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An Evaluation of the Historical Exposures of Mechanics to Asbestos in Brake Dust

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This article presents a historical analysis of published data regarding the exposure of brake mechanics to asbestos as a result of doing brake work. Concerns about this possible hazard were first raised in the late 1960s. This analysis focuses on 30 years of data collected during the brake repair event (e.g., a brake job) and 8-hour time-weighted average (TWA) personal samples. A brake job TWA represents the average concentration a mechanic experienced during brake servicing, rather than throughout the workday, and an 8-hour TWA represents the average airborne concentration of asbestos for the entire workday (which would involve brake work and other activities). Nearly 200 brake job and 8-hour TWA airborne asbestos samples were analyzed to assess how asbestos concentrations varied by type of vehicle serviced, country in which mechanics worked, time period, and brake-cleaning method. To facilitate comparisons, brake job TWAs were converted to estimated 8-hour TWAs using the durations and number of brake jobs performed per mechanic each day. Estimated and measured 8-hour TWAs for mechanics servicing automobiles and light trucks ranged from <0.002 to 0.68 f/cc, with a mean of 0.04 f/cc. In contrast, the 8-hour TWAs for mechanics servicing heavy trucks and buses ranged from 0.002 to 1.75 f/cc, with a mean of 0.2 f/cc, suggesting that these mechanics experienced higher daily asbestos exposures than automobile and light truck mechanics. Brake job and 8-hour TWAs for brake mechanics worldwide were found to be similar during the same time periods, and they were consistently below contemporaneous occupational health standards in the United States. The increased use of brake-dust control measures in some garages resulted in at least a 10-fold decrease in the TWA airborne concentrations of asbestos from the 1970s to the late 1980s.

Keywords Asbestos, Industrial Hygiene, Auto Mechanics, Brake Dust, Exposure, Occupational Health

Asbestos has been used in automobile brake linings worldwide since the early 1900s because it has superior performance characteristics.[1] It was not until the 1960s, however, that concerns arose regarding the potential health hazard associated with exposure to airborne asbestos resulting from automobile brakes. Thomson et al.[2] were the first researchers to address the potential impact of emissions from the brake linings of vehicles during braking on ambient air concentrations of asbestos. Specifically, Thomson[3] observed several cases of mesothelioma (a rare form of cancer associated with asbestos exposure) in South Africans who had no history of occupational or other exposure to asbestos and found unexplained asbestos bodies in routine histological sections of lungs collected during autopsies. Based on these findings, he concluded that these individuals were likely exposed to asbestos products in their homes or to asbestos in ambient air from brake lining wear during vehicle braking, or from disintegration by natural weathering of asbestos-containing building materials.[3]

The question raised by Thomson prompted a number of studies on the potential impact of asbestos emissions from brake linings on ambient air quality. These studies [4–8] provided data on a number of factors, including (1) the amount of asbestos in the wear debris dust from automobile braking, (2) the size distribution of observed fibers, (3) the quantities of asbestos emitted into ambient air from vehicle braking, and (4) the resulting estimated ambient air concentration. An important finding of these studies was that the asbestos content in brake dust ranged from 0.02 to <1 percent, thereby confirming the hypothesis that most of the asbestos in the original lining material (which was composed of about 35% to 65% asbestos) was thermally degraded during braking. However, none of these studies specifically addressed potential asbestos exposures of mechanics servicing brakes.

The first investigation of airborne asbestos in a brake repair garage was undertaken by Hickish and Knight[9] in the late 1960s. This study was conducted at a Ford dealership in London, apparently to evaluate compliance with the 1968 British Occupational Hygiene Standard for Chrysotile Asbestos Dust. [10] Soon thereafter, in 1971, similar studies were conducted in the United States, following the promulgation of an occupational standard for asbestos by the Occupational Safety and Health Administration (OSHA). From 1972 through 1989, the National Institute

for Occupational Safety and Health (NIOSH) conducted numerous investigations of vehicle brake servicing operations in the United States. [1,11–14] In addition, independent studies of airborne asbestos levels in brake-servicing garages were published in the 1980s and 1990s by researchers in the United States,[16] Germany,[17] Sweden,[18] and Australia.[19]

Despite the number of studies conducted over the past several decades, there has been no apparent attempt to use all of the available published air monitoring data to characterize historical exposures to asbestos from brakes for brake mechanics under various working conditions. In this article, the measured airborne asbestos concentrations from published surveys of vehicle brake repair facilities were presented and evaluated to characterize historical exposures for brake mechanics under various working conditions. The concentrations reported for mechanics servicing brakes were characterized and compared based on the period when sampling was conducted, where it was done (United States and overseas), the types of cleaning methods used, and the sizes of the vehicles (cars and light trucks or heavy trucks and buses). The data were then used to estimate the distributions of daily airborne concentrations for brake mechanics who performed brake repair work in the 1960s and 1970s, and more recently in the 1980s and 1990s. Finally, estimated 8-hour TWA concentrations experienced by brake mechanics were compared to occupational permissible exposure limits (PELs).

METHODS

Published studies from the United States and abroad that provided long-term personal air sampling data on asbestos concentrations experienced by mechanics during brake servicing operations were evaluated. Generally, only samples with sampling durations longer than 1 hour were included. Short-term samples collected during blow-out or related "peak exposure events" were not considered informative for assessing the health hazard to mechanics without considering time/motion information; however, the impacts of peak exposures are captured by the longer-term sampling evaluated here. Based on these criteria, 10 studies were identified.[1,9,12–19]

In the studies evaluated, personal air samples were collected on filters in the breathing zones of the mechanics, either during the brake servicing operations or throughout the mechanics' workdays. All of the samples were analyzed for asbestos fibers greater than 5 micrometers (μm) in length and with at least a 3-to-1 length-to-width ratio, (called an aspect ratio) using phase contrast optical microscopy (PCM). Although, as shown in Table I, slightly different sampling and analysis methods[20–23] were used to quantify airborne asbestos concentrations in these studies, the reported methods are sufficiently similar that the data are comparable and representative of the range of airborne asbestos concentrations that mechanics likely encountered during brake servicing operations in various countries and eras.

Measurements reported in the 10 studies were generally expressed as time-weighted average (TWA) airborne concentrations of asbestos for mechanics as they performed one or several brake services (i.e., "brake job TWAs"), or as averaged daily concentrations of asbestos for individual mechanics as they performed various activities throughout the course of their day (i.e., "8-hour TWAs"). Unless specifically referred to in a report as 8-hour TWAs, it was assumed that the data collected were for brake job TWAs. This assumption could usually be confirmed by examining the duration of the sampling event.

Table I summarizes the 10 published studies that we could identify that provided data on airborne asbestos concentrations for mechanics servicing car, truck, and bus brakes. Together, over the past 30 years, the concentrations of airborne asbestos in the breathing zones of mechanics have been measured in 53 brake repair facilities in the United States, 76 facilities in Germany, 23 facilities in Sweden, 4 facilities in Australia, and 1 facility in the United Kingdom. The reported brake job and 8-hour TWA concentrations for the mechanics in all of these studies are presented in Table II for automobile and light truck mechanics and in Table III for heavy truck and bus mechanics.

In the studies by Rödelspergeret al. [17] and Moore,[16] the sampling data were not available; only the mean asbestos concentrations for multiple mechanics doing various types of brake servicing activities were reported, rather than the results for individual mechanics. We did, however, attempt to obtain their original data. Although it is not possible to use their summary information in this statistical analysis of TWA concentrations, the mean concentrations that they measured can be compared to exposures among brake mechanics during relevant time periods in the various countries where samples were collected. The studies evaluated are summarized in the following sections.

United Kingdom Study

The first published study of occupational exposure to airborne asbestos due to brake dust was carried out in 1968 at a Ford dealership in London.[9] Likely prompted by the then-new 1968 British standards for asbestos in the workplace, Hickish and Knight[9] estimated the exposure of a mechanic engaged in the removal of brake dust from a brake drum using compressed air during an entire workshift, during which 11 cars were serviced. No other study has ever reported that a single mechanic worked on so many vehicles during a single day. (Even 2 –3 brake jobs per day is high for a single person in a brake shop.) The measured 8-hour TWA concentration for this mechanic, 0.68 fibers per cubic centimeter (f/cc), is the highest reported value for any mechanic servicing car brakes in any of the subsequent studies that were conducted. These researchers also reported an 8-hour TWA of 1.75 f/cc for a mechanic servicing truck brakes, which, again, is the highest reported value for truck and bus mechanics servicing brakes encountered in a review of the literature.

United States NIOSH Studies

Between 1976 and 1989, researchers at NIOSH collected personal samples for 75 mechanics in 22 settings, including commercial brake and front-end repair shops, fleet service

TABLE I
Publishedindustrialhygienestudieswithtime-weightedaverage(TWA)asbestosconcentrationsformechanicsservicingcar, bus,andtruckbrakes

