

Cumulative asbestos exposure for US automobile mechanics involved in brake repair (circa 1950s–2000)

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We analyzed cumulative lifetime exposure to chrysotile asbestos experienced by brake mechanics in the US during the period 1950–2000. Using Monte Carlo methods, cumulative exposures were calculated using the distribution of 8-h time-weighted average exposure concentrations for brake mechanics and the distribution of job tenure data for automobile mechanics. The median estimated cumulative exposures for these mechanics, as predicted by three probabilistic models, ranged from 0.16 to 0.41 fibers per cubic centimeter (f/cm³) year for facilities with no dust-control procedures (1970s), and from 0.010 to 0.012 f/cm³ year for those employing engineering controls (1980s). Upper-bound (95%) estimates for the 1970s and 1980s were 1.96 to 2.79 and 0.07–0.10 f/cm³ year, respectively. These estimates for US brake mechanics are consistent with, but generally slightly lower than, those reported for European mechanics. The values are all substantially lower than the cumulative exposure of 4.5 f/cm³ year associated with occupational exposure to 0.1 f/cm³ of asbestos for 45 years that is currently permitted under the current occupational exposure limits in the US. Cumulative exposures were usually about 100- to 1,000-fold less than those of other occupational groups with asbestos exposure for similar time periods. The cumulative lifetime exposure estimates presented here, combined with the negative epidemiology data for brake mechanics, could be used to refine the risk assessments for chrysotile-exposed populations.

Journal of Exposure Science and Environmental Epidemiology advance online publication, 9 May 2007; doi:10.1038/sj.jes.7500553

Keywords: chrysotile asbestos, brake wear debris, exposure assessment, auto mechanics.

Introduction

Chrysotile asbestos was a common component of automotive brakes until the mid-1980s (Sheehy et al., 1989). Over the past 30 years, numerous epidemiology studies and industrial hygiene surveys have been conducted to characterize exposures to chrysotile and assess any respiratory health risks associated with vehicle repair. The epidemiology studies have shown that brake-repair activities are not associated with increases in the risk of developing asbestosis (Nicholson et al., 1984; Elliehausen et al., 1985; Marcus et al., 1987), lung cancer (Rushton et al., 1983; Lerchen et al., 1987; Benhamou et al., 1988; Vineis et al., 1988; Hansen, 1989; Gustavsson et al., 1990; Morabia et al., 1992; Wong, 1993, 2001; Goodman et al., 2004), or mesothelioma (McDonald and McDonald, 1980; Petersen and Milham, 1980; Teta

et al., 1983; Olsen and Jensen, 1987; Spirtas et al., 1985, 1994; Woitowitz and Rödelersperger, 1994; Coggon et al., 1995; Teschke et al., 1997; Agudo et al., 2000; Milham and Ossiander, 2001; National Institute for Occupational Safety and Health (NIOSH), 2002; Hansen and Meersohn, 2003; Goodman et al., 2004; Hessel et al., 2004; Laden et al., 2004; McElvenny et al., 2005; Welch et al., 2005; Rolland et al., 2005).

We recently performed a comprehensive analysis of the published industrial hygiene data for brake mechanics (Hickish and Knight, 1970; Johnson et al., 1979; Roberts and Zumwalde, 1982; Rödelersperger et al., 1986; Moore, 1988; Sheehy et al., 1989; Plato et al., 1995; Yeung et al., 1999; Roberts, 1980a, b) and determined that the mean 8-h time-weighted average (TWA) asbestos concentration for car and light truck repair was 0.04 fibers per cubic centimeter (f/cm³) (range of <0.001–0.68 f/cc) (Paustenbach et al., 2003) for the period of about 1970 to 1990. It was also determined that airborne TWA asbestos concentrations measured by National Institute for Occupational Safety and Health (NIOSH) in the 1980s time frame for garages with dust control procedures in place in the US were significantly lower than those in the 1970s (mean values of 0.002 and 0.06 f/cm³,

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Received 19 August 2006; accepted 14 November 2006

respectively). The lower concentrations in the 1980s samples are attributable to the dust-control measures and better work practices that were implemented in many garages during this period (Sheehy et al., 1989; Paustenbach et al., 2003).

We believe that quantifying the cumulative lifetime exposures associated with brake repair would contribute substantially to the general understanding of the dose-response relationship for chrysotile. First, the data from brake repair may provide a benchmark to evaluate the relative risks of other low chrysotile-exposed occupational groups that lack specific epidemiologic data. Second, the brake mechanic data could be used to refine the risk assessment model proposed by Berman and Crump (2003), which suggests that chrysotile, if it can cause mesothelioma, probably only does so at high doses and when very long and thin fibers are present. Their model permits calculation of the relative risk of lung cancer and mesothelioma for a given exposure and can be adjusted to account for asbestos fiber size and type. Finally, it would be informative to determine whether the doses are consistent with no-effect doses that have been reported in epidemiologic studies of other chrysotile-exposed workers.

There are some published estimates of cumulative asbestos exposures for brake mechanics. Specifically, Rödelsperger et al. (1986), Gustavsson et al. (1990), and Plato et al. (1995), using a variety of different techniques, have developed cumulative exposure estimates that are fairly consistent, with mean values ranging from 0.54 to 2.6 f/cm^3 year. However, the applicability of these estimates for US brake mechanics is unclear, because they (1) are derived strictly from airborne data collected in European facilities in Germany and Sweden (Rödelsperger et al., 1986; Gustavsson et al., 1990; Dahlqvist et al., 1992); therefore, they do not consider the data collected by NIOSH in 22 US facilities (i.e., Johnson et al., 1979; Roberts, 1980a, b; Roberts and Zumwalde, 1982; Sheehy et al., 1989), and (2) there is some evidence to suggest that the apprentice and journeyman programs used by craftsman, including vehicle mechanics, in Europe (but not in the US) provided a more stable workforce and longer job tenure among workers in these occupations than in equivalent occupations in the US.

