An evaluation of short-term exposures of brake mechanics to asbestos during automotive and truck brake cleaning and machining activities

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Historically, the greatest contributions to airborne asbestos concentrations during brake repair work were likely due to specific, short-duration, dust-generating activities. In this paper, the available short-term asbestos air sampling data for mechanics collected during the cleaning and machining of vehicle brakes are evaluated to determine their impact on both short-term and daily exposures. The high degree of variability and lack of transparency for most of the short-term samples limit their use in reconstructing past asbestos exposures for brake mechanics. However, the data are useful in evaluating how reducing short-term, dust-generating activities reduced long-term exposures, especially for auto brake mechanics. Using the short-term dose data for grinding brake linings from these same studies, in combination with existing time-weighted average (TWA) data collected in decades after grinding was commonplace in rebuilding brake shoes, an average 8-h TWA of approximately 0.10 f/cc was estimated for auto brake mechanics that performed arc grinding of linings during automobile brake repair (in the 1960s or earlier). In the 1970s and early 1980s, a decline in machining activities led to a decrease in the 8-h TWA to approximately 0.063 f/cc. Improved cleaning methods in the late 1980s further reduced the 8-h TWA for most brake mechanics to about 0.0021 f/cc. It is noteworthy that when compared with the original OSHA excursion level, only 15 of the more than 300 short-term concentrations for brake mechanics measured during the 1970s and 1980s possibly exceeded the standard. Considering exposure duration, none of the short-term exposures were above the current OSHA excursion level.

Keywords: asbestos, brake dust, mechanics, industrial hygiene, short-term samples, exposure assessment.

Introduction

Epidemiology studies of insulation workers in the 1960s (e.g., Selikoff et al., 1964) were the first to show conclusively that use of an asbestos-containing product could pose a cancer risk to workers. As asbestos was also a major component of friction materials in automobiles and trucks (e.g., brake linings and clutch plates), researchers also began to investigate the degree of asbestos exposure experienced by vehicle mechanics during the servicing of brakes. The first survey of airborne asbestos levels associated with brake servicing was conducted in the United Kingdom in 1968 (Hickish and Knight, 1970). The first exposure survey of brake mechanics in the United States was published by the National Institute of Occupational Safety and Health (NIOSH) in 1972 (Dement, 1972), followed by several additional NIOSH surveys in the 1970s and 1980s (Johnson et al., 1979; Roberts, 1980a, b; Roberts and Zumwalde, 1982; Sheehy et al., 1989). During this same time period, major studies of potential exposures of brake mechanics were also conducted in Germany (Rödelsperger et al., 1986), Sweden (Plato et al., 1995), and Finland (Kauppinen and Korhonen, 1987). Paustenbach et al. (2003) evaluated the published airborne asbestos concentrations for brake mechanics and developed 8-h time-weighted average (8-h TWA) asbestos concentrations from the personal air sampling data. This study found that the mean 8-h TWA asbestos concentration for automobile brake mechanics in the United States decreased from 0.063 ± 0.032 fibers per cubic centimeter (f/cc) in the 1970s (n = 42) to 0.0021 ± 0.00036 f/cc in the late 1980s (n = 42), due largely to the introduction of dust control technologies during cleaning activities.

As with many types of occupational dust exposures, the TWA asbestos concentrations associated with historical brake repair were likely due to short-term activities that generated the greatest quantities of dust. These short-duration activities involved the removal of brake-wear
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weight (Anderson et al., 1973; Jacko et al., 1973; Williams 1973) to remove brake wear debris, which is composed mostly of non-fibrous materials containing less than 1% asbestos by weight (Anderson et al., 1973; Jacko et al., 1973; Williams 1973). For vehicles with asbestos brake linings or pads, the potential for the release of airborne asbestos is thought to have been greatest during cleaning of the brake assemblies and machining activities, because the old disc brake pads were simply removed and replaced with new ones. By the mid-1970s, most automobiles in the United States had a combination of front disc brakes and rear drum brakes. By the 1990s, most automobiles sold in the United States had disc brakes on all four wheels.

Due to the costs involved, some service facilities still rebuild the much larger bus and heavy-truck brakes by removing the old linings from the shoes and installing new ones. This process may still involve machining activities, including removing the old rivets and linings, and drilling and riveting the new linings.
Table 1. Asbestos short-term exposure related activities and coding.

| General activity | Specific activity | Abbreviation code |
|------------------|------------------|-------------------|
| Cleaning         | Cleaning disc brake assembly with dry brush | CCD |
| Cleaning         | Cleaning drum brake assembly with compressed air | CMA |
| Cleaning         | Cleaning drum brake assembly with compressed air and solvent | CMAS |
| Cleaning         | Cleaning drum brake assembly with compressed air and vacuum | CMAV |
| Cleaning         | Cleaning drum brake assembly with vacuum | CMV |
| Cleaning         | Cleaning drum brake assembly with dry brush | CMD |
| Cleaning         | Cleaning drum brake assembly with dry brush and vacuum | CMDV |
| Cleaning         | Cleaning drum brake assembly with wet brush | CMW |
| Cleaning         | Cleaning drum brake assembly with damp cloth | CMC |
| Cleaning         | Cleaning drum brake assembly with water | CMH |
| Machining        | Beveling new linings | B |
| Machining        | Grinding new linings | GL |
| Machining        | Grinding linings with exhaust control | GLE |
| Machining        | Grinding linings on wheels with exhaust control | GLOE |
| Machining        | Grinding linings with out exhaust | GLWE |
| Machining        | Grinding used linings | GLU |
| Machining        | Rivet removal | RR |
| Machining        | Preparation of brake shoes before riveting new linings | CS |
| Machining        | Rivet installation | RI |
| Machining        | Turning brake drums | MD |
| Machining        | Turning brake discs | MC |
| Machining        | Sanding | S |
| Other            | Assembly of drum brakes | AD |
| Other            | Changing of discs | AC |
| Other            | Changing clutch lining | AT |
| Other            | Cleaning of disc brakes with compressed air and changing pads | CCAP |
| Other            | Cleaning of brake drums with dry brush | CDD |
| Other            | Opening of drum brakes | OM |
| Other            | Mixed activities | MX |
| Other            | Miscellaneous activities | MI |

Methods

Data Collection

To identify and collect relevant asbestos air sampling data for vehicle brake mechanics, literature searches of 35 databases from the Thomson DIALOG aggregator search system were conducted. This search system has international coverage of tens of thousands of journals, government studies, conference proceedings, technical reports, and monographs. Databases searched included Medline, EMBASE, and others related to medicine; toxicology, environment, materials, transportation, engineering, and other related technical fields. Keywords included various forms of asbestos terminology (e.g., asbestos, chrysotile, brakes) limited to the title and descriptor fields of the records.

Given the disparate nature of the studies in terms of methodology and reported level of detail, it was necessary to establish minimum criteria for identifying those data most appropriate for use in quantitative analyses. Specifically, the following criteria were used to identify the air sampling data that were most appropriate for use in quantifying short-term exposures during brake cleaning and machining activities: (1) the asbestos air sampling data were published in the peer-reviewed literature or in government reports; (2) only personal sampling measurements collected in the breathing zone were evaluated; (3) samples had to be associated with a specific cleaning or machining activity; (4) samples had to have reported sampling durations; and (5) samples had to have a reported asbestos concentration or a mean and range of concentrations measured in standard units of fibers per cubic centimeter (fibers > 5 μm in length) and analyzed using phase contrast microscopy methods. As the brake-servicing activities for cars and light trucks are known to have been quite different from those of heavy trucks and buses, these two categories of vehicles are considered separately.