Type of facility	Number mechanics employed	Number mechanics evaluated	Number brake jobs/week	Personal samples collected	Reported TWA values	TWA durations (hours)	Study	Method
Service bay Ford dealer	NR	1	11/day	6	1 daily	8.0	(9)	BOHS (1968)
Fleet service garage	3	1	2–5	3	1 brake job	5.7	(12)	OSHA/NIOSH
Brake/front-end	3	1	10–14	2	1 brake job	7.9	(12)	OSHA/NIOSH
Brake/front-end	3	1	4–6	3	1 brake job	5.9	(12)	OSHA/NIOSH
Brake/front-end	3	1	20–30	7	2 brake jobs	1.5, 3.0	(12)	OSHA/NIOSH
Large brake service (1976)	5	4	35–45	16	4 brake jobs	4.7–7.7	(12)	OSHA/NIOSH
Large brake service (1977)	5	3	35–45	45	15 brake jobs	NR	(12)	OSHA/NIOSH
Brake/front-end/muffler	3	2	4–5	2	2 brake jobs	1.6, 3.0	(12)	OSHA/NIOSH
Truck brake maintenance (1976)	7	3	NR	9	2 brake jobs	4.3, 5.0	(12)	OSHA/NIOSH
Truck brake maintenance (1977)	7	3	NR	6	3 brake jobs	2.3–6.4	(12)	OSHA/NIOSH
Commercial brake	5	2	35–40	5	2 brake jobs	6.2, 6.2	(14)	OSHA/NIOSH
Brake/front-end	NR	1	NR	2	1 brake job	4.3	(13)	OSHA/NIOSH
Brake/front-end	3	1	4–6	4	4 brake jobs	4.5–5.9	(15)	OSHA/NIOSH
Large brake service	5	3	35–40	2	2 brake jobs	4.7, 5.7	(15)	OSHA/NIOSH
Municipal garage	60	2	40	2	2 brake jobs	3.3, 5.0	(15)	OSHA/NIOSH
Municipal garage	5	3	1	3	3 brake jobs	2.3–6.2	(15)	OSHA/NIOSH
Municipal garage	3	1	NR	1	1 brake job	5.4	(15)	OSHA/NIOSH
Fleet service garage	4	1	1/shift	1	1 brake job	4.0	(15)	OSHA/NIOSH
76 garages Germany	NR	NR	NR	67	Mean "combination" car	NR	(17)	AIA (1979)
31 garages United States	NR	NR	NR	35	Mean brake job	0.2–1.0	(16)	MF-PCM (400x)
Government maintenance	6	NR	6–10	18	9 brake jobs	2.0	(31)	OSHA/NIOSH
Postal maintenance	11	NR	28–36	22	11 brake jobs	2.0	(31)	OSHA/NIOSH
Fleet service garage	2	NR	1	13	7 brake jobs	2.0	(31)	OSHA/NIOSH
Postal maintenance	10	NR	6	20	10 brake jobs	2.0	(31)	OSHA/NIOSH
Private utility garages	5	NR	7–9	8	4 brake jobs	2.0	(31)	OSHA/NIOSH
Outdoors	1[A]	1[A]	NR	2	1 brake job	2.0	(31)	OSHA/NIOSH
Service station	1	1	NR	2	1 brake job	2.0	(31)	OSHA/NIOSH
Garages Sweden	NR	NR	NR	23	23 8-hour	8.0	(18)	NR
Garage Australia	NR	1	20	1	1 brake job	1.3	(19)	NOHSC (1988)
Garage Australia	NR	1	4	1	1 brake job	1.3	(19)	NOHSC (1988)
Garage Australia	NR	1	4	1	1 brake job	2.2	(19)	NOHSC (1988)
Bus service depot Australia	NR	1	2	1	1 brake job	2.1	(19)	NOHSC (1988)

Note: NR—notreported.
[A]Do-it-yourselfmechanic.

garages,truckbrakemaintenancegarages,municipalgarages, private utility maintenance garages, one service station, and one drivewaysampleforado-it-yourselfmechanic.

These evaluations were apparently prompted by the meeting among NIOSH, researchers at Mt. Sinai Hospital, and industry representatives, which was held in July 1975.[24] The NIOSH investigations provide perhaps the most extensive and well-documented characterizations of asbestos concentrations inbrakeservicingfacilities,providingdataforcarandtruck mechanicsusingavarietyofcleaningtechniquesduringvarious timeperiods.Duringthe1970sandearly1980s,mostofthesurveys by NIOSH were conducted in garages that used cleaning methodsconsistentwiththoseusedinpreviousdecades,suchas the use of compressed air to blow off brake parts. In contrast, during the late 1980s, some of the sampling was done in garages thatusedmoresophisticatedcleaningtechniquesforremoving

TABLE II

Reported and estimated time-weighted average (TWA) asbestos concentrations encountered by mechanics servicing car and light truck brakes

Level of brake servicing weekly[A]	Sampling year	Cleaning method	Personal sample concentrations (f/cc)	Reported brake job TWA (f/cc)	Reported 8-hour TWA (f/cc)	Background concentration[B] (f/cc)	Number of mechanics	Facility hours per week	Brake jobs per week	Brake job duration (min)	Brake job daily fraction	Estimated 8-hour TWA (f/cc)	Study
High	1968	Compressed air	0.63–1.12	—	0.68	NR	—	—	—	—	—	—	(9)
Low	NR	NR	0.07–0.16	0.12	—	0.02	3	40	4	65	0.04	0.02	(12)-Fac A
Moderate	NR	NR	0.1–0.15	0.12	—	0.11	3	66	12	65	0.11	0.11	(12)-Fac B
Low	NR	Compressed air	0.02–0.07	0.03	—	0.02	3	51	5	65	0.05	0.02	(12)-Fac C
High	NR	NR	0.03–0.37	0.15	—	0.09	3	54	25	65	0.23	0.10	(12)-Fac D
High	NR	NR	0.04–2.33	0.1	—	0.09	3	54	25	65	0.23	0.09	(12)-Fac D
High	1976	Compressed air	0.06–0.14	0.08	—	0.07	5	54	40	65	0.22	0.08	(12)-Fac E
High	1976	Compressed air	0.05–0.58	0.12	—	0.07	5	54	40	65	0.22	0.08	(12)-Fac E
High	1976	Compressed air	0.02–0.13	0.07	—	0.07	5	54	40	65	0.22	0.07	(12)-Fac E
High	1976	Compressed air	0.03–0.33	0.1	—	0.07	5	54	40	65	0.22	0.08	(12)-Fac E
High	1977	Compressed air	0.05–0.10	0.07	—	0.06	5	54	40	65	0.22	0.06	(12)-Fac E
High	1977	Compressed air	0.02–0.26	0.12	—	0.06	5	54	40	65	0.22	0.07	(12)-Fac E
High	1977	Compressed air	0.09–0.15	0.2	—	0.06	5	54	40	65	0.22	0.09	(12)-Fac E
High	1977	Compressed air	0.05–0.06	0.05	—	0.06	5	54	40	65	0.22	0.06	(12)-Fac E
High	1977	Compressed air	0.01–0.01	0.01	—	0.06	5	54	40	65	0.22	0.05	(12)-Fac E
High	1977	Compressed air	0.03–0.09	0.07	—	0.06	5	54	40	65	0.22	0.06	(12)-Fac E
High	1977	Compressed air	0.04–0.13	0.09	—	0.06	5	54	40	65	0.22	0.07	(12)-Fac E
High	1977	Compressed air	0.01–0.27	0.18	—	0.06	5	54	40	65	0.22	0.09	(12)-Fac E
High	1977	Compressed air	0.06–0.10	0.08	—	0.06	5	54	40	65	0.22	0.06	(12)-Fac E
High	1977	Compressed air	0.01–0.04	0.02	—	0.06	5	54	40	65	0.22	0.05	(12)-Fac E
High	1977	Compressed air	0.03–0.06	0.04	—	0.06	5	54	40	65	0.22	0.06	(12)-Fac E
High	1977	Compressed air	0.08–0.29	0.12	—	0.06	5	54	40	65	0.22	0.07	(12)-Fac E
High	1977	Compressed air	0.01–0.38	0.14	—	0.06	5	54	40	65	0.22	0.08	(12)-Fac E
High	1977	Compressed air	0.07–0.24	0.16	—	0.06	5	54	40	65	0.22	0.08	(12)-Fac E
High	1977	Compressed air	0.15–0.19	0.17	—	0.06	5	54	40	65	0.22	0.08	(12)-Fac E
Low	NR	Compressed air and dry brushing	0.02	0.02	—	0.01	3	40	5	105	0.07	0.01	(12)-Fac F
Low	NR	Compressed air and dry brushing	0.03	0.03	—	0.01	3	40	5	105	0.07	0.01	(12)-Fac F
NR	1979	Compressed air	0.005–0.06	0.04	—	0.01	3	66	12	65	0.11	0.01	(13)
High	1979	Compressed air w/solvent	0.03–0.07	0.04	—	0.01	5	54	40	90	0.30	0.02	(14)
High	1979	Compressed air w/solvent	0.002–0.01	0.006	—	0.01	5	54	40	90	0.30	0.01	(14)
Low	NR	Compressed air	0.03	0.03	—	0.01	3	51	5	65	0.05	0.01	(15)-Fac A
High	NR	Compressed air	0.12	0.12	—	0.1	5	54	40	65	0.22	0.10	(15)-Fac B
High	NR	Compressed air	0.1	0.1	—	0.08	5	54	40	65	0.22	0.08	(15)-Fac B
High	NR	Compressed air	0.19	0.19	—	0.13	5	54	40	65	0.22	0.14	(15)-Fac B
High	NR	Compressed air w/solvent	0.08	0.08	—	0.04	5	54	40	65	0.22	0.05	(15)-Fac B
High	NR	Compressed air w/solvent	0.07	0.07	—	0.03	5	54	40	65	0.22	0.04	(15)-Fac B

(Continued on next page)

TABLE II

Reported and estimated time-weighted average (TWA) asbestos concentrations encountered by mechanics servicing car and light truck brakes *(Continued)*