The primary purpose of this paper is to provide estimates of the cumulative lifetime exposure to chrysotile (hereafter referred to as "cumulative exposure") for brake mechanics in the US for the past 50 years. The NIOSH survey data are used in conjunction with US occupational tenure data to develop a plausible range of cumulative exposures for US brake mechanics. As part of this analysis, we segregate the available information into different time periods (1970s versus 1980s) to assess the influence of dust-control measures that were employed in most of the garages sampled in the 1980s (as noted in Sheehy et al., 1989). The Sheehy et al. (1989) data, which were collected in several garages employing dust control, were thought to be representative of garage

practices in the late 1980s. Central tendency (50th percentile) and lower- and upper-bound estimates (5th and 95th percentiles, respectively) of the cumulative exposure distributions are presented with comparisons to (1) the previously published exposure estimates for European brake mechanics, (2) the Occupational Safety and Health Administration (OSHA) permissible exposure level (PEL) assuming a full 45-year working lifetime, (3) cumulative exposures for other occupations that handled raw asbestos or asbestos products, and (4) no-effect threshold values for asbestosis and lung cancer, as suggested by other investigators.

Methods

In this analysis, cumulative exposures (in f/cm^3 year) for brake mechanics working on passenger vehicles and light trucks in commercial garages were calculated using distributions of 8-h daily TWA airborne concentrations (f/cm^3) and a distribution of job tenure data (year) for automobile mechanics working in repair garages. Although mechanics may experience peak exposures during certain activities (such as grinding or arcing), these exposures would be included in the 8-h TWA for a given workday. The TWA is the most appropriate metric for evaluating cumulative lifetime exposures, as they take into account the exposures of mechanics to asbestos via various activities that occur throughout the entire workday.

Monte Carlo Analysis

The probabilistic exposure model was developed using Crystal Ball software (Decisioneering, Inc., Denver, CO). Crystal Ball was used to calculate cumulative exposures for brake mechanics in units of f/cm^3 year (calculated by multiplying the years worked by the pertinent 8-h TWA asbestos concentration in f/cm^3). The distributions of 8-h TWA asbestos concentrations were developed by fitting distributions to available airborne concentration data for brake mechanics working in garages without and with dust-control measures. Using the Carey (1988) data, the distribution of projected tenure was developed for US automobile mechanics, of which brake mechanics are a portion of the mechanic population.

Airborne Asbestos Data

For the purposes of this analysis, we use all of the air concentration data that met the following criteria: (1) the data were collected and published in the US; (2) air samples were collected during brake-repair activities and analyzed using the NIOSH phase-contrast microscopy method; (3) the air samples were individual, personal samples; and (4) the sampling duration was at least 1 h in length and was reported or could be reasonably estimated from the available information. During 1976 and 1987, NIOSH researchers

collected 84 personal airborne asbestos samples during brake jobs in 22 different settings, including commercial brake and front-end repair shops, fleet service garages, municipal garages, private utility maintenance garages, one service station, and one driveway sample for a “do-it-yourself” mechanic (Johnson et al., 1979; Roberts and Zumwalde, 1982; Sheehy et al., 1989; Roberts, 1980a, b). A majority of these samples were collected for the duration of the brake job (approximately 1–2 h). These are the only publicly available data. Owing to the diversity of the types of shops in which the samples were taken and the various activities evaluated, the authors believe that these data are both sufficient and representative of the exposures of US brake mechanics. In addition, because of the use of Monte Carlo methods, all possible scenarios using the historic data were evaluated taking into account variability and uncertainties in the data (e.g., high weekly servicing with long tenure, low weekly servicing with short tenure, and everything in between). As such, although the data are considered sufficient to stand on their own, using probabilistic methods to cover a variety of scenarios provides confidence that most, if not all, possible exposures of mechanics were included in the analysis.

Paustenbach et al. (2003) recently converted these brake-job data to 8-h TWA concentrations using background concentration data for the specific facilities (see Paustenbach et al. (2003) Table II, pages 789–792, summarizing reported and estimated 8-h TWAs). In their calculations, they used measured concentrations during brake work and site-specific background concentrations for the remaining time to calculate 8-h TWAs. Although using background values may theoretically contribute to dilution of exposure values, because of the fact that mechanics perform a certain number of brake jobs per day and conduct other tasks for the remainder of the day (e.g., pumping gas, other repairs), using background concentrations reported in the studies themselves is appropriate. The NIOSH studies reported TWA concentrations for sample durations ranging from 1.3 to 7.9 h for shops conducting between one and 15 brake jobs during the sampling period.

The studies by Johnson et al. (1979), Roberts (1980a, b), and Roberts and Zumwalde (1982) contain data (42 samples) collected in the 1970s in garages that generally did not employ dust-control procedures, whereas the Sheehy et al. (1989) study contains data (42 samples) collected in the 1980s primarily in garages that did use dust-control procedures. All of the data collected in the 1970s can be placed into one of two distinct groups: samples collected during periods of relatively low activity (defined here as an average of four brake jobs or fewer per week) *versus* samples collected during high-activity periods (defined here as an average of eight or more brake jobs per week). No such distinction can be made from the 1980s data, because activity levels were not reported in Sheehy et al. (1989); however, these data were considered to be representative of garage

practices in the 1980s when engineering and dust-control measures were used.

For the purposes of this paper, the 8-h TWA estimates were used to develop concentration distributions from each of the following data sets: (1) all data collected in the 1970s (“all 1970s”), (2) data collected in the 1970s during low to moderate weekly brake servicing (“low 1970s”), (3) data collected in the 1970s during high weekly brake servicing (“high 1970s”), and (4) all data collected in the 1980s (“all 1980s”). We believe that the data for the 1970s, when compressed air was still a common practice in brake repair activities, is generally representative of work activities in earlier years (Paustenbach et al., 2003); thus, we considered the “all 1970s” data to be representative of possible exposures during the 1940s and 1950s (see also Discussion). Exposure data from different time periods (1970s and 1980s) were not combined for the analyses presented in this paper. In a separate analysis (not presented), we applied a gradient of 10% per year to exposure concentration data from 1980 to 1989, such that 100% of garages were considered to have engineering controls in place by 1989, represented by the Sheehy et al. (1989) data. This gradient was applied to “fill the gap” in exposure data between the studies and represents a linear interpolation between the 1970s and 1980s data. Using the combination of 1970s and 1980s data resulted in lower cumulative exposure values compared with using only 1970s data; therefore, our presentation of exposure estimates using the 1970s concentration data represents a conservative estimate of cumulative exposure.