A summary of the five government reports (Johnson et al., 1979; Roberts, 1980a, b; Roberts and Zumwalde, 1982; Sheehy et al., 1989) and ten published studies (Hatch, 1970; Knight and Hickish, 1970; Lorimer et al., 1976; Rohl et al., 1976; Jahn, 1983; Cheng and O’Kelly, 1986; Rödelsperger et al., 1986; Kauppinen and Korhonen, 1987; Plato et al., 1995; Weir et al., 2001) identified as containing short-term asbestos air sampling data for brake mechanics is presented in Table 2. These 15 studies, conducted in the United States, United Kingdom, Finland, Germany, and Hong Kong between 1968 and 2000, represent more than 300 short-term personal asbestos air samples for automobile and truck mechanics collected during brake machining and cleaning activities. Tables 3 and 4 present more detailed information on the individual air samples collected during specific brake repair activities involving cars and light trucks, and heavy trucks and buses, respectively. The manner in which each sample is evaluated in this paper is indicated in these tables in the “Concentration analysis” and “Short-term dose analysis” columns. Rödelsperger et al. (1986) was the only report that took into account the exposure duration, providing a summary of short-term asbestos doses for brake mechanics performing cleaning and machining activities for a duration of 3 to 60 minutes.

Seven other studies (Lloyd, 1975; Johnson, 1976; Rohl et al., 1977; Roberts and Zumwalde, 1980; Nicholson et al., 1983; Jahn et al., 1985; Rödelsperger, 1987) with short-term asbestos air sampling data were identified, but were excluded because these data duplicated those in the other evaluated studies. A few studies (Knight and Hickish, 1970; Dement, 1972; Lorimer et al., 1976) were not included in the
quantitative evaluation because they lacked sufficient sampling information.

**Data Analysis**

The short-term asbestos air sampling data were interpreted using two different methods. First, all samples that were collected for less than 15 min were evaluated in the "concentration analysis." As some of the concentration data were presented as summaries, it was only possible to determine the total number of samples and the averages, maximums, and minimums. Because most of the data for individual samples were unreported in these summaries, the summary data could not be aggregated with individual sample data for further statistical analyses. Second, all individual samples with both a concentration and a specific sampling duration were used to calculate short-term asbestos doses associated with machining and cleaning activities to account for the relatively wide range of sampling durations associated with specific activities. For the purposes of this paper, these calculations are termed "short-term dose analyses." Specifically, short-term asbestos doses were calculated as time-integrated estimates in terms of f/cc*min:

\[
\text{Short-term dose (f/cc*min) = concentration (f/cc) } \\
\times \text{sampling duration (min)}
\]

**Reconstructing Past Long-Term Exposures**

It seems reasonable that the short-term dose data for grinding brake linings could be used to adjust the available long-term TWA concentrations collected after grinding had decreased to estimate earlier TWA concentrations for mechanics performing brake jobs where the grinding of linings had occurred. Potential mechanic exposures that included grinding were estimated based on the available, later brake-job and 8-h TWA concentrations and short-term grinding dose and duration data. The TWA for a brake job including grinding was estimated as follows:

\[
\text{TWA}_{BJ+G} = ((\text{TWA}_{BJ} \times \text{duration}) + \text{grinding dose}) \\
/ (\text{brake job duration} + \text{grinding duration})
\]

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**Table 2. Summary of short-term brake dust exposure studies.**

| Author                  | Type of facility                  | Vehicle typea | Number of samples | Sampling durationsb | Methods          |
|-------------------------|-----------------------------------|---------------|-------------------|---------------------|-----------------|
| Knight and Hickish (1970) | Dealership Service Bay           | T             | 2                 | NA                  | BOHS            |
| Hatch (1970)            | Fleet Service Garage             | C             | 1                 | I                   | Unknown         |
| Dement (1972)           | Municipal Garage                 | C             | 4                 | 15                  | NA              |
| Lorimer et al. (1976)   | Dealership, Taxi Fleet Repair, Municipal Truck Shop | C       | 15                | 9                   | R               |
| Rohl et al. (1976)      | Dealership, Taxi Fleet Repair, Municipal Truck Shop | C       | 1                 | 3                   | R               |
| Johnson et al. (1979)   | Fleet Service Garage, Auto Brake Service, Truck Brake Maintenance | C       | 4                 | 1                   | R               |
| Roberts (1980a)         | Brake/Front-end                  | C             | 1                 |                     | OSHA/NIOSH      |
| Roberts (1980b)         | Commercial Brake                 | C             | 2                 |                     | OSHA/NIOSH      |
| Roberts and Zumwalde (1982) | Brake/Front-end, Large Brake Service, Municipal Garage, Fleet Service Garage | C       |                     | 22                  | OSHA/NIOSH      |
| Jahn (1983)             | 22 Garages in Germany            | T             | 1                 |                     | OSHA/NIOSH      |
| Rödelsperger et al. (1986) | 76 Garages in Germany       | T             | 3                 |                     | OSHA/NIOSH      |
| Cheng and O’Kelly (1986) | 12 Garages in Hong Kong         | T             | 3                 |                     | ARC             |
| Kauppinen and Korhonen (1987) | 24 Garages in Finland       | C             | 35                | 1                   | SFS             |
| Weir et al. (2001)      | Auto/Truck Repair                | T             | 173               | 3                   | SFS             |

*a Cars and light trucks (C), heavy trucks and buses (T), or combined cars and light trucks and heavy trucks and buses (C/T).

*b Unknown sample type.

*c Represents samples taken with a probe held near the head (P-head).

*d Represents combined personal and area samples.

*e Durations given for individual samples (I) or a range (R).
Table 3. Data for short-term brake dust exposure studies for mechanics servicing cars and light trucks.

| Author | Sampling duration (min) | Sample type | Sample size | Concentration (f/cc) | Short-term dose (f/cc*min) | General activity | Specific activity | Concentration analysis | Short-term dose analysis | Reason for exclusion |
|--------|-------------------------|-------------|-------------|----------------------|----------------------------|------------------|------------------|----------------------|----------------------|-----------------------|
| Hatch (1970) | 10 | S | 1 | 0.8* | NA | Cleaning | CMA | N | N | Collected inside dust cloud |
| Dement (1972) | NA | NA | 1 | 2.0 | NA | Cleaning | CMA | N | N | No sampling type or duration reported |
| Dement (1972) | NA | NA | 1 | 0.8 | NA | Cleaning | CMA | N | N | No sampling type or duration reported |
| Dement (1972) | NA | NA | 1 | 0.6 | NA | Cleaning | CMA | N | N | No sampling type or duration reported |
| Dement (1972) | NA | NA | 1 | 3.2 | NA | Cleaning | CMA | N | N | No sampling type or duration reported |
| Dement (1972) | NA | NA | 1 | 2.1 | NA | Cleaning | CMA | N | N | No sampling type or duration reported |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | P | 1 | 13.8 | NA | Cleaning | CMA | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | P | 1 | 29.4 | NA | Cleaning | CMA | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | P | 1 | 6.6 | NA | Cleaning | CMA | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | P | 1 | 13.6 | NA | Cleaning | CMA | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | P | 1 | 3.8 | NA | Cleaning | CMA | N | N | Distance > 5 ft |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | P | 1 | 2.0 | NA | Cleaning | CMA | N | N | Distance > 5 ft |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | P | 1 | 4.2 | NA | Cleaning | CMA | N | N | Distance > 5 ft |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | P | 1 | 0.4 | NA | Cleaning | CMA | N | N | Distance > 5 ft |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | P | 1 | 4.8 | NA | Cleaning | CMA | N | N | Distance > 5 ft |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | A | 1 | 0.3 | NA | Cleaning | CMA | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | A | 1 | 0.8 | NA | Cleaning | CMA | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | A | 1 | 0.2 | NA | Cleaning | CMA | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | A | 1 | 0.1 | NA | Cleaning | CMA | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | A | 1 | 0.1 | NA | Cleaning | CMA | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | A | 1 | 0.1 | NA | Cleaning | CMA | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | A | 1 | 0.1 | NA | Cleaning | CMA | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | A | 1 | 4.8 | NA | Machining | GL | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | A | 1 | 2.7 | NA | Machining | GL | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2-10 | A | 1 | 0.4 | NA | Cleaning | CMA | N | N | Area sample |
| Rohl et al. (1976) | 3-8 | P | 1 | 3.6 | NA | Cleaning | CMD | Y | N | Sampling duration reported as range |
| Rohl et al. (1976) | 3-8 | P | 1 | 1.3 | NA | Cleaning | CMD | Y | N | Sampling duration reported as range |
| Rohl et al. (1976) | 3-8 | A | 1 | 0.0 | NA | Cleaning | CMD | N | N | Area sample |
| Rohl et al. (1976) | 3-8 | A | 1 | 0.1 | NA | Cleaning | CMD | N | N | Area sample |
| Rohl et al. (1976) | 3-8 | A | 1 | 0.2 | NA | Cleaning | CMD | N | N | Area sample |
| Johnson et al. (1979) | 3 | P | 1 | 1.82 | 5.5 | Cleaning | CMD | N | N | Presented in Roberts and Zumwalde (1982) |
Table 3. Continued