Level of brake servicing weekly[A]	Sampling year	Cleaning method	Personal sample concentrations (f/cc)	Reported brake job TWA (f/cc)	Reported 8-hour TWA (f/cc)	Background concentration[B] (f/cc)	Number of mechanics	Facility hours per week	Brake jobs per week	Brake job duration (min)	Brake job daily fraction	Estimated 8-hour TWA (f/cc)	Study
High	1979	Dry brush	0.2	0.2	—	0.07	60	40	40	65	0.02	0.07	(15)-Fac C
High	1979	Dry brush	0.19	0.19	—	0.03	60	40	40	65	0.02	0.03	(15)-Fac C
Low	1979	Wet brush	0.23	0.23	—	0.07	5	40	5	300	0.13	0.09	(15)-Fac D
Low	1979	Wet brush	0.28	0.28	—	0.07	5	40	5	300	0.13	0.10	(15)-Fac D
Low	1979	Wet brush	0.24	0.24	—	0.07	5	40	5	300	0.13	0.09	(15)-Fac D
NR	1979	Squirt bottle	0.21	0.21	—	0.06	3	40	5	65	0.05	0.07	(15)-Fac E
Low	NR	Vacuum	0.01	0.01	—	0.01	8	80	10	65	0.03	0.01	(15)-Fac F
NR	NR	Compressed air[C]	—	0.10	—	0.05	1	40	4.6	120	0.23	0.06	(17)
NR	NR	Dry brush[D]	—	0.09	—	0.045	1	40	4.6	120	0.23	0.06	(17)
NR	NR	Combinations[E]	—	0.04	—	0.02	1	40	4.6	120	0.23	0.02	(17)
NR	NR	NR	<0.01–0.15	0.03[F]	0.002[G]	NR	—	—	—	—	—	—	(16)
Low	1986	Vacuum enclosure A	<0.004	0.004	—	0.002	6	45	8	120	0.07	0.002	(1)
Low	1986	Vacuum enclosure A	<0.004	0.004	—	0.002	6	45	8	120	0.07	0.002	(1)
Low	1986	Vacuum enclosure A	<0.004	0.004	—	0.002	6	45	8	120	0.07	0.002	(1)
Low	1986	Vacuum enclosure A	<0.004	0.004	—	0.002	6	45	8	120	0.07	0.002	(1)
Low	1986	Vacuum enclosure A	<0.004	0.004	—	0.002	6	45	8	120	0.07	0.002	(1)
Low	1986	Vacuum enclosure A	<0.004	0.004	—	0.002	6	45	8	120	0.07	0.002	(1)
Low	1986	Vacuum enclosure A	<0.004	0.004	—	0.002	6	45	8	120	0.07	0.002	(1)
Low	1986	Vacuum enclosure A	<0.004	0.004	—	0.002	6	45	8	120	0.07	0.002	(1)
High	1987	Vacuum enclosure B	<0.004	0.004	—	0.002	11	40	32	120	0.15	0.002	(1)
High	1987	Vacuum enclosure B	<0.004	0.004	—	0.002	11	40	32	120	0.15	0.002	(1)
High	1987	Vacuum enclosure B	<0.004	0.004	—	0.002	11	40	32	120	0.15	0.002	(1)
High	1987	Vacuum enclosure B	<0.004	0.004	—	0.002	11	40	32	120	0.15	0.002	(1)
High	1987	Vacuum enclosure B	<0.004	0.004	—	0.002	11	40	32	120	0.15	0.002	(1)
High	1987	Vacuum enclosure B	<0.004	0.004	—	0.002	11	40	32	120	0.15	0.002	(1)
High	1987	Vacuum enclosure B	<0.004	0.004	—	0.002	11	40	32	120	0.15	0.002	(1)
High	1987	Vacuum enclosure B	<0.004	0.004	—	0.002	11	40	32	120	0.15	0.002	(1)
High	1987	Vacuum enclosure B	<0.004	0.004	—	0.002	11	40	32	120	0.15	0.002	(1)
High	1987	Vacuum enclosure B	<0.004	0.004	—	0.002	11	40	32	120	0.15	0.002	(1)
High	1987	Vacuum enclosure B	<0.004–0.006	0.005	—	0.002	11	40	32	120	0.15	0.002	(1)
Low	1986–7	HEPA vacuum	0.006–0.016	0.011	—	0.002	2	40	2	120	0.05	0.002	(1)
Low	1986–7	HEPA vacuum	0.008–0.015	0.012	—	0.002	2	40	2	120	0.05	0.003	(1)
Low	1986–7	HEPA vacuum	<0.004	0.004	—	0.002	2	40	2	120	0.05	0.002	(1)
Low	1986–7	HEPA vacuum	<0.004	0.004	—	0.002	2	40	2	120	0.05	0.002	(1)
Low	1986–7	HEPA vacuum	0.005–0.006	0.005	—	0.002	2	40	2	120	0.05	0.002	(1)
Low	1986–7	HEPA vacuum	0.007–0.009	0.008	—	0.002	2	40	2	120	0.05	0.002	(1)
Low	1986–7	HEPA vacuum	0.004	0.004	—	0.002	2	40	2	120	0.05	0.002	(1)
Low	1986	Wet brush/recycle	<0.004	0.004	—	0.002	10	40	6	120	0.03	0.002	(1)
Low	1986	Wet brush/recycle	<0.004	0.004	—	0.002	10	40	6	120	0.03	0.002	(1)
Low	1986	Wet brush/recycle	<0.004	0.004	—	0.002	10	40	6	120	0.03	0.002	(1)
Low	1986	Wet brush/recycle	<0.004	0.004	—	0.002	10	40	6	120	0.03	0.002	(1)
Low	1986	Wet brush/recycle	<0.004	0.004	—	0.002	10	40	6	120	0.03	0.002	(1)
Low	1986	Wet brush/recycle	<0.004	0.004	—	0.002	10	40	6	120	0.03	0.002	(1)
Low	1986	Wet brush/recycle	<0.004	0.004	—	0.002	10	40	6	120	0.03	0.002	(1)
Low	1986	Wet brush/recycle	<0.004	0.004	—	0.002	10	40	6	120	0.03	0.002	(1)
Low	1986	Wet brush/recycle	<0.004	0.004	—	0.002	10	40	6	120	0.03	0.002	(1)
Low	1986	Wet brush/recycle	<0.004–0.006	0.005	—	0.002	10	40	6	120	0.03	0.002	(1)

Low	1986–7	Aerosol spray	0.004–<0.005	0.004	—	0.002	89	*40*	6	*120*	0.003	0.002	(1)
Low	1986–7	Aerosol spray	0.011–0.016	0.014	—	0.002	89	*40*	6	*120*	0.003	0.002	(1)
Low	1986–7	Wet brush	<0.004	0.004	—	0.002	89	*40*	6	*120*	0.003	0.002	(1)
Low	1986–7	Aerosol *spray*	0.005–0.007	0.006	—	0.002	89	*40*	6	*120*	0.003	0.002	(1)
Low	NR	No cleaning[H]	<0.008	0.008	—	*0.002*	*1*	*40*	*1*	*120*	0.05	0.002	(1)
Low	NR	Solvent/water hose[I]	<0.006–0.008	0.007	—	*0.000*	*1*	*40*	*0.02*	*120*	0.001	0.00001	(1)
NR	NR	NR	—	—	0.02	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.02	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.02	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.03	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.03	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.05	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.05	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.07	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.08	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.095	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.1	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.13	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.14	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.15	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.15	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.17	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.19	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.20	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.20	NR	—	—	—	—	—	—	(18)
NR	NR	NR	—	—	0.20	NR	—	—	—	—	—	—	(18)
High	NR	No cleaning	<0.05	0.05	—	*0.025*	—	—	—	—	0.75	0.04	(19)
Low	NR	Aerosol spray	<0.05	0.05	—	*0.025*	—	—	—	—	0.15	0.03	(19)
Low	NR	Squirt bottle	<0.05	0.05	—	*0.025*	—	—	—	—	0.15	0.03	(19)

Note: Values in italics are estimated based on similar situations. NR—Not reported.
[A]Low indicates fewer than 10 brake jobs per week; moderate indicates 10 to 19 brake jobs per week; high indicates 20 or more brake jobs per week.
[B]Background values calculated from time-weighting of samples. Estimates set at one-half brake job TWA.
[C]Mean for 4 mechanics.
[D]Mean for 4 mechanics.
[E]Mean for 11 mechanics.
[F]Mean for 35 mechanics.
[G]Estimated daily TWA assuming zero exposure for unsampled portion of shift.
[H]Mechanic in service station.
[I]Do-it-yourself mechanic working outdoors.

Reported and estimated time-weighted average (TWA) asbestos concentrations encountered by mechanics servicing heavy truck and bus brakes

Level of brake servicing weekly[A]	Sampling year	Cleaning method	Personal sample concentrations (f/cc)	Reported brake job TWA (f/cc)	Reported 8-hour TWA (f/cc)	Background concentration[B] (f/cc)	Number of mechanics	Facility hours per week	Brake jobs per week	Brake job duration (min)	Brake job daily fraction	Estimated 8-hour TWA (f/cc)	Study
NR	1968	Compressed air	0.08–7.09	—	1.75	0.07	—	—	—	—	—	—	(9)
NR	1976	Compressed air & dry wipe	0.03–0.09	0.05	—	0.06	7	*40*	3	450	0.08	0.05	(12)-Fac G
NR	1976	Compressed air & dry wipe	0.03–0.72	0.18	—	0.06	7	*40*	3	450	0.08	0.07	(12)-Fac G
NR	1977	Compressed air & dry wipe	0.08–3.24	1.68	—	0.79	7	*40*	3	450	0.08	0.87	(12)-Fac G
NR	1977	Compressed air & dry wipe	0.29–0.62	0.53	—	0.79	7	*40*	3	450	0.08	0.77	(12)-Fac G
NR	1977	Compressed air & dry wipe	0.52	0.52	—	0.79	7	*40*	3	450	0.08	0.77	(12)-Fac G
Low	1986	Vacuum enclosure A	<0.004	0.004	—	0.002	6	45	*1*	*450*	0.03	0.002	(1)
Low	1986–1987	Aerosol spray	<0.003	0.003	—	0.002	89	*40*	*1*	*120*	0.001	0.002	(1)
NR	NR	Compressed air[C]	NR	0.05	—	*0.025*	1	40	2.6	240	0.26	0.03	(17)
NR	NR	Dry brush[D]	NR	0.15	—	*0.075*	1	40	2.6	240	0.26	0.09	(17)
NR	NR	Combinations[E]	NR	0.08	—	*0.04*	1	40	2.6	240	0.26	0.05	(17)
Low	NR	Dry wipe	<0.05	0.05	—	*0.025*	—	—	—	—	0.08	0.03	(19)

Note: Values in italics are estimated based on similar situations. NR—Not reported.
[A]Low indicates fewer than 10 brake jobs per week; moderate indicates 10 to 19 brake jobs per week; high indicates 20 or more brake jobs per week.
[B]Background values calculated from time-weighting of samples. Estimates set at one-half brake job TWA.
[C]Mean from 4 samples.
[D]Mean from 1 samples.
[E]Mean from 5 samples.

thebrakedust,suchasenclosedhigh-ef ficiency particulate air (HEPA) vacuum systems.