The only published US brake-job data that do not meet the aforementioned criteria are those of Dement (1972) and Moore (1988). In Dement (1972), sampling duration was not provided, so it is unclear whether the data presented in this paper represent long- or short-term measurements. As described elsewhere (Paustenbach et al., 2003), Moore (1988) does not provide measurements for individual mechanics, so these data could not be used in the present analysis of cumulative exposure. There are also some unpublished data from automobile company industrial hygiene surveys of brake mechanics. These surveys generally do not provide the same level of detail regarding sampling as the NIOSH studies and, therefore, these data are not included in this analysis; however, the results of these company studies (shown in Appendix A) are generally consistent with the NIOSH results (described in more detail below).

Distributions of Airborne Concentration Data

Distributions of 8-h TWA asbestos concentrations (in f/cm^3) were developed in a multistep process. First, the concentrations were fit to a lognormal distribution (Figure 1). The upper bound for these data was defined as three standard deviations (SDs) from the mean, where the distribution was truncated. The maximum values at three SDs from the mean were 30%–300% higher than the maximum values in the

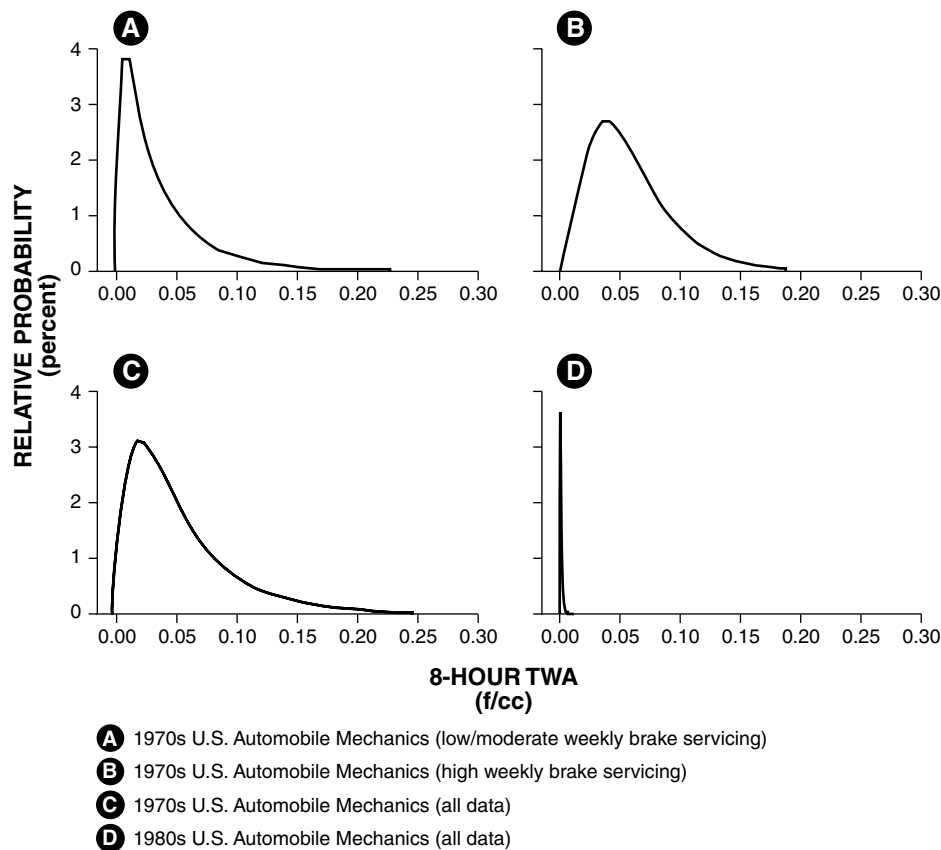


Figure 1. Distribution of 8-h TWA asbestos concentrations for US automobile mechanics in the 1970s and 1980s.

concentration data sets and thus reflect “plausible bounds” for each distribution (US Environmental Protection Agency (EPA) 1999). Results for truncated concentration distributions were compared with those for untruncated distributions, to quantify the effect of truncation on cumulative exposure, and to verify the appropriateness of distribution truncation. Second, a discrete custom distribution was also developed, setting the upper bound to the maximum value in each data set. Thus, the custom distribution was based solely on the raw data, with no truncation or other manipulations performed. Finally, the data were fit with a range of continuous distributions provided by the Crystal Ball software program to determine the best-fit distribution for the data set. The best-fit distribution was selected based on the Anderson–Darling test statistic, which favors distributions that have a good fit at the tails of the distribution (Stephens, 1974). No truncation was performed on the best-fit distribution.

Job Tenure Data

Job tenure was defined as the length of time a person spent as a mechanic regardless of employer; thus, interruptions in occupation are accounted for in overall tenure as a mechanic. Job tenure data that are specific to brake mechanics are not

available in the published literature or government reports. However, three times over the last two decades (1987, 1991, and 1996), the US Department of Labor’s Bureau of Labor Statistics (BLS) has published tenure data from the current population survey for various occupations, including automobile mechanics (US Department of Labor, 1997). In a ranking of occupations by years of tenure based on the January 1987 current population survey, Carey (1988) provided data on the years worked by automobile mechanics that includes work within the time period of interest — the 1960s through most of the 1980s. The later tenure reports do not appear to add substantial data for the time period of interest; however, the Carey study used a subset of the data presented by the BLS, provides more specific information related to automobile mechanics and also provides tenure data weighted by age, gender, and ethnicity. It is possible that the survey category “automobile mechanics” included most of the mechanics doing automobile brake-repair work in the US during those decades, because the BLS describes brake mechanics as a subset of the broader category, automobile mechanics (US Department of Labor, 1980). Therefore, although the tenure data for automobile mechanics are not specific to brake mechanics, they appear generally representative of this occupational cohort.