| Author                     | Sampling duration (min) | Sample type | Sample size | Concentration (f/cc) | Specific activity | Concentration analysis | Short-term dose analysis | Reason for exclusion |
|----------------------------|-------------------------|-------------|-------------|----------------------|-------------------|------------------------|-------------------------|----------------------|
| Johnson et al. (1979)      | 0.5–1.0 (0.75)          | P           | 1           | 2.84                 | Cleaning          | CMA                    | N                       | N                    | Presented in Roberts and Zumwalde (1982) |
| Johnson et al. (1979)      | 0.5–1.0 (0.75)          | P           | 1           | 0.68                 | Cleaning          | CMA                    | N                       | N                    | Presented in Roberts and Zumwalde (1982) |
| Johnson et al. (1979)      | 0.5–1.0 (0.75)          | P           | 1           | 14.54                | Cleaning          | CMD                    | N                       | N                    | Presented in Roberts and Zumwalde (1982) |
| Johnson et al. (1979)      | 0.5–1.0 (0.75)          | P           | 1           | 0.45                 | Cleaning          | CMD                    | N                       | N                    | Presented in Roberts and Zumwalde (1982) |
| Roberts (1980a)            | 1                       | P           | 1           | 0.33                 | Cleaning          | CMA                    | Y                       | Y                    | NA |
| Roberts (1980b)            | 1                       | P           | 1           | 0.25                 | Cleaning          | CMAS                   | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 3                       | P           | 1           | 0.37                 | Cleaning          | CMAS                   | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 3                       | P           | 1           | 1.82                 | Cleaning          | CMA                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 0.63                    | P           | 1           | 0.14                 | Cleaning          | CMA                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 0.57                    | P           | 1           | 0.77                 | Cleaning          | CMA                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 0.43                    | P           | 1           | 0.35                 | Cleaning          | CMA                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 0.33                    | P           | 1           | 2.69                 | Cleaning          | CMA                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 0.91                    | P           | 1           | 2.84                 | Cleaning          | CMA                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 0.75                    | P           | 1           | 14.54                | Cleaning          | CMA                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 0.5                     | P           | 1           | 1.5                  | Cleaning          | CMA                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 0.5                     | P           | 1           | 0.25                 | Cleaning          | CMAS                   | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 0.75                    | P           | 1           | 0.45                 | Cleaning          | CMAS                   | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 0.5                     | P           | 1           | 0.68                 | Cleaning          | CMAS                   | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 0.75                    | P           | 1           | 0.37                 | Cleaning          | CMAS                   | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 0.5                     | P           | 1           | 0.81                 | Cleaning          | CMD                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 21                      | P           | 1           | 0.61                 | Cleaning          | CMD                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 12                      | P           | 1           | 15                   | Cleaning          | CMW                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 21                      | P           | 1           | 2.62                 | Cleaning          | CMW                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 3                       | P           | 1           | 2.28                 | Cleaning          | CMW                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 21                      | P           | 1           | 0.87                 | Cleaning          | CMW                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 3                       | P           | 1           | 1                   | Cleaning          | CMW                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 2                       | P           | 1           | 0.07                 | Cleaning          | CMW                    | Y                       | Y                    | NA |
| Roberts and Zumwalde (1982) | 0.09                    | P           | 1           | 0.03                 | Cleaning          | CMV                    | Y                       | Y                    | NA |
| Jahn (1983)                | 22                      | P           | 1           | 0.23                 | Other              | AC                     | N                       | N                    | Not a specific activity |
| Jahn (1983)                | 68                      | P           | 1           | 0.04                 | Other              | CCD                    | N                       | Y                    | Duration >15 min |
| Jahn (1983)                | 28                      | P           | 1           | 0.06                 | Other              | Cleaning               | CCD                    | N                       | Y                    | Duration >15 min |
| Jahn (1983)                | 34                      | P           | 1           | 0.22                 | Other              | Cleaning               | CCD                    | N                       | Y                    | Duration >15 min |
| Jahn (1983)                | 22                      | P           | 1           | 0.14                 | Other              | MX                     | N                       | N                    | Not a specific activity |
| Jahn (1983)                | 46                      | P           | 1           | 0.07                 | Other              | MX                     | N                       | N                    | Not a specific activity |
| Jahn (1983)                | 12                      | P           | 1           | 0.33                 | Other              | MX                     | N                       | N                    | Not a specific activity |
| Jahn (1983)                | 37                      | P           | 1           | 0.13                 | Other              | MX                     | N                       | N                    | Not a specific activity |
| Jahn (1983)                | 36                      | P           | 1           | 0.24                 | Machining           | GL                     | N                       | Y                    | Duration >15 min |
| Jahn (1983)                | 2.2                     | P (Head)    | 1           | 1.7                  | Machining           | CCD                    | N                       | N                    | Collected near head using probe |
| Jahn (1983)                | 10                      | P (Head)    | 1           | 6.7                  | Machining           | S                      | N                       | N                    | Collected near head using probe |
| Jahn (1983)                | 0.4                     | P (Head)    | 1           | 6                    | Machining           | S                      | N                       | N                    | Collected near head using probe |
| Jahn (1983)                | 0.4                     | P (Head)    | 1           | 10                   | Machining           | S                      | N                       | N                    | Collected near head using probe |
| Jahn (1983)                | 1.2                     | S           | 1           | 1.4                  | Cleaning           | CCD                    | N                       | N                    | Area dust cloud samples |
| Jahn (1983)                | 1.5                     | S           | 1           | 2.2                  | Machining           | RR                     | N                       | N                    | Area dust cloud samples |
| Jahn (1983)                | 1.4                     | S           | 1           | 3.0                  | Machining           | S                      | N                       | N                    | Area dust cloud samples |
| Jahn (1983)                | 0.4                     | S           | 1           | 6.0                  | Machining           | S                      | N                       | N                    | Area dust cloud samples |
| Rödelsperger et al. (1986) | 0.5                     | P           | 14          | 5.5 (NA–20)          | Other              | MI                     | N                       | N                    | Presented by Jahn (1983) |
| Rödelsperger et al. (1986) | 3                       | P           | 20          | 0.47                 | Other              | MI                     | N                       | N                    | Presented by Jahn (1983) |
| Author | Sampling duration (min) | Sample type \(^a\) | Sample size | Concentration (f/cc) \(^b\) | Short-term dose (f/cc*min) \(^c\) | General activity | Specific activity \(^d\) | Concentration analysis \(^e\) | Short-term dose analysis \(^e\) | Reason for exclusion |
|--------|-----------------------|-----------------|-------------|----------------|--------------------------|----------------|----------------|----------------|-------------------|------------------|
| Cheng and O’Kelly (1986) | 10 | P | 1 | 0.20 | 2.0 | Cleaning | CMA | Y | Y | NA |
| Cheng and O’Kelly (1986) | 10 | P | 1 | 0.24 | 2.4 | Cleaning | CMA | Y | Y | NA |
| Cheng and O’Kelly (1986) | 10 | P | 1 | 0.01 | 0.10 | Cleaning | CMA | Y | Y | NA |
| Cheng and O’Kelly (1986) | 10 | P | 1 | 0.02 | 0.20 | Cleaning | CMA | Y | Y | NA |
| Cheng and O’Kelly (1986) | 10 | P | 1 | 0.05 | 0.50 | Cleaning | CMA | Y | Y | NA |
| Cheng and O’Kelly (1986) | 10 | P | 1 | 0.24 | 2.4 | Cleaning | CMA | Y | Y | NA |
| Cheng and O’Kelly (1986) | 10 | P | 1 | 0.1 | 1.0 | Cleaning | CMA | Y | Y | NA |
| Cheng and O’Kelly (1986) | 10 | P | 1 | 0.1 | 1.0 | Cleaning | CMA | Y | Y | NA |
| Cheng and O’Kelly (1986) | 10 | P | 1 | 0.04 | 0.4 | Cleaning | CMA | Y | Y | NA |
| Cheng and O’Kelly (1986) | 10 | P | 1 | 0.12 | 1.2 | Cleaning | CMA | Y | Y | NA |
| Cheng and O’Kelly (1986) | 10 | P | 1 | 0.16 | 1.6 | Cleaning | CMA | Y | Y | NA |
| Cheng and O’Kelly (1986) | 10 | P | 1 | 0.28 | 2.8 | Cleaning | CMA | Y | Y | NA |
| Cheng and O’Kelly (1986) | 10 | P | 1 | 0.08 | 0.80 | Cleaning | CMA | Y | Y | NA |
| Kauppinen and Korhonen (1987) | 2-13 | P | 4 | 0.4 (0.3–0.6) | NA | Cleaning | CMD | Y | N | Not a specific activity |
| Kauppinen and Korhonen (1987) | 1-10 | P | 9 | 1.5 (<0.1–8.2) | NA | Cleaning | CMA | Y | N | Not a specific activity |
| Kauppinen and Korhonen (1987) | 2-15 | P | 5 | 0.1 (<0.1–0.2) | NA | Cleaning | CMDV | Y | N | Not a specific activity |
| Kauppinen and Korhonen (1987) | 1 | P | 1 | 0.1 | NA | Other | CDD | N | N | Not a specific activity |
| Kauppinen and Korhonen (1987) | 3 | P | 1 | 0.5 | 1.5 | Machining | MD | Y | Y | NA |
| Kauppinen and Korhonen (1987) | 7-38 | P | 8 | <0.1 (<0.1–0.2) | NA | Other | CCAP | N | N | Not a specific activity |
| Kauppinen and Korhonen (1987) | 23 | P | 1 | <0.1 | NA | Other | AC | N | N | Not a specific activity |
| Kauppinen and Korhonen (1987) | 23 | P | 1 | <0.1 | NA | Other | AC | N | N | Not a specific activity |
| Kauppinen and Korhonen (1987) | 10 | P | 1 | <0.1 | 1.0 | Machining | MC | Y | Y | NA |
| Kauppinen and Korhonen (1987) | 10 | P | 1 | 0.2 | 2.0 | Machining | MC | Y | Y | NA |
| Kauppinen and Korhonen (1987) | 8-12 | P | 1 | <0.1 | NA | Other | AT | N | N | Not a specific activity |
| Kauppinen and Korhonen (1987) | 8-12 | P | 1 | 0.1 | NA | Other | AT | N | N | Not a specific activity |
| Kauppinen and Korhonen (1987) | 8-12 | P | 1 | <0.1 | NA | Other | AT | N | N | Not a specific activity |
| Kauppinen and Korhonen (1987) | 44 | A | 1 | 0.1 | NA | Other | MI | N | N | Area sample |
Assuming that the background concentration would have increased proportionately, the 8-h TWA for the brake job including grinding was calculated by extrapolating from the 8-h TWA assumed to be without grinding using the following equation:

$$8\text{-h TWA}_+G = 8\text{-h TWA}_- / C_{TWA_{BJ+G}} / C_{TWA_{BJ}}$$

### Results

**Cleaning Methods**

The data for car and light-truck mechanics consist of 69 air samples collected during the cleaning of drum brake assemblies (see Figure 1). The vast majority of these samples were collected during compressed air \( (n = 39) \) and dry-brush \( (n = 13) \) cleaning events, with relatively few samples collected for the other cleaning methods. The highest mean and maximum asbestos air concentrations were from samples collected during “blow-out” using compressed air (3.0 and 29 f/cc, respectively). Mean levels for samples collected during other brake cleaning methods for cars and light trucks ranged from 0.04 f/cc (vacuum) to 1.6 f/cc (wet brush).

The data for heavy-truck and bus mechanics consist of 42 samples collected during the use of seven different methods for cleaning of drum brake assemblies (Figure 2). Interestingly, the mean airborne asbestos levels (which ranged from 0.25 f/cc for opening/water washing to 1.9 f/cc for damp cloth wiping) were comparable to the range of means calculated for the car and light-truck samples.

Of all the studies evaluated, only Rödelsperger (1987) reported measured durations of various cleaning activities for cars vs. trucks and buses. The reported mean and standard deviations per axle for eight activities are shown in Table 5. On the basis of these data, the cleaning of brake assemblies on cars using either compressed air or dry brushing took an average of about 5 min per vehicle (for all four wheels), while cleaning truck or bus brake assemblies took approximately 14 min. More recently, as part of a brake-change simulation for six cars with drum brakes, Blake et al. (2003) reported that the duration of compressed-air blowout for all four wheels ranged from 0.37 to 0.77 min, a much shorter duration than that reported by Rödelsperger (1987). As can be seen in Tables 3 and 4, while the majority of the reported sampling durations for cleaning activities are 10 min or less, the sampling durations for any given type of activity were highly variable across the different studies, ranging from a fraction of a minute up to 10 min (and in a few instances longer than 30 min).