The firstNIOSHinvestigationofabrakerepairfacilitywas conducted in 1972;[11] however, the report is unclear as to whetherthesamplescollectedwerepersonalsamples.Also,because the sampling durations were not included, it is unknown whethertheresultsareforpeakorlong-termexposures;thus, theywerenotusedinthisanalysis.

In 1976 and 1977, NIOSH researchers sampled 16 mechanics in seven different brake service facilities.[12,25] Six of the 7 facilitieswerecommercialautomobilebrakeservicecentersthat performed from 2 to 45 brake jobs per week, at an average of 65 minutes per vehicle (Table I). The seventh facility, a truck service center, performed an average of 3 brake jobs per week, but servicingtookanaverageof6to9hourspervehicle.Johnsonet al.[12] reportedTWAconcentrationsfor26automobile(TableII) and fivetruck(TableIII)mechanics.Becausenoneoftheresults are referred to as 8-hour TWAs, and where given, the sampling durations are all less than 8 hours, it was assumed that the results were for brake job TWAs.

The description of brake servicing operations was as follows: "The vehicle is driven into the repair stall or bay for a brake examination. Pending repairs, the wheels are elevated, removed and then inspected. Loose dust is then cleaned from the drums and brake assemblies by vacuuming, wiping, brushing, using compressed air, or a combination of these methods. Parts are then replaced or repaired as needed and the brake system is reassembledandadjusted."

Although not provided in the report, the mean and standard deviationcalculatedfromthedataforthe26automobilebrake job TWAs are 0.095 and 0.053 f/cc, respectively, with a maximum of 0.20 f/cc. For the five brake job TWAs for trucks, the mean and standard deviation are 0.59 and 0.64 f/cc, respectively, with a range of 0.05 to 1.68 f/cc.

Two commercial automobile brake service facilities were evaluated by NIOSH in 1979.[13,14] Oneofthesefacilitieswas previously sampled by NIOSH in 1977, while the second was an active shop that operated 6 days per week and performed from 35to45brakemaintenanceoperationsperweek(TableI).These investigationsprovidedthreebrakejobTWAconcentrationestimates,rangingfrom0.006to0.04f/cc(TableII).

During 1979 and 1980, NIOSH collected additional samplesin6brakeservicefacilities,including2commercialbrake servicegarages,3municipalautomobileservicegarages,and 1 fleetservicegarage.[15,26] Oneofthecommercialfacilities,a largebrakeservicegarage,waspreviouslysampledbyNIOSHin 1976 and 1977.[12] Theseevaluations,whichinvolvedsampling times of about 2 to 6 hours, provided brake job TWA estimates for13additionalmechanicsusingsixdifferentcleaningmethodsforbrakeservicing,includingcompressedair,compressed air and solvents, dry brushing, wet brushing, squirt bottle washing, and vacuuming (Table II). Although not reported by the authors,themeanandstandarddeviationare0.15and0.09f/cc, respectively,witharangeof0.01to0.28f/cc.

The final NIOSH investigations were conducted in 1986, 1987, and 1988 and are summarized in Sheehy et al.[1] Thorough sampling surveys were conducted at five facilities, each usingadifferentmethodforcontrollingexposuretoasbestos duringbrakerepair.[27–31] The stated purpose of these surveys wastoevaluatedustcontroltechnologies(TableI).Theyevaluated the effectiveness of two commercial enclosure devices with ventilation provided by a HEPA vacuum, a HEPA filterequippedvacuumalone,abrushwithrecirculatingcleaningsolution, and cleaning solvents in aerosol cans. The investigators alsoevaluatedasmallservicestationgaragewherenodustcontrol measures were used, and brake repair conducted outdoors by a do-it-yourself mechanic who used a spray can of solvent to wet the brake surfaces and water from a garden hose to flush surfaces. These investigations provide 44 additional brake job TWA measurements, 42 for autos and 2 for light trucks, all of which were collected for the maximum of either 2 hours or the duration of the brake job (Table II). Using detection limits in the statisticalanalysisforthosesamplesinwhichasbestoswasnot detected, we calculated a mean and standard deviation for the 42 auto brake job TWAs of 0.005 and 0.002 f/cc, respectively, with a range of <0.004to0.014f/cc.

Other U.S. Studies

The only published study of mechanics servicing brakes in the United States other than those conducted by NIOSH was that of Moore in 1998.[16] Asbestossampleswerecollectedin 31 different brake service facilities (Table I). He describes the objective of his study as the collection of personal samples from thebreathingzonesofautomobilemechanicstoestimatetheir exposures while performing actual brake removal and repair work in different facilities with widely diverse work practices. No specificdescriptionsofthefacilitiesaresupplied,norare TWA data provided for individual mechanics; however, he does indicate that the brake job durations ranged from 10 to 60 minutes, with an average time of 29 minutes. For the 35 samples collected, the mean and median values were <0.03 and <0.02, respectively,witharangeof <0.01to0.15f/cc(TableII).

German Study

Rödelsperger et al.[17] sampled 31 mechanics servicing passenger car brakes and 36 mechanics servicing truck and bus brakes in West Germany (Table I). Personal samples were collectedgenerallyduringthewholeservice,but,insomecases, samples were limited to specific dust-generating activities. Based on personal samples of 30 minutes or longer, the authors estimatedmeanconcentrationsformechanicsperformingbrake servicesblowingoutdrumswithcompressedair(0.10f/cc),dry brushingdrums(0.09f/cc),andforcombinationsofactivities involving cleaning out brakes (0.04 f/cc). Brake job TWA concentrationdataforindividualmechanicswerenotprovided.The authorsconcludedthatthemeanasbestosconcentrationduring

brakeserviceoperationswaslessthan0.1f/ccforsamplingdurationsgreaterthan30minutes.

Swedish Study

Platoetal. [18] provideanevaluationbasedontwenty-three 8-hour TWA personal samples at different car and bus repair shops for the period 1976 to 1988 from a Swedish National Board of Occupational Health database (Table I). Although a table of the measurements is not provided in their article, 20 of these 23 TWA concentrations were estimated from one of the figurespresentedintheirpaper.Thesevaluesrangedfrom 0.02 to 0.20 f/cc, with a mean of 0.10 and a standard deviation of 0.07 f/cc. Although the values from Plato et al.[18] are for a combinationofvehicles,theywereincludedintheanalysisfor automobiles and light trucks, even though some of the higher valuesaremorelikelyforheavytruckandbusbrakerepairwork.

Plato et al.[18] also provide independent estimates of asbestos concentrations, rather than direct measurements, experienced bycar,truck,andbusmechanicsservicingbrakesbetween1938 and 1986, based on the sampling data described above and application of factors accounting for the types of vehicles serviced (car, bus, truck), sizes and ventilation of repair shop rooms, task activities, frequency of work, and whether work as a vehicle mechanic was performed before or after 1975. Based on their model, the authors estimated an 8-hour TWA for all car mechanics of 0.09 f/cc during the period from 1938 to 1986.

Australian Study

Themostrecentinvestigationofasbestosconcentrationsin brake service garages was carried out in Australia in the late 1990s by Yeung et al.[19] Personal samples were collected on mechanicsinthreegaragesservicingbrakesforpassengerand lightcommercialvehiclesandonegarageservicingbusbrakes (TablesI,II,andIII).Allfourofthesamplesyieldedresults belowthedetectionlimitof0.05f/cc.

Other Studies Providing TWA Estimates

Two other documents provided estimates of 8-hour TWA concentrationsformechanicsservicingbrakes;however,thesees-timates are based on data from studies described previously. Nicholsonetal. [32] estimated an 8-hour TWA concentration of 0.1f/ccformechanicsinmunicipalgaragesand "an upper limit of the average exposure" of 0.2 f/cc for commercial garage mechanics. These estimates appear to be based largely on the NIOSH data reported by Roberts and Zumwalde.[15] The *Federal Register*[33] reported a mean 8-hour TWA concentration of 0.03 f/cc for mechanics servicing vehicle brakes from 1979 to 1984 and a mean 8-hour TWA concentration of 0.012 f/cc from 1986 to 1989, presumably based on NIOSH data.

An additional study, which was conducted in Finland by Kauppinen and Korhonen,[34] provided 8-hour TWA concentration estimates for various vehicle mechanics based on short-term samples(generallylessthan30minutes)forspeci ficoperations undertakenduringbrakeservicing.TheestimatedTWAconcentrationswerecalculatedusingthemeasuredmeanandmaximum concentrationsandthemeandurationsofnumerousoperations (althoughthedurationdataandcalculationsarenotprovided in the article). It was assumed that brake maintenance of four wheelswascarriedoutduringtheworkdayandthatotherinfrequent operations, such as the grinding of brake linings, were one hour in duration. Based on these data and assumptions, Kauppinen and Korhonen[34] estimatedthatthemeanasbestos workdayconcentrationformechanicswasunder0.05f/ccduring therepairofcarbrakesandunder0.1to0.2f/ccduringtherepair oftruckandbusbrakes.BecausetheseTWAconcentrationestimates were not derived from long-term sample measurements, theyarenotincludedinthisanalysisofTWAconcentrationdata. However,theirestimatesoftheworkplaceconcentrationsofasbestosduetobrakerepairarevirtuallyidenticaltotheresults reportedintheUnitedStatesandelsewhere.

DATA ANALYSIS

A total of 162 TWA asbestos concentrations were found in the published literature for individual mechanics servicing automobileandlighttruckbrakesfromthelate1960stothepresent. An additional 19 TWA concentrations were reported for individual mechanics servicing heavy truck and bus brakes during the same time period. Most of the reported TWA asbestos air concentrations represent brake job TWAs, whereas only a few studies (e.g., Plato et al.[18])reportdatathatrepresent8-hour TWAs.

All of the TWA sampling data were compiled from the available published studies and entered into a database for analysis.Additionalinformationwasalsosummarizedonfactorsthat mightaffectairborneasbestosconcentrations,suchastheyear in which samples were collected, the type of cleaning method employedduringbrakeservicing,thetypeoffacility,andthe estimated number of brake jobs performed weekly in the garage (level of service) (see Tables I and II).