Carey (1988) estimated that automobile mechanics had a median tenure of 9.3 years for the time period spanning the mid-1960s to 1987, compared with a median tenure for all job categories of 6.6 years. When categorizing the population of 933,000 mechanics evaluated in the 1987 current population survey, more than 51% of the population had 9 years of tenure or less (Carey, 1988). Approximately 22% of the automobile mechanic population indicated job tenures of 20 years or more.

To account for variability in job tenure for mechanics, probability distributions were generated for automobile mechanics based on quartile data presented by Carey (1988). Using the Carey (1988) data, the categories of interest were tenures of 3 years or less, 4–9 years, 10–19 years, and greater than 20 years. A maximum job tenure of 45 years was assumed for the Carey data, based on the OSHA definition of a maximum working lifetime. The job tenure distribution for automobile mechanics derived directly from the Carey (1988) data indicates that many mechanics had relatively short tenures. This characteristic is owing, in part, to job turnover and in part to the design of the survey itself. For the remainder of this paper, we use the term “surveyed tenure” to indicate a tenure value calculated directly from cross-sectional survey data, “true tenure” to represent the actual tenure over a person’s lifetime, and “projected tenure” to represent an estimate of true tenure, based on adjustments to the surveyed tenure.

In general, cross-sectional surveys such as the BLS data suffer from two shortcomings when the data are applied for the purpose of estimating longitudinal or long-term behavior. First, respondents are asked to specify the total amount of time spent in a profession up to the point of the survey, so time spent in the profession after the survey is not accounted for. This leads to an underprediction of tenure duration for all surveyed individuals. If enough workers are sampled in a survey, if the size of a working population stays constant, and if tenure durations remain stable over time, the average

surveyed tenure would be approximately one-half the true tenure. In this case, if a random variable was generated that represented the fraction of surveyed tenure over true tenure, it would be a uniform distribution from 0 to 1.

Second, short-tenure durations are not sampled in proportion to their relative occurrence over a long time period. For example, consider a hypothetical workplace, where at all points in time, there are five short-term workers (1-year true tenure) and one long-term worker (10-year true tenure). Over a 50-year period, there will have been five long-term workers and 250 short-term workers. Therefore, the ratio of short- to long-term workers will be 5:1 in a cross-sectional survey and 50:1 in a longitudinal survey of at least 10 years duration or greater. This undersampling is also termed the “longevity bias,” which leads to overprediction of tenure duration (Price et al., 1998).

The survey tenure distribution derived directly from Carey does not account for these two shortcomings. Work by other investigators has outlined two methods for addressing these shortcomings and for providing reasonable estimates of projected tenure (Price et al., 1994, 1998; Burmaster, 2000). These investigators have determined that, for the data analyzed and presented, surveyed tenure will exceed projected tenure at all percentiles.

The median, mean, 95th, and 99th percentile surveyed tenure values from the Carey data, assuming a maximum working lifetime of 45 years, are 9.3, 12.8, 39.2, and 43.8 years, respectively. We applied the methodology of Price et al. (1994, 1998) to the Carey (1988) data and calculated median, mean, 95th, and 99th percentile projected tenure values of 6.3, 11.0, 36.0, and 49.1 years. Consistent with the results of Burmaster and Price et al., all surveyed tenure values exceed project tenure values, except at the 99th percentile. This exception is a result of applying a maximum value of 45 years to the survey data, while leaving the projected tenure unconstrained. The projected tenure distribution for automobile mechanics in Figure 2 provides the exposure duration

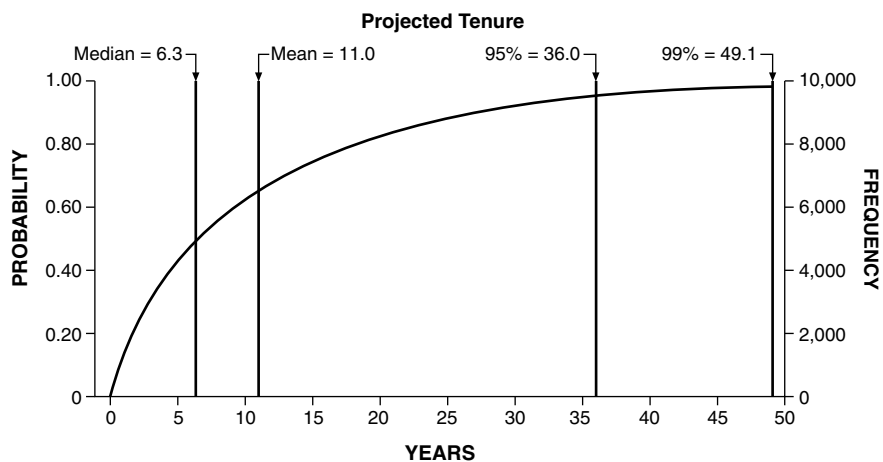


Figure 2. Distribution of job tenure for US automobile mechanics over a 45-year work history.

data used in the cumulative exposure calculations and shows the relative frequency of tenure durations.

Results

Figure 3 presents the 5th, 50th (median), and 95th (upper bound) percentile cumulative exposures for each concentration data set, as derived from the three distribution models (truncated lognormal, custom, and best-fit). All estimated cumulative exposure using the different models were below the 4.5 f/cm³ year theoretical lifetime cumulative exposure associated with the current PEL or 0.1 f/cm³.

Influence of Different Data-Fitting Models

Cumulative exposures obtained using truncated (at three SDs from the mean) lognormal airborne asbestos concentration distributions were compared with values obtained using untruncated distributions (data not shown). The 5th, 95th percentile, and mean values of estimated cumulative exposure using untruncated concentration distributions are all within 12% of values estimated using the truncated distribution, indicating that truncation has a minor effect on the overall estimated cumulative exposure. In addition, the fact that upper bounds of the truncated distributions are from 30% to 300% greater than the maximum values in the data sets indicates that the truncated lognormal distribution provides a plausible upper bound for the airborne asbestos concentration data.

As shown in Figure 3, the three different concentration distribution models (truncated lognormal, custom, and best-

fit) yield very similar cumulative exposures, with median values from each of the three models generally within 10% of one another, except for the “all 1970s” data, which differed by 30%. This suggests that, in general, the selection of the model has little effect on the distribution of concentrations.