When the task (or sampling) duration data were available, estimates of short-term doses were calculated (Table 6). For car and light-truck mechanics, compressed-air blowout, dry-brushing, and wet-brushing samples yielded the highest mean short-term exposure values of all the cleaning methods. The relative magnitudes of some of these doses do not correspond to the concentration data. For example, the mean short-term...
Table 4. Data for short-term brake dust exposure studies for mechanics servicing heavy trucks and buses.

| Author | Sampling duration (min) | Sample type | Sample size | Concentration (f/cc) | General activity | Specific activity | Concentration analysis | Short-term dose analysis | Reason for exclusion |
|--------|-------------------------|-------------|-------------|----------------------|------------------|------------------|----------------------|-----------------------|----------------------|
| Knight and Hickish (1970) | NA | P | 1 | 87 | NA | Cleaning | CMA | N | N | Represents maximum or worst-case exposure conditions |
| Knight and Hickish (1970) | NA | P | 1 | 87 | NA | Cleaning | CMA | N | N | Represents maximum or worst-case exposure conditions |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 2.7 | NA | Machining | GLU | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 7.0 | NA | Machining | GLU | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 2.2 | NA | Machining | GLU | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 4.1 | NA | Machining | GLU | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 5.0 | NA | Machining | GLU | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 4.7 | NA | Machining | GLU | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 5.6 | NA | Machining | GLU | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 1.7 | NA | Machining | GLU | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 2.5 | NA | Machining | GLU | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 2.0 | NA | Machining | GLU | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | A | 1 | 1.2 | NA | Machining | GLU | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | A | 1 | 1.7 | NA | Machining | GLU | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | A | 1 | 1.0 | NA | Machining | GLU | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | A | 1 | 0.6 | NA | Machining | GLU | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | A | 1 | 0.2 | NA | Machining | GLU | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 31.7 | NA | Machining | B | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 23.7 | NA | Machining | B | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 32.7 | NA | Machining | B | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 72.0 | NA | Machining | B | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | P | 1 | 26.3 | NA | Machining | B | Y | N | Sampling duration reported as range |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | A | 1 | 0.6 | NA | Machining | B | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | A | 1 | 0.5 | NA | Machining | B | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | A | 1 | 0.3 | NA | Machining | B | N | N | Area sample |
| Lorimer et al. (1976); Rohl et al. (1976) | 2–10 | A | 1 | 0.3 | NA | Machining | B | N | N | Area sample |
| Rohl et al. (1976) | 3–8 | P | 1 | 1.9 | NA | Machining | RI | Y | N | Sampling duration reported as range |
| Rohl et al. (1976) | 3–8 | P | 1 | 2.0 | NA | Machining | RI | Y | N | Sampling duration reported as range |
| Rohl et al. (1976) | 3–8 | P | 1 | 2.4 | NA | Other | MI | N | N | Not a specific activity |
| Rohl et al. (1976) | 3–8 | P | 1 | 3.6 | NA | Other | MI | N | N | Not a specific activity |
| Rohl et al. (1976) | 3–8 | A | 1 | 3.1 | NA | Other | MI | N | N | Area sample |
| Roberts and Zumwadle (1982) | 10 | P | 1 | 0.54 | 5.4 | Cleaning | CMH | Y | Y | Not a specific activity |
| Jahn (1983) | 36 | P | 1 | 0.04 | NA | Other | OM | N | N | Not a specific activity |
| Jahn (1983) | 14 | P | 1 | 0.11 | 1.5 | Cleaning | CMA | Y | Y | Not a specific activity |
| Jahn (1983) | 7 | P | 1 | 1.1 | 7.7 | Cleaning | CMA | Y | Y | Not a specific activity |
| Jahn (1983) | 35 | P | 1 | 0.07 | 2.5 | Cleaning | CMA | N | Y | Sample duration > 15 min |
| Jahn (1983) | 61 | P | 1 | 0.05 | 3.1 | Cleaning | CMA | N | Y | Sample duration > 15 min |
| Jahn (1983) | 10 | P | 1 | 1.9 | Machining | GLOE | Y | Y | NA |
| Jahn (1983) | 44 | P | 1 | 0.03 | 1.3 | Machining | GLOE | N | N | Sample duration > 15 min |
| Jahn (1983) | 1 | P (head) | 1 | 20 | 20 | Cleaning | CMA | N | Y | Collected w/probe near head |
| Jahn (1983) | 1 | P (head) | 1 | 8.0 | 8.0 | Cleaning | CMA | N | Y | Collected w/probe near head |
| Jahn (1983) | 1.5 | P (head) | 1 | 0.84 | 1.3 | Machining | GLOE | N | Y | Collected w/probe near head |
| Jahn (1983) | 3 | P (head) | 1 | 1.7 | 5.1 | Machining | GLOE | N | Y | Collected w/probe near head |
| Jahn (1983) | 0.5 | P (head) | 1 | 14 | NA | Other | MX | N | N | Not a specific activity |
| Jahn (1983) | 0.5 | P (head) | 1 | 3.4 | NA | Other | MX | N | N | Not a specific activity |
| Author               | Sampling duration (min) | Sample type<sup>a</sup> | Sample size | Concentration (f/cc)<sup>b</sup> | General activity | Specific activity<sup>2</sup> | Concentration analysis<sup>e</sup> | Short-term dose analysis<sup>e</sup> | Reason for exclusion |
|---------------------|------------------------|--------------------------|-------------|-----------------------------------|------------------|-----------------------------|----------------------------------|----------------------|---------------------|
| Jahn (1983)         | 3.2                    | S                        | 1           | 0.79                              | NA               | Cleaning CMA               | N                  | N                   | Area dust cloud samples |
| Jahn (1983)         | 1.5                    | S                        | 1           | 0.56                              | NA               | Cleaning CMA               | N                  | N                   | Area dust cloud samples |
| Jahn (1983)         | 1                      | S                        | 1           | 1.7                               | NA               | Machining S                | N                  | N                   | Area dust cloud samples |
| Jahn (1983)         | 3                      | S                        | 1           | 3.7                               | NA               | Machining GLOE             | N                  | N                   | Area dust cloud samples |
| Jahn (1983)         | 2.8                    | S                        | 1           | 0.76                              | NA               | Machining GLOE             | N                  | N                   | Area dust cloud samples |
| Jahn (1983)         | 3.3                    | S                        | 1           | 1.5                               | NA               | Machining GLOE             | N                  | N                   | Area dust cloud samples |
| Jahn (1983)         | 3                      | S                        | 1           | 2                                 | NA               | Machining GLOE             | N                  | N                   | Area dust cloud samples |
| Jahn (1983)         | 2                      | S                        | 1           | 2.5                               | NA               | Machining GLOE             | N                  | N                   | Area dust cloud samples |
| Jahn (1983)         | 11                     | S                        | 1           | 0.54                              | NA               | Other MX                   | N                  | N                   | Area dust cloud samples |
| Jahn (1983)         | 1.5                    | S                        | 1           | 23                                | NA               | Other MX                   | N                  | N                   | Area dust cloud samples |
| Cheng and O'Kelly (1986) | 10                   | P                        | 1           | 0.04                              | Machining GL     | Y                            | Y                  | NA                  |
| Cheng and O'Kelly (1986) | 10                   | P                        | 1           | 0.78                              | Machining GL     | Y                            | Y                  | NA                  |
| Kauppinen and Korhonen (1987) | 2-25                | P                        | 25          | 0.4 (<0.1-1.9)                     | NA               | Other OM                   | N                  | N                   | Not a specific activity |
| Kauppinen and Korhonen (1987) | 1-12                | P                        | 6           | 0.3 (<0.1-1.0)                     | NA               | Cleaning CMD               | Y                  | N                   | Sampling duration reported as range and represents summary data (>1 sample) |
| Kauppinen and Korhonen (1987) | 2-12                | P                        | 8           | 1.3 (0.1-4.5)                      | NA               | Cleaning CMD               | Y                  | N                   | Sampling duration reported as range and represents summary data (>1 sample) |
| Kauppinen and Korhonen (1987) | 1-14                | P                        | 9           | 1.2 (0.2-3.0)                      | NA               | Cleaning CMAV              | Y                  | N                   | Sampling duration reported as range and represents summary data (>1 sample) |
| Kauppinen and Korhonen (1987) | 2-5 (3.5)            | P                        | 1           | 1.1                               | 3.9              | Cleaning CMC               | Y                  | Y                   | NA                  |
| Kauppinen and Korhonen (1987) | 2-5 (3.5)            | P                        | 1           | 3.3                               | 12               | Cleaning CMC               | Y                  | Y                   | NA                  |
| Kauppinen and Korhonen (1987) | 2-5 (3.5)            | P                        | 1           | 1.3                               | 4.6              | Cleaning CMC               | Y                  | Y                   | NA                  |
| Kauppinen and Korhonen (1987) | 2-10                 | P                        | 6           | 0.2 (<0.1-0.3)                     | NA               | Cleaning CMH               | Y                  | N                   | Sampling duration reported as range and represents summary data (>1 sample) |
| Kauppinen and Korhonen (1987) | 4-18                 | P                        | 6           | 0.1 (<0.1-0.2)                     | NA               | Cleaning CMH               | Y                  | N                   | Sampling duration reported as range and represents summary data (>1 sample) |
| Kauppinen and Korhonen (1987) | 5-29                 | P                        | 12          | 0.3 (<0.1-1.6)                     | NA               | Machining RR               | Y                  | N                   | Sampling duration reported as range and represents summary data (>1 sample) |
| Kauppinen and Korhonen (1987) | 3-5 (4)              | P                        | 1           | 0.3                               | 1.2              | Machining CS               | Y                  | Y                   | NA                  |
| Kauppinen and Korhonen (1987) | 3-5 (4)              | P                        | 1           | 0.4                               | 1.6              | Machining CS               | Y                  | Y                   | NA                  |
| Kauppinen and Korhonen (1987) | 3-60                 | P                        | 28          | 0.7 (0.1-3.5)                      | NA               | Machining RI                | Y                  | N                   | Sampling duration reported as range and represents summary data (>1 sample) |
| Kauppinen and Korhonen (1987) | 4-27                 | P                        | 5           | 56 (0.3-125)                       | NA               | Machining GLWE             | Y                  | N                   | Sampling duration reported as range and represents summary data (>1 sample) |
| Kauppinen and Korhonen (1987) | 4-33                 | P                        | 30          | 1.5 (0.1-5.9)                      | NA               | Machining GLE              | Y                  | N                   | Sampling duration reported as range and represents summary data (>1 sample) |
| Kauppinen and Korhonen (1987) | 2-5                   | P                        | 7           | 0.4 (0.1-0.9)                      | NA               | Machining B                | Y                  | N                   | Sampling duration reported as range and represents summary data (>1 sample) |
| Kauppinen and Korhonen (1987) | 5-6                  | P                        | 1           | 0.5                               | NA               | Other CDD                  | N                  | N                   | Not a specific activity |
| Kauppinen and Korhonen (1987) | 5-6                  | P                        | 1           | 0.7                               | NA               | Other CDD                  | N                  | N                   | Not a specific activity |
| Kauppinen and Korhonen (1987) | 3-26                 | P                        | 6           | 0.2 (0.1-0.3)                      | NA               | Machining MD               | Y                  | N                   | Sampling duration reported as range and represents summary data (>1 sample) |