Conversion of Brake Job to 8-Hour TWAs

Tocharacterizethehistoricalexposuresofbrakemechanics in the United States so that one can compare the information with occupational exposure limits, such as OSHA permissible exposure limits (PELs) and American Conference of GovernmentalIndustrialHygienists(ACGIH ®) threshold limit values (TLVs®), it was necessary to convert the brake job TWA values to 8-hour TWA concentrations. This approach is a standard and customary practice in industrial hygiene, and in the fieldofrisk assessment, when attempting to characterize the risk of lifetime exposure to chronic toxicants.

The 8-hour TWAs were estimated by assuming that mechanics were exposed at the brake job TWA levels during the period of the day they serviced brakes and at the background levels of the garages during the rest of their 8-hour days. The fraction of the day during which a mechanic was actually doing brake

work at each facility was estimated by using the number of brake mechanics at the facility, the number of hours mechanics work per week, the number of brake jobs per week, and the average duration for a brake job at each facility.

$$\text{Daily Fraction} = \frac{\text{jobs per week} \times \text{duration}}{\text{mechanics} \times \text{hours per week}} \quad [1]$$

The brake job TWAs were then converted to 8-hour TWAs using the fractions of day, brake job TWAs, and mean background concentrations for the facilities.

$$\text{8-Hour TWA} = (\text{Brake job TWA} \times \text{Daily Fraction}) + [\text{Background} \times (1 - \text{DailyFraction})] \quad [2]$$

The values used were either taken directly from the applicable report or estimated based on available information. The parameters used and the results for the conversions are shown in Tables II and III.

Concentration Distributions and Statistical Comparisons

The TWA concentration data were analyzed statistically to characterize and compare asbestos exposure levels for mechanics performing brake services under various exposure conditions. The data were characterized based on when the sampling was conducted, where it was done (United States and other countries), the types of cleaning methods used, and the types of vehicles serviced (cars and light trucks or heavy trucks and buses). Statistical comparisons were made to determine whether differences existed between exposure levels as a result of (1) the time of sampling (1970s vs. 1980s), (2) the location (United States vs. Europe), and (3) the methods of cleaning brakes.

Statistical comparisons were conducted where possible, given the limitations of the data to assess how locations and cleaning methods may have affected asbestos concentrations. To eliminate the impact of the amount of brake work done at a site, the comparisons were made only for those facilities with the same level of service. Low was assigned to shops with fewer than 10 brake jobs per week, medium for 11 to 20, and high for more than 20 brake jobs per week.

Nonparametric methods (Kruskal-Wallis and Wilcoxon rank-sum tests) were used for comparisons, because the concentration data could not satisfy the homogeneity of variance and normality assumptions underlying analysis of variance methods. Significance was determined after correcting individual test p-values for the multiple comparisons that were made; specifically, individual test p-value was multiplied by the number of tests.

Differences among locations were assessed for early U.S. (1970s), late U.S. (1980s), and Swedish data, only because these data sets all have sufficient measurements for individual mechanics to support such an analysis (42, 42, and 20, respectively). Assessment of cleaning methods was conducted within a location and service level to avoid confounding the interpretation of cleaning method influence with other factors. Cleaning methods that were very similar, such as compressed air only and compressed air with a dry brush, were combined to create cleaning method categories for evaluating differences. Early U.S. and late U.S. studies both reported multiple concentrations for multiple cleaning method categories. Early U.S. cleaning method categories included compressed air with and without dry brush, wet brush, and vacuum-HEPA for low-service-level shops, and compressed air with and without dry brush, compressed air–solvent, and dry brush for high-service-level shops. Late U.S. low-service-level shops were assumed to use the following cleaning method categories: aerosol spray, vacuum-HEPA, wet brush–recycle, vacuum enclosure, wet brush, waterhose–squirt bottle, and no cleaning.

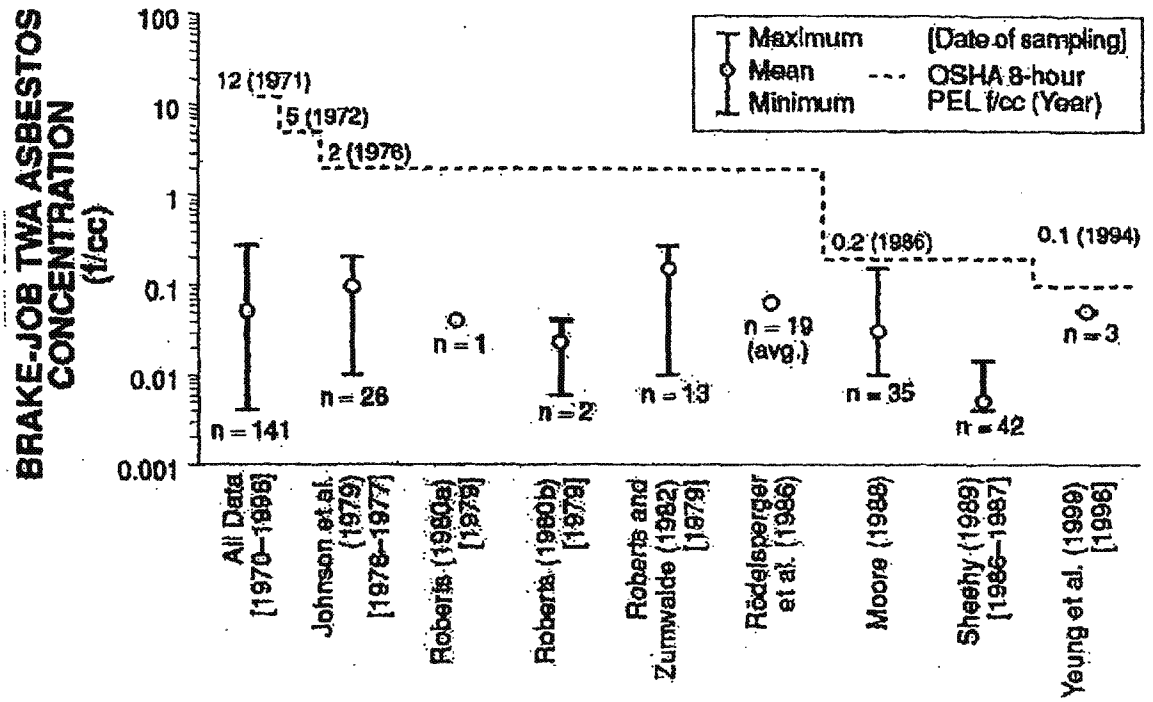
RESULTS

The TWA concentrations measured for automobile and light truck mechanics, and heavy truck and bus mechanics, are described separately. Differences in asbestos concentrations related to different brake cleaning methods are evaluated. Comparison of the asbestos concentrations experienced by U.S. and European mechanics repairing automobile brakes during the same time period are made, and changes in exposure concentrations over time from the 1970s to 1990s are evaluated.

Automobiles and Light Truck Mechanic Exposures

Automobiles and light trucks were evaluated together, because the tasks involved in servicing the brakes and the durations of the brake servicing were similar. The means and ranges for the nine studies that provided data on the airborne concentrations during the actual brake job (rather than 8-hour TWA samples) are presented in Figure 1. The mean brake job TWA for the 141 automobile mechanics evaluated between 1968 and 1996 is 0.05 f/cc, with a range of 0.004 to 0.28 f/cc. It is notable that brake job TWA concentrations for the more recent surveys in the late 1980s and 1990s are generally much lower than those reported for mechanics working in the 1970s and early 1980s. These lower concentrations are not surprising, given the greater awareness and concern about exposure to airborne dusts of any type by most workers.

The estimated 8-hour TWA concentrations for the above nine studies, and the measured 8-hour TWA concentrations from Hickish and Knight[9] and Plato et al.[18] for automobile and light truck mechanics, are presented in Figure 2. The mean 8-hour TWA concentration based on 162 values is 0.04 f/cc. The maximum reported 8-hour TWA was 0.68 f/cc from Hickish and Knight,[9] with the next highest reported value being 0.20 f/cc. The relatively high value from Hickish and Knight is for a mechanic who cleaned the brakes of 11 cars in one shift, which was an unusually high number of vehicles serviced in a day (two to three was more typical).



Note: Dates in parentheses are publish dates; dates in square brackets are sampling dates, if different than the publish date.

FIGURE 1

Brake job time-weighted average (TWA) asbestos concentrations for mechanics servicing brakes on automobiles and light trucks.

Heavy Truck and Bus Mechanic Exposures

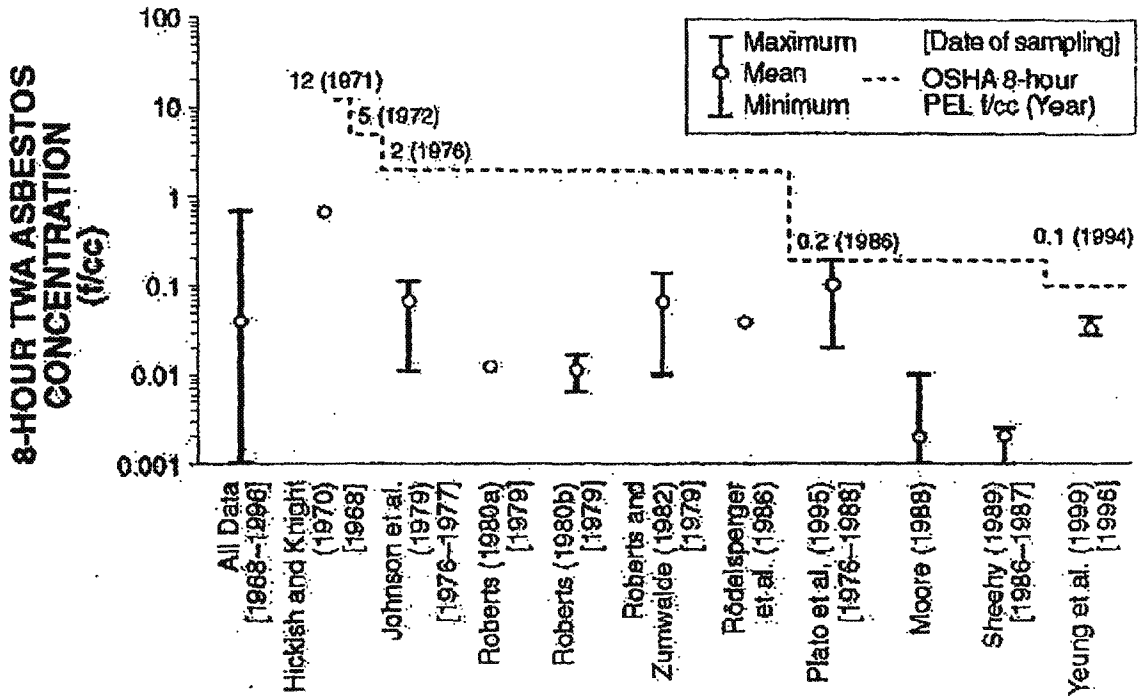
Fewer TWA concentration measurements are available for mechanics servicing heavy truck and bus brakes than for those servicing automobile and light truck brakes. The means and ranges for the four studies providing brake job TWAs for heavy trucks and buses are presented in Figure 3. The mean brake job TWA concentration for the 18 mechanic sevaluatedis 0.21 f/cc, with a maximum of 1.68 f/cc.