Influence of Brake-Servicing Activity on Cumulative Exposure Estimates

Median cumulative exposures derived from the “low 1970s” data (maximum of four brake jobs per week) were lower than those derived from the “high 1970s” data (minimum of eight brake jobs per week) (Figure 3). The median exposures from the “low 1970s” data ranged from 0.16 to 0.17 f/cm³ year, whereas those from the “high 1970s” data ranged from 0.37 to 0.41 f/cm³ year. Upper-bound exposures from the “low 1970s” data were also lower than those associated with the “high 1970s” data. These results indicate that, although the ranges of cumulative exposures were fairly narrow regardless of the level of brake activity, mechanics changing fewer brakes experienced lower exposures, as would be expected.

Influence of Dust Control on Cumulative Exposure Estimates

It is clear that the implementation of dust-control measures resulted in lower cumulative exposures (Figure 3). For example, upper-bound exposures from the “all 1970s” (2.63–2.79 f/cm³ year), “low 1970s” (1.96–2.49 f/cm³ year), and “high 1970s” (2.69–2.71 f/cm³ year) data distributions were all at least 10 times higher than the upper-bound exposures derived from the “all 1980s” data (0.06–0.09 f/cm³ year).

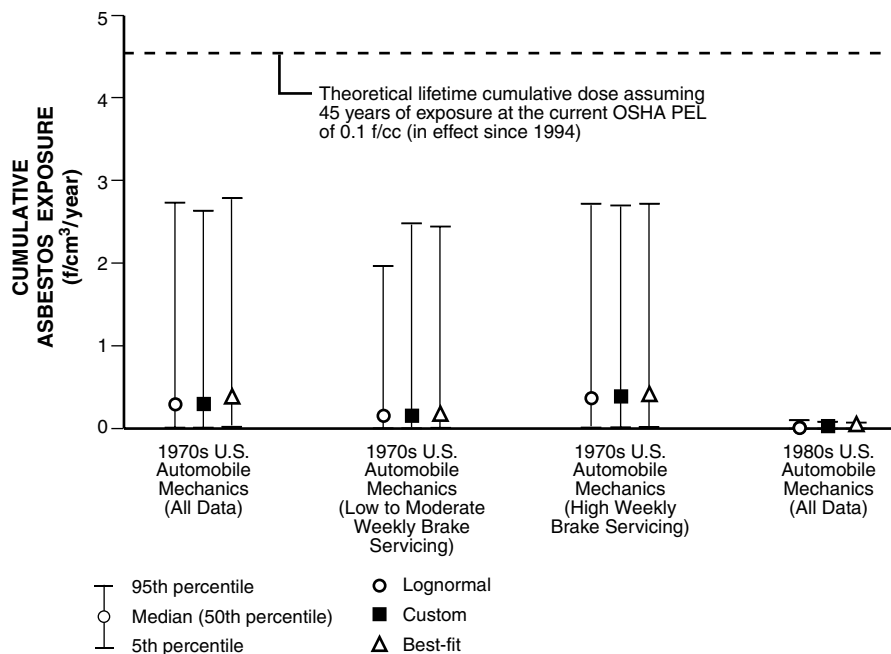


Figure 3. Cumulative asbestos exposure distributions of US automobile mechanics compared with OSHA theoretical lifetime dose over 45 years.

Discussion

This analysis indicates that over 95% of US mechanics performing automobile brake repair work experienced cumulative lifetime exposures to chrysotile of less than $3 \text{ f/cm}^3 \text{ year}$, regardless of the decade(s) during which the mechanic was employed. The results also indicate that over 99% of brake mechanics had cumulative exposures of less than $5 \text{ f/cm}^3 \text{ year}$. Not surprisingly, the cumulative exposures for brake mechanics working in garages with dust-control procedures in place (in the 1980s) were lower than those calculated for mechanics in previous decades.

Several factors influence the calculated cumulative exposures for brake mechanics, including exposure concentrations, estimates of job tenure, work activities and treatment/handling of brake products, and types of vehicles and brakes with which mechanics worked.

Exposure Concentrations

The Monte Carlo analyses and distributions of airborne asbestos concentrations used in the present study allow for the range of plausible concentrations to be evaluated, rather than relying on point estimates of concentration to represent all mechanics. The use of Monte Carlo techniques ensures that variability and uncertainty in the underlying data are accounted for, preventing undue influence of outliers or extreme data on the final results.

The mean 8-h TWA concentrations used in this study for US automobile brake mechanics, as summarized by Paustenbach et al. (2003), were 0.062 f/cm^3 in the 1970s and 0.002 f/cm^3 in the 1980s. When combining both the 1970s and 1980s concentration data from NIOSH, the mean 8-h TWA exposure concentration used in the present investigation was 0.03 f/cm^3 (range, $0.0001\text{--}0.14 \text{ f/cm}^3$). Plato et al. (1995) estimated a mean annual asbestos concentration of 0.09 f/cm^3 (range, $0.01\text{--}0.46 \text{ f/cm}^3$) in car mechanics. Rödelsperger et al. (1986) calculated mean exposure concentrations of car and truck mechanics as 0.04 and 0.08 f/cm^3 , respectively, based on a combination of activities. In the Gustavsson et al. (1990) study, data from garages were used to estimate asbestos concentrations for three levels of exposure: 0.0 , 0.08 , and 0.16 f/cm^3 . Thus, the mean airborne asbestos exposure concentrations used in the present study are within the range of the exposure concentrations used in other investigations of average cumulative lifetime occupational exposure. When combining all available data from the US and European studies, Paustenbach et al. (2003) reported a mean 8-h TWA of 0.04 f/cm^3 for automobile and light truck mechanics.

These authors found no statistically significant differences between 8-h TWA concentrations experienced by US versus Swedish brake mechanics (Plato study) in the late 1970s/early 1980s time frame (such a comparison cannot be conducted for the Rödelsperger et al. (1986) data, because

data for individual mechanics were not provided.) Therefore, the lower cumulative lifetime exposure estimate for US brake mechanics is more likely to be attributable to shorter job tenure (as compared with European mechanics) than to differences in airborne chrysotile concentrations.