NA = not available or not applicable; ND = non-detect.

<sup>a</sup>Represents personal (P), area (A), or dust cloud source (S) samples.

<sup>b</sup>Represents single estimate, except if >1 sample represents arithmetic mean (minimum and maximum values are presented in parentheses).

<sup>c</sup>Calculated by multiplying the asbestos concentration times the sampling duration.

<sup>d</sup>Abbreviation code represents specific cleaning, machining, or other activity (see Table 1).

<sup>e</sup>Y for yes, included in analysis, N for no, not included. If both no, discussed qualitatively only.
doses for cleaning with compressed air (1.8 f/cc·min) and dry brushing (3.3 f/cc·min) were relatively similar, whereas the mean concentration for compressed-air (3.0 f/cc) was about five times higher than that for dry-brush cleaning (0.59 f/cc). However, the doses are similar to the average values reported by Rödelsperger et al. (1986) of 4.7 f/cc·min (n = 5) for
compressed-air blowout and 4.0 f/cc*min (n = 6) for dry brushing per axle. Although there are too few samples for cleaning disc brakes to permit a thorough comparison of cleaning drum vs. disc brake assemblies on cars (comparative data are available only for the dry brushing), it is notable that the mean short-term doses for dry brushing are similar for the two braking systems.

For heavy-truck and bus mechanics, the mean short-term doses were similar among the three cleaning methods sampled (range of 3.8 f/cc*min for compressed air to 6.7 f/cc*min for damp cloth) and were similar to the range of means measured for cleaning cars and light trucks (Table 6). These values are similar to those Rödelsperger et al. (1986) who reported an average dose of 5.3 f/cc*min (n = 8) for compressed-air blowout per axle.

**Machining Methods**

As can be seen in Tables 3 and 4, the majority of the car/light-truck mechanic data were collected during cleaning activities, whereas the majority of heavy-truck/bus mechanic data were collected during machining activities. The relative paucity of the car/light-truck machining data (four samples) is likely due to the fact that when asbestos sampling for brake mechanics began in the early 1970s, new brake shoes for cars and light trucks were typically pre-assembled and did not require the use of machining methods during most brake-servicing operations. Measured airborne asbestos concentrations ranging from 0.15 to 0.50 f/cc were reported for turning brake discs and drums. Both of these machining activities remove wear debris from the metallic surfaces of the brake assemblies and do not actively machine the asbestos brake linings or pads.

More than 100 air samples were collected during a wide range of machining activities for heavy trucks and buses (Figure 3). For most machining activities, the means ranged from 0.20 f/cc (turning brake drums) to 3.8 f/cc (grinding used linings). Two operations in particular produced substantially greater airborne asbestos concentrations—machine beveling of new linings, with a mean fiber concentration

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**Table 5. Durations for short-term cleaning and machining activities performed by mechanics servicing car and truck/bus brakes.**

| Specific activity         | Activity durations (minutes per axle) | Cars | Tracks and buses |
|---------------------------|---------------------------------------|------|------------------|
|                           | Number | Mean | SD  | Number | Mean | SD  |
| Blowing out               | 29     | 2.39 | 2.46 | 18     | 6.86 | 7.16 |
| Brushing out              | 31     | 2.94 | 2.25 | 11     | 16.36| 5.52 |
| Deriveting                | 10     | 10.7 | 6.33 | 12     | 24.58| 24.91|
| Riveting                  | 11     | 13.36| 4.52 | 20     | 27.3 | 19.49|
| Machine spot grinding     | 14     | 5.43 | 3.14 | 4      | 16.75| 23.8 |
| Manual sanding            | 28     | 1.77 | 1.95 | 4      | 8.5  | 8.06 |
| Turning brake drums       | 1      | 1    |     | 52     | 32   | 17.86|
| Blowing out after turning | 2      | 1    |     | 14     | 0.89 | 0.29 |

From Table 3 in Rödelsperger (1987).