The estimated 8-hour TWA concentrations for the above four studies, and the measured 8-hour TWA from Hickish and Knight[9] for heavy truck and bus mechanics, are presented in Figure 4. The mean 8-hour TWA concentration, based on 19 data points, is 0.25 f/cc. The maximum reported TWA was 1.75 f/cc from Hickish and Knight,[9] with the next highest value being 0.87 f/cc.

As for the automobile and light truck mechanics, the brake job and 8-hour TWA concentrations for truck and bus mechanics were generally lower in surveys from the late 1980s and 1990s than from surveys for earlier periods. As shown in Figure 5, the 8-hour TWA concentrations for mechanics servicing heavy truck and bus brakes are significantly greater than those for mechanics servicing automobile and light truck brakes. This difference is likely due to several factors. The brakes on trucks and buses are larger and require more time to service. In addition, truck and bus mechanics generally replace just the brake linings, which often requires riveting and machining. Because automechanics normally replace the entire brake shoe —not just the lining — these dust-generating operations are not usually performed by auto mechanics.

Eight-Hour TWA Concentration Distributions

It is apparent that the data from the NIOSH surveys provide the most complete characterization for estimating the 8-hour TWA concentrations experienced by brake mechanics in the United States in the 1970s and late 1980s. The cumulative distribution plots of the NIOSH survey data (Figure 5) show that 8-hour TWA concentrations for automobile mechanics in the 1970s were generally within a narrow range, with a 50th percentile value of 0.07 f/cc and a 90th percentile of 0.10 f/cc.



Note: Dates in parentheses are publish dates; dates in square brackets are sampling dates, if different than the publish date.

FIGURE 2
Eight-hour time-weighted average (TWA) asbestos concentrations for mechanics servicing brakes on automobiles and light trucks.

(That is, it can be expected that at least 90% of the mechanics were exposed to concentrations below 0.1 f/cc during that 20-year period.) The cumulative distribution plot for the later NIOSH survey in the 1980s shows a substantially lower and narrower 8-hour TWA concentration distribution, with both the 50th and 90th percentiles at 0.002 f/cc. The plot for heavy truck and bus brake mechanics indicates that the 50th percentile value for this group (0.08 f/cc) was similar to that for automobile brake mechanics from the 1970s NIOSH studies but that the 90th percentile values for truck and bus mechanics (1.65 f/cc) was substantially higher than that for automobile mechanics.

Comparison of U.S. and European Brake Mechanic Exposures

Differences among locations were assessed using the early U.S. (1970s), late U.S. (1980s), and Swedish data sets, because they were the only ones that had sufficient numbers of individual samples for statistical analysis (42, 42, and 20 TWA concentrations, respectively). The distributions for the three data sets are shown in Figure 5. A statistical comparison of 8-hour TWA concentrations derived from the NIOSH studies of United States mechanics from 1976 to 1982 and the 8-hour TWAs reported for Swedish mechanics from 1976 to 1988 found no significant difference in mean concentrations (see Table IV). U.S. mechanics evaluated in the late 1980s by NIOSH were exposed to significantly lower airborne concentrations of asbestos than either the early U.S. or Swedish mechanics. This difference is likely due to the improved cleaning methods discussed below.

TWA Concentrations Relative to Cleaning Method

As early as 1970, studies or surveys of the concentration of airborne asbestos for vehicle mechanics servicing brakes noted that the cleaning process, particularly compressed air blow-out of drum brakes, was the major contributor to airborne fiber levels. The mean and ranges for brake job TWAs using the various cleaning methods are represented in Figure 6. The distributions of

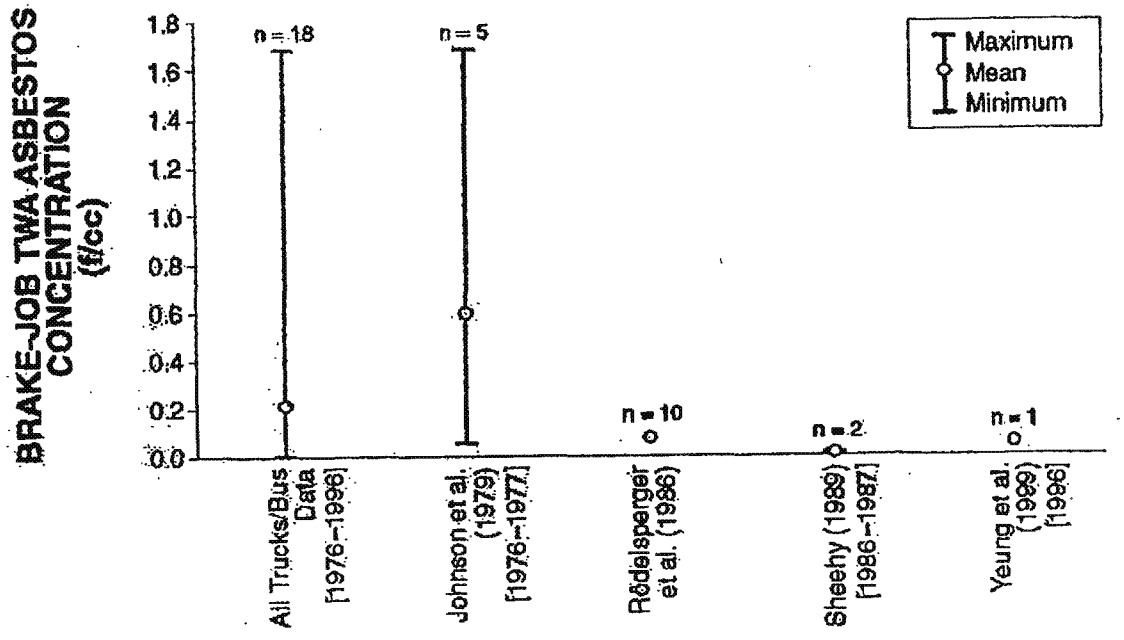


FIGURE 3

Brakejobtime-weightedaverage(TWA)asbestosconcentrationsformechanicsservicingbrakesonheavytrucksandbuses.

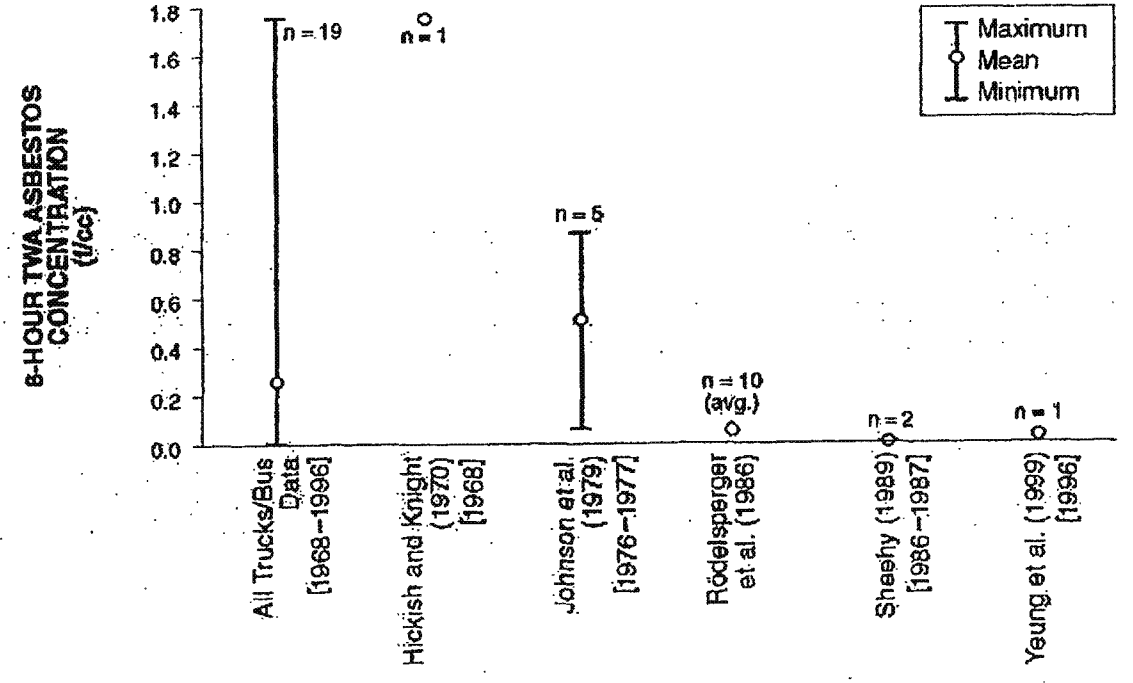
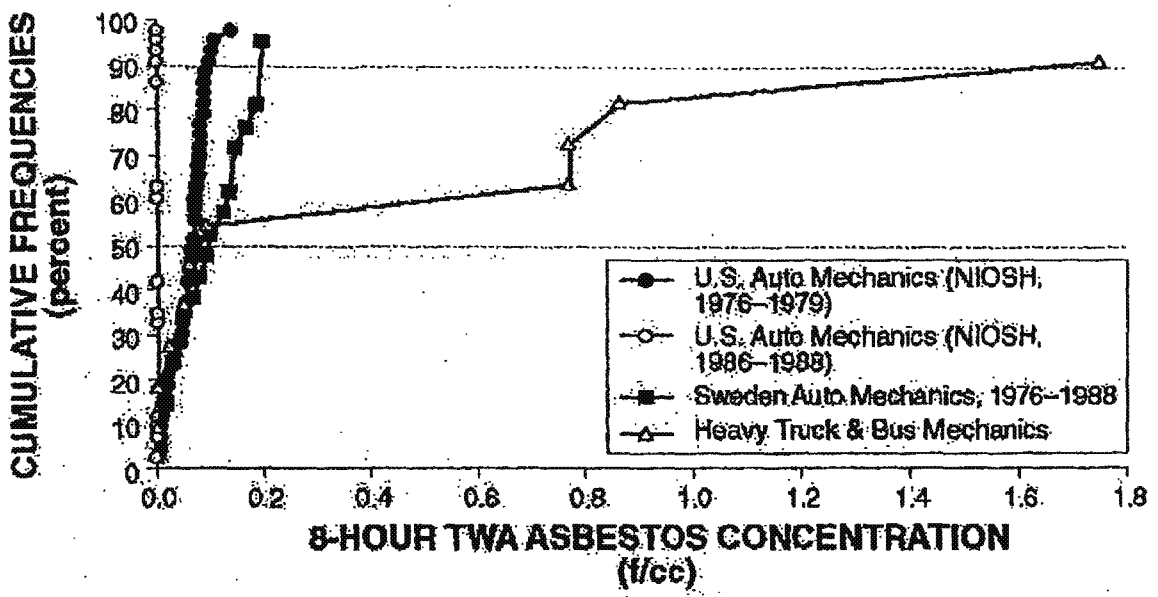