Job Tenure

Based on our analysis, the median occupational tenure of an automobile mechanic was estimated to be 6.3 years, with a mean tenure of 11.0 years. In Europe, on the other hand, the tenure of mechanics in their chosen profession is significantly longer, with occupational tenures of between 20 and 30 years reported. For example, Plato et al. (1995) reported a mean employment of 29 years (range, 20–48 years) and a mean exposure of 26 years (range, 14–48 years) based on company records and subject questionnaires. Rödelsperger et al. (1986) report that the mean employment duration in German mechanics was 21 years (SD of 10 years).

The Current Population Survey data summarized by Carey (1988) are from a cross-sectional survey that provides a “snapshot” of the population and estimates of surveyed tenure. A cross-sectional survey does not represent the true tenure, because it measures the duration of a job to the moment of the survey, effectively censoring the future tenure in that job, and also undersamples short-duration tenures with respect to their occurrence over long time periods (Price et al., 1994, 1998; Burmaster, 2000). Correcting for both shortcomings results in projected tenures that are shorter than surveyed tenures for all but the highest percentiles. Analysis of trends in occupational tenure indicates that job tenure in some occupations, such as automobile and repair services, has increased over time (Carey, 1990). Given Carey’s observation that job tenure has increased over time, it is reasonable to infer that the job tenure of mechanics who ended their careers in the 1960s was shorter than those who ended their careers in later decades. Thus, use of the 1987 current population survey data for automobile mechanics provides a conservative starting point for calculating projected tenure, because it probably would not underestimate the years worked by brake mechanics in the 1960s, 1970s, and 1980s.

Work Activities and Treatment/Handling of Brake Products

Work activities such as grinding, cleaning, and general handling of brake products influence the cumulative asbestos exposure experienced by a mechanic. In the 1970s, the most common procedures used for cleaning brake assemblies included the use of compressed air or a wire brush (Johnson et al., 1979; Roberts and Zumwalde, 1982; Sheehy et al., 1989). Surveys of the airborne asbestos concentrations during brake servicing in the 1970s noted that the compressed air blowout of drum brakes was a major contributor to airborne fiber levels. With the introduction of bonded and pre-arced replacement brake shoes in the

1950s, the need for drilling, facing, and grinding during automobile brake repair was reduced substantially (Sheehy et al., 1989). However, there are limited reports of grinding of automobile brakes in foreign countries in the 1970s and 1980s (e.g., Jahn, 1983; Kauppinen and Korhonen, 1987; Cheng and O'Kelly, 1986; Rödelsperger et al., 1986), and it is therefore probable that grinding (and related activities) occurred to some degree in commercial garages in the US during the same time frame.

The introduction of dust-control technologies beginning in the late 1970s served to reduce the peak exposures experienced during cleaning and ultimately prevented the distribution of airborne dust into other areas of the work environment. These changes in dust control are reflected in the comparison of cumulative lifetime exposures calculated for US mechanics in the 1970s and 1980s. In addition, beginning in the 1980s, there was a transition from asbestos-containing brake linings to linings made from other materials, owing to concerns about the toxicity of asbestos and increasing regulation of asbestos fibers in end products. By the mid-1990s, non-asbestos alternatives gradually replaced asbestos-based materials on drum brakes and replaced some of the semi-metallic front disc pads on US vehicles (Jacko and Rhee, 1992). By 2000, vehicle manufacturers in the US had eliminated the use of chrysotile-based brake linings and pads in new vehicles for virtually all new passenger vehicles and light trucks sold in the US. It has been reported that asbestos may be present at some concentration in some after-market brakes today that are manufactured outside the US.

Comparison to the OSHA Occupational Limit

The calculated cumulative exposures for brake mechanics for both the 1970s and 1980s are significantly lower than the theoretical lifetime cumulative exposure of 90 f/cm³ year that would be permitted following 45 years of work at the former OSHA PEL of 2 f/cm³, which was in place from 1976 to 1985. In addition, all of the estimated cumulative lifetime exposures for automobile and light truck mechanics working in the late 1980s and early 1990s are also below the theoretical lifetime cumulative exposure of 9.0 f/cm³ year, assuming 45 years at the PEL of 0.2 f/cm³ (in place from 1986 to 1994), as are the cumulative exposures of mechanics servicing brakes in the period from the late 1990s to the present. More than 95% of the exposures would be expected to be less than the cumulative exposure of 4.5 f/cm³ year, which would be associated with 45 years of exposure at the current OSHA PEL of 0.1 f/cm³ (in place since 1994). Thus, the cumulative exposures experienced by these mechanics were well below those associated with the occupational standards of the 1960s to the present.

Comparison to European Cumulative Exposure Estimates

The three cumulative occupational lifetime exposure studies published to date for European brake mechanics reported

lifetime asbestos exposures generally greater than those calculated for US brake mechanics (Figure 4), although results are consistent. The average cumulative lifetime exposure for the three European studies is 1.8 f/cm³ years (mean value) as compared with mean values of 0.28 to 0.36 f/cm³ year for US mechanics working in the 1950s, 1960s, and 1970s. These slight differences are primarily owing to the longer job tenure of mechanics in Europe.

Rödelsperger et al. (1986) calculated a mean exposure of 0.54 f/cm³ year over a 30-year period (1955–1985) and a median of 0.3 f/cm³ year for mechanics in German car and truck workshops (range 0 to 13 f/cm³ year). Some mechanics were probably also exposed outside of the 30-year time period, but the mean employment duration was 21 years (SD of 10 years). Gustavsson et al. (1990) reported a mean lifetime cumulative exposure of 2.2 fiber/cm³ years for brake mechanics exposed between 1945 and 1970. Similar to the Rödelsperger study, some mechanics may have been exposed outside of the 25-year period examined. Gustavsson et al. (1990) reported up to 6 f/cm³ year for bus garage mechanics (no truck or bus mechanics were included in the current analysis). Finally, Plato et al. (1995) reported a mean cumulative exposure of 2.6 f/cm³ year (range, 0.1–11.6 f/cm³ year) using their approach for brake mechanics exposed during the 1938–1986 time period. This is consistent with a previous study published by this group of authors, who reported a median lifetime exposure of 2.3 f/cm³ years (Dahlqvist et al., 1992). The Plato study, like those of Gustavsson and Rödelsperger, also includes some truck and bus mechanics.

