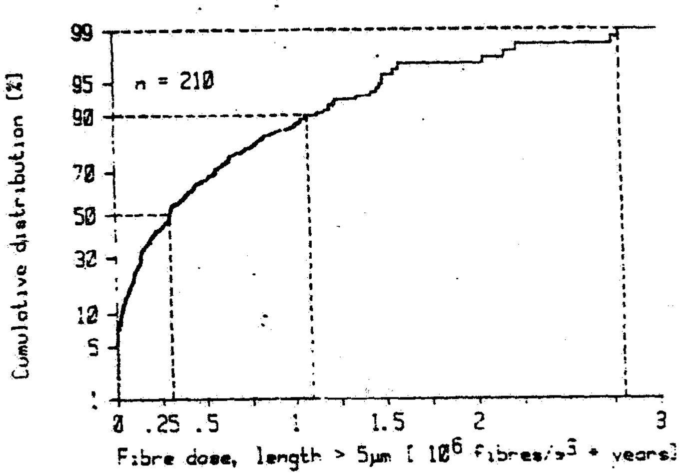

Fig. 2. Exposure of 210 vehicle mechanics during brake maintenance. Cumulative probability distribution function of cumulative fiber dose for fibers with lengths > 5 μm. For 99% of all mechanics, exposure is less than $3 \cdot 10^6$ fibers/m^3 · years. For two further mechanics (1%), doses of 7 and $13 \cdot 10^6$ fibers/m^3 · years are calculated.

average value amounts to $\bar{x} \pm s = (0.54 \pm 1.1) \cdot 10^6$ fibers/m^3 · years. This corresponds to an exposure of about 6 months with an asbestos fiber concentration of $1 \cdot 10^6$ fibers/m^3 with lengths of > 5 μm.

In 1981 Nicholson et al estimated about 350 asbestos cancer deaths per year among car mechanics for the United States. This number was based on an average fiber exposure level of 0.1 to $0.3 \cdot 10^6$ fibers/m^3. Compared to our results of an average dose of $0.54 \cdot 10^6$ fibers/m^3 · years during an average period of 21 years,