FIGURE 4

Eight-hourbrakejobtime-weightedaverage(TWA)asbestosconcentrationsformechanicsservicingbrakesonheavytrucks and buses.



Note: Graph presents data from studies for which there are measurements reported for individual mechanics. Data from Moore (1988) and Rödelsperger et al. (1986) are excluded because only group averages were presented. Data from Hickish and Knight (1970) and Yeung et al. (1999) did not provide sufficient data for a separate analysis.

FIGURE 5

Cumulativedistributionsof8-hourtime-weightedaverage(TWA)asbestosconcentrationsformechanicsservicingbrakeson automobiles, trucks, and buses.

the most frequently used methods are shown on Figure 7. With the exception of a few TWA concentrations, most of the data are from NIOSH studies.

Itisevidentfromtheplotsandthestatisticaltestresults summarized in Table IV that the introduction of dust control technologies significantlyreducedboththemagnitudeandvariabilityofasbestosexposuresforbrakemechanics.Asshownin Figure7,the50thand90thpercentilebrakejobTWAconcentrationsformechanicsusingcompressedairforcleaningduringthe 1970s and early 1980s were approximately 0.10 and 0.18 f/cc, respectively. The use of solvents with compressed air in the early 1980s reduced the 50th and 90th percentiles to about 0.03 and 0.08f/cc,respectively.Theuseofwetbrush/recycle,HEPAvacuum, and vacuum enclosure reduced most asbestos exposures tolessthan0.01f/cc —levelsatorbelowthedetectionlimitfor NIOSH sampling.

The use of these dust control technologies served several purposes.Theydramaticallyreducedthepeakexposuresduring cleaning, they prevented the distribution of airborne dust into other areas of the work environment, and they kept brake dust from being deposited on the floor of the work area, where it couldsubsequentlyberesuspendedbyfoottraf fic or sweeping.

The 50th and 90th percentile brake job TWA concentrations formechanicsusingcompressedairforcleaningaresimilarto thoseforU.S.mechanicsasagroupinthe1970s,likelybecause compressed air was the method most frequently used for brake cleaning during that period.

Changes in Exposures Over Time

The decrease in 8-hour and brake job TWA asbestos concentrationsinthelate1980sisevidencedbythedistributionsof early and late NIOSH values for auto brake mechanics shown in Figure5.ThisstatisticalcomparisonissummarizedinTableIV. Basedontheavailabledata,itisclearthatmuchofthedecrease is due to dust control measures that were first introduced in the late1970s.However,theintroductionofdiscbrakesduringthis period would also have led to decreased exposures for mechanics.Duringtheperiodofnearlyallthesestudies,discbrakes were placed predominantly only on the front wheels because of problems in using disc brakes in conjunction with the rear parking brake system. Because disc brakes have many fewer places where dust can collect than do drum brakes, there would havebeenmuchlessbrakedustavailableforsuspensionintothe

Results of statistical comparisons of time-weighted averages (TWAs) by time and location and cleaning method and level of service

Type	Cleaning method	Service level	Number of results	Mean	Standard deviation	Test conclusions
Time and location (8-hour TWAs)						
Early United States [A]	NA	NA	42	0.063	0.032	
Late United States [B]	NA	NA	42	0.0021	0.00036	Significantly different from early U.S., Sweden (w/multiple test correction)
Sweden [C]	NA	NA	20	0.10	0.067	
Cleaning methods and level of service (brake job TWAs)						
Early United States [A]	Com air w/ & w/o dry brush	Low	4	0.028	0.0050	Significantly different from wet brush (w/o multiple test correction)
	Wet brush		3	0.25	0.026	Significantly different from com air w/ & w/o dry brush (w/o multiple test correction)
	Vacuum & HEPA		1	0.010	—	
Early United States [A]	Compresed air w/ & w/o Dry brush	High	22	0.10	0.053	Significantly different from com air w/solvent, dry brush (w/o multiple test correction)
	Compressed air w/solvent		4	0.049	0.033	Significantly different from com air w/ & w/o dry brush (w/o multiple test correction)
	Dry brush		2	0.20	0.0071	Significantly different from com air w/ & w/o dry brush (w/o multiple test correction)
Late United States [B]	Aerosol spray	Low	3	0.0080	0.0053	Significantly different from wet brush/rec, vacencl (w/o multiple test correction)
	Vacuum & HEPA		7	0.0069	0.0035	Significantly different from wet brush/rec, vacencl (w/o multiple test correction)
	Wet brush/rec		10	0.0041	0.000316	Significantly different from aerosol spray, vac & HEPA (w/o multiple test correction)
	Vacuum enclosure		8	0.0040	0	Significantly different from aerosol spray, vac & HEPA (w/o multiple test correction)
	No cleaning		1	0.0080	—	
	Wet brush		1	0.0040	—	
	Water hose & squirt bottle		1	0.0070	—	

Note: Significant differences determined by overall type-1 error rate of 0.05.
[A] Early United States are samples from the 1970s by NIOSH.
[B] Late United States are samples from 1980s by NIOSH.
[C] Sweden are samples from 1980s by Plato et al.

air during brake servicing operations. In addition, non-asbestos brake pad materials began to be used in disc brakes in the 1980s.

Although there are no published data on the exposure of vehicle mechanics to asbestos during brake repair activities prior to 1968, it is possible to speculate on earlier exposure levels for automobile brake mechanics. With the introduction of bonded brakes in 1948, the need for drilling, facing, and grinding was significantly reduced, and with factory-supplied, tapered, bonded brake replacements available in the 1950s, the need for beveling was also greatly reduced.[1] By the early 1960s, the

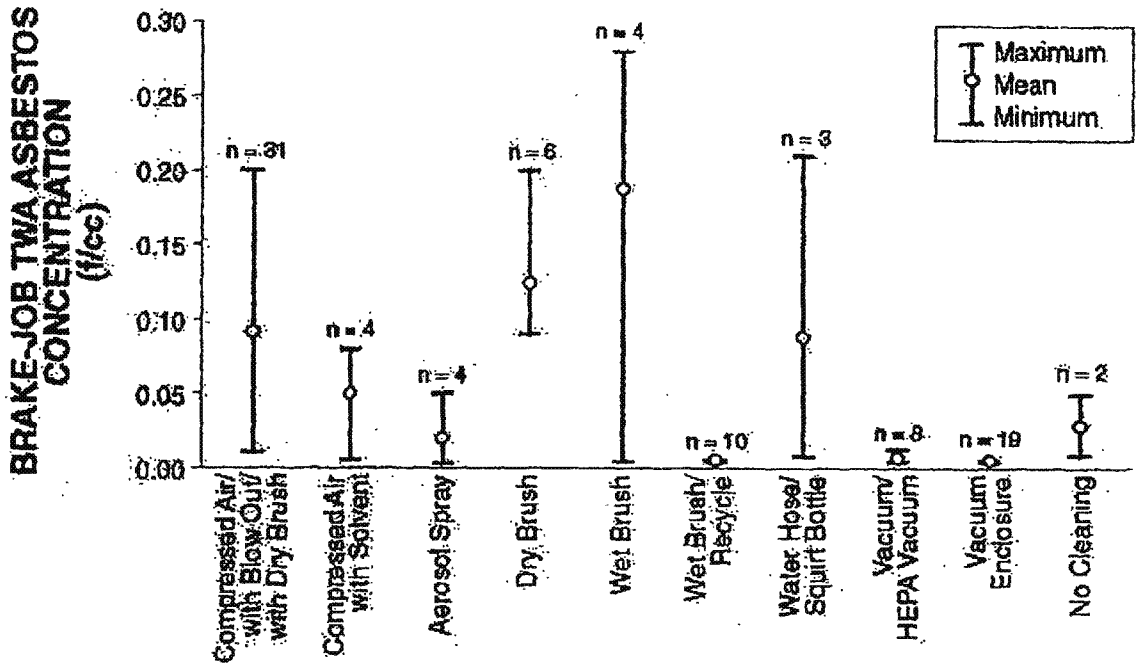


FIGURE 6
Brakejobtime-weightedaverage(TWA)asbestosconcentrationsformechanicsservicingbrakesonautomobilesandlighttrucks using different cleaning methods.

methods for performing brake jobs on autos were similar to those used in the 1970s—cleaning brake assemblies with compressedairorawirebrushandreplacingtheentirebrakeshoes withfactorysupplied,tapered,bondedshoes.Thus,itisquite likely that the exposure levels experienced in the late 1950s and the 1960s were similar to those in the 1970s.