The shorter tenure of US automobile mechanics compared with that observed in Europe is not surprising. For example, in Europe, the rigor of the apprentice and journeyman programs in the vehicle mechanic industry apparently bring about a more stable workforce and longer job tenure among workers in these occupations than in equivalent occupations in the US. This is clearly evident by comparing the tenure of greater than 20 years in Europe to the mean tenure of US mechanics of 11.0 years.

Comparison to No-Effects Threshold Estimates for Asbestosis and Lung Cancer

The upper-bound estimates of the cumulative exposure for US automobile mechanics are well below the 25-f/cm³ year chrysotile exposure threshold that has been suggested for asbestosis (Dupre et al., 1984; Doll and Peto, 1985; Churg and Green, 1988) and lung cancer (Browne, 1986; Churg, 1998). Even the upper-bound (95th percentile) estimates for the 1970s (1.96 to 2.79 f/cm³ year) are approximately 10-fold below the suggested threshold. Because brake servicing conditions during the early 1970s (i.e., those with no dust control technologies in place) are probably to be representative of earlier decades, we believe this analysis indicates that brake mechanic exposures during the 1950s through 1970s,

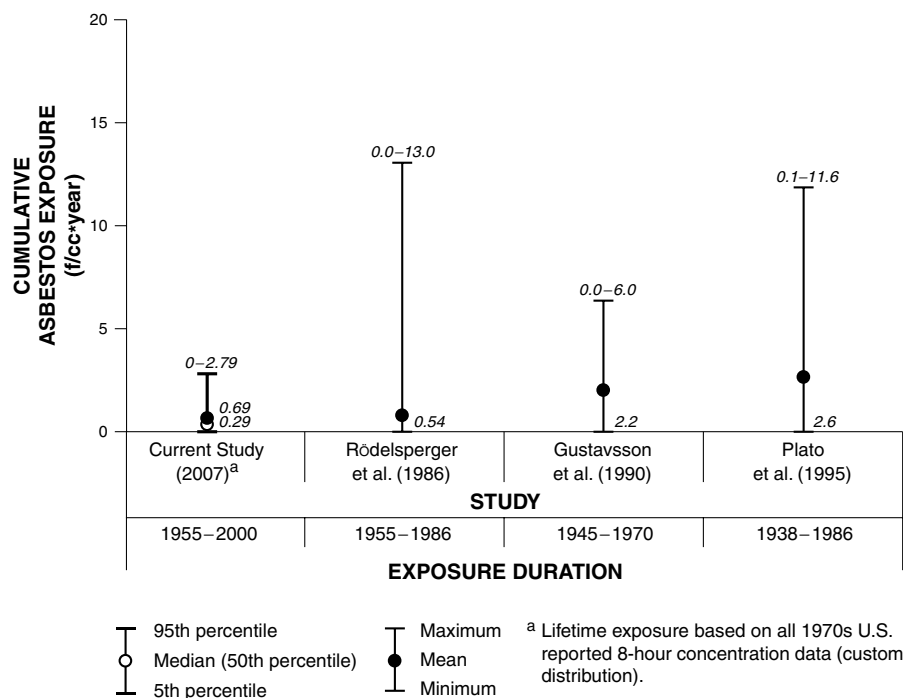


Figure 4. Comparison of cumulative asbestos exposure for US automobile mechanics and studies of European mechanics.

when brake rebuilding activities ceased, were also below the suggested threshold. The 95th percentiles of the 1980s estimates (0.07 to 0.10 f/cm³ year), a period during which dust control was far more prevalent, are over 100-fold below the suggested threshold.

These findings are consistent with the numerous epidemiology studies of US brake mechanics. Regarding asbestosis, data presented in Nicholson et al. (1984), Marcus et al. (1987), Elliehausen et al. (1985), and Boillat and Lob (1973) found no increased incidence of abnormal X-rays or lung function in brake-repair workers. With respect to lung cancer, several studies (wherein the results were adjusted for smoking) found no increase in lung cancer incidence in occupations that included or consisted of US brake mechanics. Specifically, Williams et al. (1977), Hrubec et al. (1992, 1995), Lerchen et al. (1987), and Vineis et al. (1988) all examined case populations ranging in size from several hundred (e.g., 333 cases in Lerchen et al., 1987) to several hundred thousand (e.g., 248,046 total cases in cohort study by Hrubec et al. (1992, 1995)), and none found an increased risk of lung cancer associated with vehicle repair or garage work. Although we are not aware of any evaluations of bystander exposure to chrysotile as a result of brake repair activities (e.g., service station workers not directly involved in brake repair, or so-called “take-home” exposures wherein fibers that have adhered to clothing of the brake mechanic are subsequently released in the home), it can be logically inferred that any such chrysotile exposures will be lower than those experienced by a career brake mechanic.

Comparison to Asbestos Exposures in Other Occupations
Most asbestos exposure assessments have evaluated workers involved in the mining of asbestos, the manufacture of asbestos products, and certain other occupations. Many of these occupations are known to be associated with an increased risk of asbestos-related respiratory disease. As shown in Figure 5, the cumulative lifetime exposure for brake mechanics is a very small fraction (between one 100th and one 1,000th) of the exposures associated with other occupations that are typically associated with exposure to chrysotile (data from Hodgson and Darnton, 2000). Furthermore, there is abundant scientific information to suggest that chrysotile asbestos is far less carcinogenic than the amphibole types of asbestos (Hodgson and Darnton, 2000; Berman and Crump, 2003). In short, the comparatively low chrysotile exposures estimated for mechanics are consistent with the lack of risk of asbestos-related diseases reported for this occupation.