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**Table 6. Summary of calculated short-term asbestos doses for brake mechanics.**

| Specific activity (code) | Short-term doses (f/cc*min) |
|-------------------------|-----------------------------|
|                         | Count | Min | Max | Median | Mean | SD |

**Cars and light trucks**

- **Cleaning**
  - Compressed air (CMA) 26 0.09 7.5 1.0 1.8 2.0
  - Compressed air and solvent (CMAS) 6 0.25 1.1 0.34 0.57 0.42
  - Vacuum (CMV) 3 0.060 0.14 0.060 0.087 0.046
  - Wet brush (CMW) 4 6.0 7.9 7.2 7.1 0.90
  - Dry brush — drum brake (CMD) 8 0.10 12.8 0.80 3.3 5.0
  - Dry brush — disc brake (CCD) 3 1.7 7.5 2.7 4.0 3.1

**Heavy trucks and buses**

- **Cleaning**
  - Compressed air (CMA) 5 1.5 7.7 3.1 3.8 2.4
  - Damp cloth (CMC) 3 3.9 12 4.6 6.7 4.3
  - Water washing (CMH) 1 5.4 5.4 5.4 5.4 0.0

- **Machining**
  - Grinding new linings (GL) 3 0.40 8.3 7.8 5.5 4.4
  - Grinding linings on wheels w/exhaust (GLWE) 2 1.3 19 10 10 13
  - Preparation of brake shoes for riveting new linings (CS) 2 1.2 1.6 1.4 1.4 0.3
of 37 f/cc, and grinding new linings without exhaust controls, with a mean concentration of 56 f/cc. The data for grinding of linings are divided into five groups, because information is lacking as to whether the linings were new or used and whether exhaust controls were used. For example, Cheng and O’Kelly (1986) do not report whether the grinding was done with or without exhaust controls, whereas Rödelsperger et al. (1986) indicate that the grinding was done in an enclosed shroud, with the shoes mounted on the truck and exhaust controls in place. As indicated by the data, the use of exhaust controls during the grinding of truck brake linings did significantly reduce airborne asbestos concentrations; the mean level without exhaust (56 f/cc) was approximately 40 times higher than the mean level with exhaust (1.5 f/cc). By comparison, Rödelsperger et al. (1986) reported an average dose of 9.9 f/cc*min (n = 4) for grinding of truck brakes per axle.

The mean concentration for hand beveling of brake linings (0.40 f/cc) was almost 100 times less than that for machine beveling (37 f/cc). The hand method was the type used most often by car and light truck mechanics before the introduction of pre-beveled linings.

As indicated above, only the study by Rödelsperger (1987) reported measured durations of various machining activities for cars vs. trucks and buses (see Table 5). On the basis of these data, the average duration of grinding activities on truck brake linings (34 min) was substantially longer than that reported for car brake linings (11 min), which is simply due to the larger wheel assemblies on these vehicles and the complexity of the process. The more recent assessment by Blake et al. (2003) reported that arc grinding for two cars averaged about 19 min, which was about 8 min longer than what Rödelsperger (1987) reported. Both authors reported arc grinding durations that lasted much longer than the actual grinding of the brake lining which takes only a few minutes; the reported durations are, in fact, for the entire time required to mount the brake shoe, set the radius, arc the lining, and remove the brake shoe from the grinder.

When taking the sampling duration information into account, the calculation of short-term doses for brake mechanics performing machining activities is based on only four samples for cars and light trucks (Table 6), only one of which involves brake linings. The doses ranged from 1.5 f/cc*min for turning disc rotors and brake drums to 8.6 f/cc*min for grinding new linings. However, it should be noted that there are additional short-term dose data for grinding automobile brake linings, although these are not reported as individual samples. For one auto axle (two wheels) Rödelsperger et al. (1986) reported a mean short-term dose of 3.9 f/cc*min based on 10 samples for mechanical grinding and 3.9 f/cc*min for 5 samples for hand

- Figure 3. Short-term asbestos concentrations for mechanics performing various brake machining activities for heavy trucks and buses.
grinding of brake-shoe linings. The authors stated that most of
the bag filter systems for grinding were unsuitable for asbestos.
These short-term machining doses are similar to those calculated
for cleaning activities on cars and light trucks.

For heavy-truck and bus mechanics, seven samples were
available to calculate doses during machining activities. As
shown in Table 6, exposures were calculated for heavy-truck
and bus mechanics grinding new linings, grinding linings with
exhaust controls, and preparing brake shoes before riveting
new linings. There was less than a 10-fold difference in
doses for these activities, with mean values ranging from
1.4 f/cc*min (preparation of brake shoes before riveting new
linings) to 10 f/cc*min (grinding linings on wheels
with exhaust controls). As with cars and light trucks, the
machining exposures during heavy truck brake repair are
similar to the cleaning exposures. The mean estimate
for grinding new linings on heavy trucks and buses
(5.5 f/cc*min) is similar to that for the one sample for
grinding linings on cars and light trucks (8.6 f/cc*min).

Reconstructing Earlier Long-Term Exposures

Earlier long-term exposures for automobile brake mechanics
that used grinding in rebuilding brake shoes were estimated
based on the available brake-job and 8-h TWA concentra-
tions, short-term grinding dose data, and several assump-
tions. Due to the lack of statistical data for grinding
automobile brake shoes, only the average TWA concentra-
tions were determined.

From the Paustenbach et al. (2003) data, during the
1970s, the average brake-job TWA was 0.11 f/cc over a
period of approximately 90 min, resulting in a dose of 9.9
f/cc*min. These exposures definitely included the use of
compressed air and/or dry brushing, but may not have
included the machining of brake shoes. The best estimate
of the short-term dose for grinding is 3.9 f/cc*min per axle
(or 7.8 f/cc*min for both axles and all four wheels) for the
10 samples from Rödelsperger et al. (1986). The adjusted
brake-job TWA was then calculated by adding the
brake-job dose of 9.9 f/cc*min and the grinding dose for
two axles of 7.8 f/cc*min, and then dividing by the total
adjusted time of 101 min. Adjusted for grinding, the
brake-job TWA is approximately 0.18 f/cc, about a 60% increase
over the brake-job TWA, for which it was assumed
grinding was not conducted during brake repair. This
estimate is comparable with the airborne concentrations
reported by Blake et al. (2003) for two brake jobs (0.20 and
0.44 f/cc) where arc grinding was evaluated. Using the
average 8-h TWA of Paustenbach et al. (2003) for the
1970s of 0.063 f/cc, when cleaning was not controlled
and assuming that background airborne concentrations in
the garage would have increased proportionately due to
grinding, the estimated average 8-h TWA for auto mechanics
who performed grinding could have been approximately
0.10 f/cc.

Discussion

Data Variability

Our review indicates that for one of the most common dust-
generating activities, compressed air cleaning of automobile
brakes, the short-term concentrations ranged over about
three orders of magnitude, from 0.01 to 29 f/cc, whereas the
doses ranged over approximately two orders of magnitude,
from 0.1 to 7.5 f/cc*min. Thus, incorporating the sampling
duration into the exposure estimates did little to reduce the
variability in estimating exposures, which suggests that there
may have been substantial differences in fiber emissions from
compressed-air blowout by individual mechanics. A similar
degree of variability was observed in the short-term doses of
mechanics grinding brake linings on heavy trucks and buses,
with values ranging from 0.4 to 8.3 f/cc*min. This variability
is likely due in large part to differences in study objectives and
variations in mechanic work practices, neither of which was
usually described in detail. These apparent anomalies could
be due to several different factors, such as: (1) sample
durations were variable and short samples may have captured
a high concentration but were of too short a duration to have
consistently captured a majority of the emitted fibers, (2)
limited data and/or high variability among samples did not
permit meaningful comparisons, and/or (3) brake mechanics
conduct specific cleaning and machining activities quite
differently from one another.

These findings are similar to those reported in other
studies. For example, Rödelsperger et al. (1986) provided
a summary of asbestos doses (3 to 60 min duration) for
car and truck mechanics performing several cleaning and
machining activities. In general, the estimates of dose from
Rödelsperger et al. (1986) for comparable cleaning and
machining activities were about twofold higher than the dose
values calculated in this analysis; however, caution should be
taken when comparing these results to this study, because it
was not always clear how many wheels or axles were being
worked on while the samples were collected.