DISCUSSION

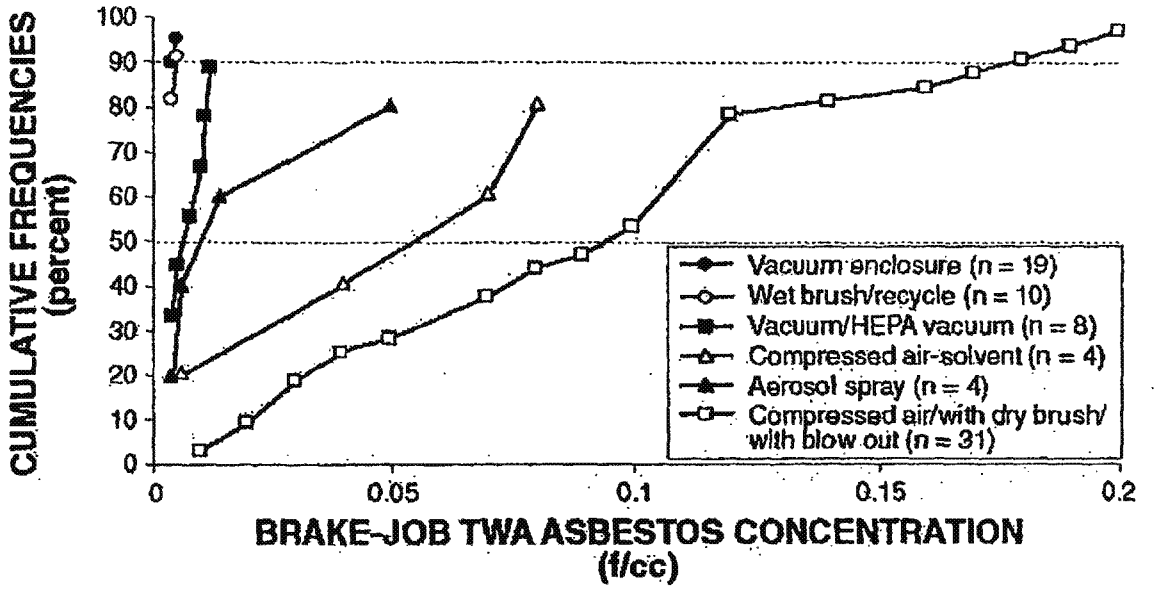
ThisevaluationofTWAairborneconcentrationsofasbestos due to brake dust experienced by mechanics presents a comprehensive picture of exposure levels for brake repair work over thepast30years.Themeanconcentrationidenti fied (e.g., about 0.04f/cc)appearstobeconsistentwithbthosereportedinother evaluationsofmechanicexposuresandaresubstantiallylower thanlevelsreportedforworkersinotheroccupationshandling asbestos-containing products.

SimilaritiestoOtherStudies

Thisanalysisfoundthatthe8-hourTWAconcentrationsfor brake mechanics obtained or derived from the early NIOSH survey data[15] weresimilartothoseestimatedbyPlatoetal. [18] for Swedish automobile mechanics in the 1970s (the mean for both was about 0.04 to 0.09 f/cc). Likewise, data from the United States (e.g., NIOSH) were similar to those estimated for Finnish mechanics by Kauppinen and Korhonen[34] using short-term concentrationdata(meanofabout0.05f/cc).Theconsistency among these independent 8-hour TWA airborne concentrations for asbestos due to brake dust indicates substantial similarities in brake repair operations and the asbestos content in brake linings in various countries during the 1970s and 1980s. The similarityinresultsbysomanydifferentresearchers,insuch different geographic locations, gives significant confidence in the conclusions.

Comparison to Regulatory Standards

TheU.S.regulatorystandardforoccupationalexposureto asbestos has changed numerous times over the last 30 years.[35] In 1971, OSHA set a PEL for asbestos in workplace air of 12 f/cc as an 8-hour TWA, which was based on the TLV established by ACGIH in 1968. Since then, the PEL has become more strict over time. Specifically, in December 1971, OSHA issued an emergency temporary standard that lowered the asbestos PEL to 5 f/cc, and in June 1972, OSHA officially lowered the PEL standard to 5 f/cc for 1972 and 2 f/cc commencing in July 1976. In 1986, the PEL was lowered to 0.2 f/cc, and in 1994, it was again lowered to its present value of 0.1 f/cc. Comparisons of themeasuredasbestosairborneconcentrationsingaragestothe OSHA PEL at the corresponding times indicate that both the



Note: Graph presents data from studies for which there are measurements reported for individual mechanics and a reported cleaning method. Cleaning methods with fewer than five data points are not shown.

FIGURE 7

Cumulativedistributionsofbrakejobtime-weightedaverage(TWA)asbestosconcentrationsformechanicsservicingbrakeson automobilesandlighttrucksusingdifferentcleaningmethods.

brake job and 8-hour TWA concentrations of asbestos for brake mechanicswereconsistentlybelowtheapplicablefederalstandard. This observation is further confirmed by the lack of OSHA citations of garages for exceeding the PEL for asbestos from 1972–2002.

Comparison to Other Occupational Exposures

To better understand the relative magnitude of brake mechanicexposures,onecanevaluateotheroccupationsthathandledrawasbestosanduseditinthemanufactureofothergoods. From 1964 to 1985, for example, the U.S. Public Health Service and NIOSH conducted seven studies at brake manufacturing facilities.[36–41] During the 1960s, the mean asbestos concentrationfor381samplescollectedduringthreestudieswas 6.0 f/cc, with a range of 0 to 130 f/cc. In the 1970s, the mean value for 269 samples from two facilities was 1.5 f/cc, with a range of 0 to 17.5 f/cc. In the 1980s, the mean value for 49 samples from two facilities was 0.38 f/cc, with a range of 0.01 to 1.1 f/cc. By comparison, the mean brake job TWA for automobile brake mechanics was 0.11 f/cc during the 1970s and 0.005 f/cc during the 1980s. Thus, at comparable times, automobile brake mechanics had asbestos exposures that were 10 to 100 times less than for those persons who manufactured the brake linings.

Characterizing Variability

As with any analysis of multiple studies, there were some limitationsintheavailabledataforestimatingthemean8-hour TWA concentrations to which brake mechanics were exposed over time. For example, nearly all of the sampling data collected in the field on brake mechanics involved 1- to 2-hour samples; thus, the data needed to be corrected to predict the typical 8-hour TWA airborne concentration to which mechanics were exposed. Few 8-hour TWA samples were collected on brake mechanics, becausetheindustrialhygienistsapparentlyconcludedthatif the results of a shorter sampling period (e.g., during a brake job) did not exceed the PEL, then surely the 8-hour TWA would be less than the PEL, given that the remainder of a mechanic's day wouldhavebeenspentawayfrombrakerepairactivities. Also, because exposures were sporadic and of short duration, they couldbeestimatedbyconductingatime/motionanalysis,which accountedfortheactualtimeduringwhichexposuresoccurred.

This analysis was limited by the lack of certain information in thereportsregardingthevarioustasksperformedbymechanics

duringthesamplingperiod(aswellastheentireworkday).Except for several of the NIOSH surveys, little information was provided on the number of brake jobs performed per day by mechanics, or the amount of time spent each day actually performing brake repair work. None of the long-term studies provided specificmechanictime/motiondataforactivities,which would have enabled better comparisons of the data. Several of the original authors of these studies were contacted in an attempt togainabetterunderstandingofwhatwasactuallydoneandfor how long. They provided an adequate verbal account of what they did, but either the original notes describing their work had been discarded, or much of the desired information was never recorded.

Though there are some limitations associated with these data, comparedtothemajorityofoccupationsthatweresurveyedfor asbestosconcentrationspriorto1980,theaccumulateddataare quite good. For example, almost 200 measurements were identified and included in this analysis. The data were sufficient to compare the ranges of exposure for brake mechanics working on different types of vehicles, in different countries, during differenttimeperiods,andusingdifferentcleaningmethods.The brake job TWA data set establishes the upper bounds of the asbestosconcentrationstowhichmechanicscouldbechronically exposed if they performed brake jobs 40 hours per week for many years. Because the process of changing drum brakes and theasbestoscontentofthelinings didnotchangeappreciably fromabout1940to1975,thesedatashouldbeapplicableforthe entire 35 years during which drums were the primary braking mechanism used on automobiles in the U.S. Airborne concentrations of asbestos for auto mechanics would have decreased substantially only over the past 20 years due to the fewer asbestos brake linings on cars (conversion to nonasbestos linings), the conversion to disc brakes, and better techniques for controllingexposuretobrakedustinrepairshops.

CONCLUSIONS

Based on this review and analysis of the available data on theconcentrationsofairborneasbestosforvehiclemechanics servicing brakes, several conclusions were reached:

- TWAconcentrationdatafromthe10publishedstudies are sufficient to characterize exposures of vehicle brake mechanics from the 1970s to the present with a high degree of confidence.
- The 8-hour TWA concentrations for auto brake mechanics in other industrialized countries studied were similarduringthesametimeperiodsfortheyears1970 to 1990.
- As dust control methods were implemented, the 8-hour TWA concentrations dropped by at least an order of magnitude from 1970 to 1990.
- Airborne concentrations of asbestos during the process of changing brake linings (1- to 2-hour samples), as well as the 8-hour TWA concentrations, were consistently below the applicable OSHA occupational standard for the 1970s, 1980s, and 1990s.
- Becauseboththeclean ingandbrakereplacementmethods were similar after the introduction of tapered bonded brakes, it is quite likely that asbestos exposure levels inthelate1950sandthe1960sweresimilartothosein the 1970s for auto brake mechanics.
- For comparable time periods, asbestos TWA concentrations for vehicle brake mechanics were 10 to 100 timeslowerthanthoseexperiencedbyfrictionproduct manufacturingworkers.

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