Risk Assessment Applications

Brake mechanic exposures are appropriately characterized as those involving short chrysotile fiber (Sheehy et al., 1989), primarily less than 5 μm in length, with most daily exposures during the 1970s and 1980s to fibers (greater than 5 μm in length) less than the current OSHA PEL of 0.1 f/cm³. There are several other occupations, particularly in the construction industry, that use or have used products that contain chrysotile, including electricians, carpenters, welders, installers of floor tile, roofers, and masons. For most of these

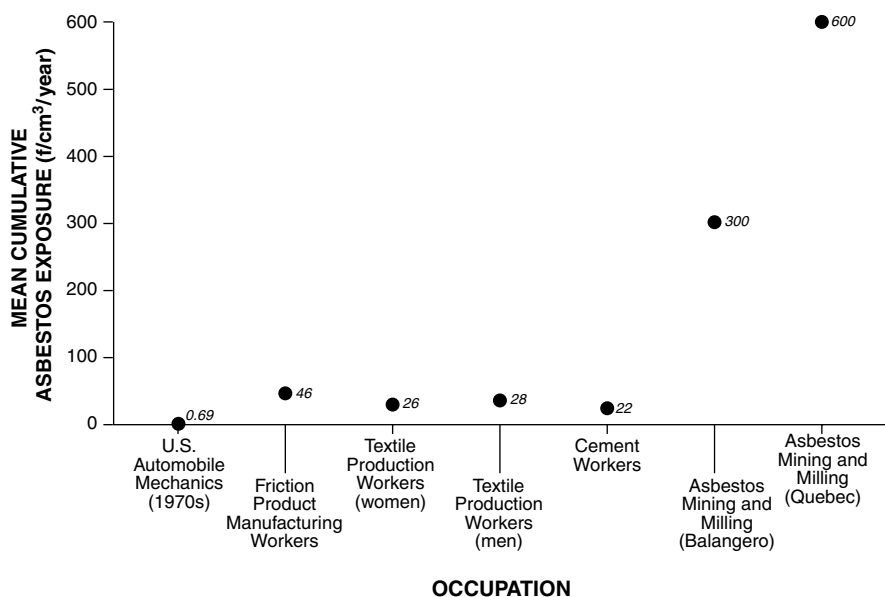


Figure 5. Comparison of mean cumulative asbestos exposure of US automobile mechanics to other asbestos-related occupations.

occupations, there is sufficient industrial hygiene data and job tenure information available to develop reasonable estimates of cumulative chrysotile exposures. However, unlike brake mechanics, there is often limited exposure and medical information (e.g., epidemiologic data) that can be used to determine the degree of risk associated with these occupations. Specifically, the epidemiologic information is either absent or is confounded by the fact that these workers often experienced significant exposures to amphibole asbestos (i.e., insulation) during work in naval yards or in other occupations during their careers.

The cumulative exposure estimates for brake mechanics, therefore, could provide an exposure “benchmark” or empirical threshold for estimating the risks associated with other populations that were likely exposed to low concentrations of airborne chrysotile asbestos. Specifically, if the cumulative chrysotile exposures associated with these occupations are determined to be similar to or less than the exposures estimated for brake mechanics (and assuming a similar degree of uncertainty in the exposure estimates), then such a comparison would indicate that the use of such products does not pose a significant respiratory hazard to the workers, bystanders, or persons in the home. In addition, the cumulative exposure and relative risk estimates for vehicle mechanics could be used to refine current theoretical risk-assessment models for asbestos. For example, the automobile mechanics data provide a cumulative lifetime exposure that is less than one 10th of the least-exposed occupational group currently considered in the Berman and Crump (2003) assessment. In addition, the vehicle mechanics’ data also suggest that an empirical threshold could be added to the chrysotile risk assessment model to account for the lack of association between occupational exposure and risk. This

would allow for further refinement of the risk coefficients and potency estimates provided in the EPA’s 2003 proposed model for estimating the risks of low level exposure to chrysotile asbestos.

Summary

In view of this review and analyses of the available data on the cumulative lifetime exposures to asbestos of US vehicle mechanics servicing brakes, the following conclusions can be offered:

- The median and upper-bound cumulative exposures for US automobile and light truck brake mechanics who worked in the 1950s, 1960s, and 1970s without installation of specific dust-control technologies ranged (50 to 95th percentile) from 0.16 to 0.41 and 1.96 to 2.79 f/cm³ years, respectively. The cumulative exposures of brake mechanics who worked in garages with dust-control measures in place were substantially lower, with median and upper-bound (50 to 95th percentile) values that ranged from 0.010 to 0.012 and 0.07 to 0.10 f/cm³ year, respectively.
- The cumulative occupational lifetime exposures of US brake mechanics were well below the cumulative lifetime exposure of asbestos permitted under the OSHA PEL of the time (assuming 45 years of work).
- The estimated cumulative lifetime exposures for US brake mechanics are consistent with, but generally slightly lower than, those reported for brake mechanics in Europe, which is owing, primarily, to the shorter job tenure of US mechanics.
- The estimated cumulative lifetime exposures for brake mechanics, compared with other occupations, indicate that

brake mechanics experience exposures between one 100th and one 1,000th that of other occupational groups that handled raw asbestos or friable asbestos products.

- This information should be useful to agencies when revisions to occupational and environmental standards for asbestos are revisited. In addition, the cumulative exposure estimates and epidemiology data for brake mechanics could be used to refine the risk assessments for other chrysotile-exposed populations.

Acknowledgements

The research supporting this analysis and the time needed to write the paper were funded almost entirely by Daimler-Chrysler Corporation, Ford Motor Company, and General Motors Corporation, which have been involved in litigation involving brake dust. These three funding sources (and their counsel) did not provide editorial comments or review the paper before submission to the journal. Some of the authors have served and may continue to serve as expert witnesses regarding the historical exposures of mechanics to asbestos during brake repair.

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Appendix A

Results of exposure surveys conducted by automobile companies

Table 1.

Sampling year	8-h TWA (f/cm ³)	Description	Study
1973	0.13	Passenger vehicle brake rebuilding, disc brakes on all four wheels	Lick (1973)
1973	0.06	General brake work	Ford (1974)
1975	ND ^a	Brake mechanic	Krebs (1976)
1980	<0.03	Brake shoe replacement	O'Brien (1981)
1989	<0.02	Brake inspection/change	Fischer (1989a)
1989	<0.03	Brake inspection operation	Fischer (1989b)

^aND, not detected (no detection limit provided).References:

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