Although some understanding of sample duration is available
for all of the results that met the data selection criteria, most
researchers, with the exception of Rödelsperger (1987), did not
report the duration of the cleaning or machining activity relative
to the sampling duration. Hence, it is highly likely that many
samples were collected over a duration that was either shorter or
longer than the actual activity itself. An airborne dust sample
collected for a duration that is less than or equal to the “peak”
of the dust-generating activity is likely to contain a higher dust
concentration than a sample collected for several minutes
following the completion of that same activity. Conversely, the
short-term dose metric (f/cc*min) will increase as the sampling
duration continues beyond the cessation of activity until dust
dissipates from the breathing zone. Hence, sampling durations
that do not last beyond the activity duration may yield higher
concentrations but underestimate the total extent of exposure as
measured by the dose, because it often takes a few minutes after cleaning or grinding for airborne concentrations to return to background levels. Ideally, the sample duration should have extended beyond the activity duration to ensure that the residual suspended dust was collected and the total dose from a specific activity determined.

Usefulness of Short-Term Sample Data for Reconstructing Asbestos Exposures

The second purpose of this analysis was to determine whether the short-term sampling data could be used to develop estimates of pre-1970s exposures, either by using the short-term data alone or by incorporating short-term machining data into the (post-1970s) brake-job and 8-h TWAs.

It would be difficult to use these short-term data to estimate the degree of exposure due largely to the substantial variability in the reported measurements and the lack of descriptions of the specific activities that were sampled. Specifically, the variabilities in concentrations and doses for specific cleaning and machining activities are high, often spanning several orders of magnitude. This is most apparent for the measurements of compressed air cleaning of automobile brake assemblies and grinding of truck brake linings. Clearly, there are substantial differences in how the mechanics performed these activities, and in garage conditions, and a lack of documentation as to what contributes to the high and low values reported. Therefore, the combined short-term data from the studies evaluated provide a less than ideal basis for reconstructing short-term or long-term exposures historically experienced by a brake mechanic. However, it is clear that subsets of these data from groups intimately involved with sampling the brake servicing process, such as that proposed by Rödelperger et al. (1986), have been used to estimate long-term TWAs based on a sum of short-term doses for specific activities, and that these data could be used by others evaluating similar activities and exposure conditions.

Although the variability of the data makes the results of total reconstruction quite uncertain, it has been shown that short-term grinding dose data could be used to adjust the long-term TWA values for mechanics performing brake jobs where the grinding of linings occurred, as that took place when brake shoes were rebuilt in the period before collection of the available TWA data (i.e., pre-1970s).

Impact of Short-term Activities on Long-Term Exposures Over Time

As evidenced by our analysis of the short-term exposure data, the decrease in dust-generating activities over time had a large impact on both the short-term and the long-term asbestos exposures for brake mechanics. The need for machining activities, especially for cars and light trucks, was minimized by the introduction of pre-arc'd, replacement brake shoes for drum brakes in the 1950s and 1960s, and the conversion to disc brakes in the 1970s and 1980s. The changes in cleaning methods during the 1980s, when employed correctly, further reduced asbestos dust generation to the point where long-term exposure concentrations were at or below the detection limits.

On the basis of our assumptions and the data from Paustenbach et al. (2003), the average brake-job and 8-h TWAs for automobile mechanics were 0.18 and 0.10 f/cc when grinding and compressed air or similar cleaning methods were used. Removing grinding activities from brake servicing reduced the average brake-job and 8-h TWA values to 0.11 and 0.063 f/cc, respectively. The introduction of dust control measures, such as HEPA vacuuming, during cleaning further reduced the average TWAs to 0.005 f/cc during the brake job and to 0.0021 f/cc for 8 h.

Comparison to OELs

The OSHA ceiling limit for asbestos in the workplace from 1972 to 1986 was 10 f/cc for a 15-min period (Martonik et al., 2001). There was no ceiling limit in place between June 1986 and August 1988, and from September 1988 to the present, an excursion limit of 1 f/cc for 30 min has been in place. The purposes of the short-term limit for asbestos, and most other cumulative toxicants, are to minimize the opportunity for the lifetime cumulative dose to rise above that permitted by the 8-h TWA, to reduce the nuisance associated with exposure to dusty conditions (the vast majority of dust associated with a brake change is either brake-wear debris or dust from the road), and to ensure that engineering controls are generally available to reduce exposure from these short-term activities. In fact, in reintroducing the short-term exposure limit in 1988, OSHA (1988) stated that, “compliance would further reduce a significant health risk ‘...’ However, while related to long-term health-based values, short-term exposures at or above the ceiling limit are not necessarily indicative of an increased acute or chronic health risk.

Most of the short-term samples for mechanics were collected during the time when the 10-f/cc OSHA standard was in place. Few of the approximately 300 short-term samples reported for mechanics were collected for a 15-min period, including those collected by NIOSH. This can complicate comparisons of the short-term exposure concentrations to the 15-min OSHA standard. Specifically, if a sample of less than 15 min is collected during a particular activity and that sample meets the standard, then one can conclude that the sample would also have met the standard if it had been collected for a full 15 min. However, if a sample of less than 15 min exceeds that standard, then it is possible that continued sample collection for a 15-min period could possibly have resulted in an exceedance of the standard. A review of the more than 130 personal samples for mechanics servicing cars and light trucks indicated that only five samples could possibly have exceeded the ceiling limit if they had persisted for 15 min. Of the more than 180 personal samples reported for brake servicing on
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trucks and buses, only 10 samples had concentrations that could have exceeded the OSHA ceiling limit. Therefore, although direct comparison to the ceiling limit is hampered by a lack of samples of appropriate duration, the reported concentrations for the vast majority of short-term brake cleaning and machining samples were sufficiently low to support a conclusion that the ceiling limit would rarely have been exceeded in most brake maintenance facilities.

Comparisons to short-term limits can also be made on the basis of the dose (concentration × time for the task). For example, assuming an exposure duration of 15 min and a maximum concentration of 10 f/cc yields an equivalent short-term dose of 150 f/cc/min for the original excursion limit. Similarly, a duration of 30 min at a concentration of 1 f/cc yields a dose of 30 f/cc/min based on the current excursion level. As shown in Table 6, the highest calculated short-term doses were 12.8 f/cc/min for cars and light trucks mechanics and 19 f/cc/min for heavy-truck and bus mechanics. This analysis again shows that short-term doses historically experienced by mechanics cleaning brake assemblies and machining brake linings were below the acceptable short-term dose (exposure limit) implied within the contemporaneous ceiling limit as well as the current excursion level.

Conclusions

Taking into consideration the strengths and limitations of the short-term sampling data for brake mechanics, the following conclusions were reached:

- Because of the lack of specificity in the reports describing these short-term samples, the substantial variability in concentration and doses, and the lack of data for some older machining activities, it would be difficult to reconstruct brake-job and 8-h mechanic exposures exclusively from these short-term data.
- However, by making several assumptions about the data it is possible to adjust the available 8-h TWA concentrations to include grinding of brake linings for automobiles. The average airborne concentration of asbestos for brake mechanics during the era when arc grinding was more routinely performed could have been about 60% higher than in the 1970s and later decades when arc grinding during typical brake servicing was less common.
- Over time, the decrease in machining activities, such as grinding, reduced the average 8-h TWAs for automobile brake mechanics from about 0.10 f/cc during the 1940s through 1960s, to 0.063 f/cc during the 1970s. The introduction of less dusty cleaning methods in the early 1980s caused a further reduction to an average of 0.0021 f/cc by the late 1980s.
- On the basis of the available literature, short-term exposures for brake mechanics cleaning or machining brakes were well below both the original and current OSHA standards.

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