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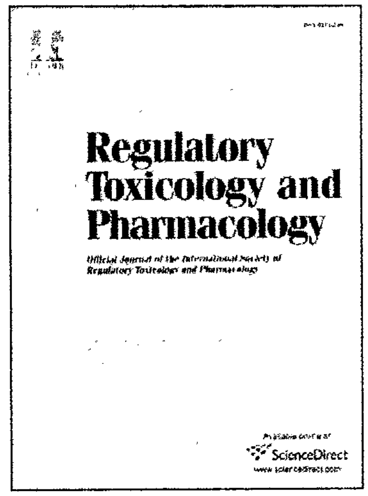

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A Study of Airborne Chrysotile Concentrations Associated with Handling, Unpacking, and Repacking Boxes of Automobile Clutch Discs

George C.T. Jiang [1], Amy K. Madl [1], Kelsey J. Ingmundson [1], Dana M. Murbach [1], Kurt A. Fehling [1], Dennis J. Paustenbach [1], and Brent L. Finley [1]

[1] ChemRisk, 25 Jessie Street, Suite 1800, San Francisco, CA 94105

* Corresponding Author:
Brent L. Finley
ChemRisk, Inc.
25 Jessie Street, Suite 1800
San Francisco, CA 94105
Phone: (415) 896-2400
Fax: (415) 896-2444
Email: bfinley@chemrisk.com

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0.001 f/cc and 0.004 ± 0.002 f/cc when 1 or 2 boxes of clutches were handled, respectively. Estimated 8-hr TWA asbestos exposures for a worker handling 1 or 2 boxes of clutches over a workday ranged from 0.002 to 0.006 f/cc. The 30-min PCM adjusted average airborne asbestos concentration for a worker continuously stacking unopened boxes of clutches was 0.212 ± 0.014 f/cc; the 8-hr TWA was 0.013 f/cc. Additionally, 30-min PCM adjusted average airborne asbestos concentrations following cleanup and clothing handling were 0.002 ± 0.001 f/cc and 0.002 ± 0.002 f/cc, respectively, both resulting in estimated 8-hr TWA asbestos exposures of 0.0001 f/cc. The results of this study indicate that the handling, unpacking, and repacking of clutches, and the subsequent cleanup and clothes handling by a worker within a short-term period or over the entire workday, result in exposures below the historical and current short-term and 8-hr occupational exposure limits for asbestos.

INTRODUCTION

The purpose of an automotive manual clutch is to allow for alternate connection and separation of the engine to the transmission shaft that drives the wheels. Similar to automotive brake pads and linings, clutch disc faces frequently contain friction materials that come in contact with rotating metallic surfaces. Over time, the friction materials on the clutch will wear and the clutch disc must eventually be replaced or the clutch will begin to slip Manual clutches typically require repair or replacement every 50,000 to 100,000 miles. Figure 1 illustrates the location of a clutch and a cut-away schematic drawing of a clutch disc.

Chrysotile asbestos was a primary component of the friction material in manual automobile and truck clutch discs from the early 1900s to the 1980s. The chrysotile fibers, if present, which comprised approximately 30-60% of the original clutch disc facing material, offered superior frictional characteristics such as good tensile strength, durability, flexibility, and heat resistance (Paustenbach et al., 2004; Sheehy et al., 1989; Skinner et al., 1988). By the mid-1980's, several acceptable substitutes for chrysotile asbestos were identified and the manufacture and use of asbestos-containing manual clutches was gradually discontinued in the United States (Paustenbach et al., 2004; Paustenbach et al., 2003).

During manual clutch installation and repair, asbestos fibers might become airborne if clutch wear debris is present. Clutch wear debris is formed when the friction material degrades due to the heat and pressure generated when the clutch surface is in contact with the flywheel and pressure plate. It has been known for several decades that, similar to brake wear debris, the levels of chrysotile asbestos in clutch wear debris are very low, if any are detected (Boelter et al., 2007; Kauppinen and Korhonen, 1987; Lynch, 1968; R J. Lee Group, 2004; Yeung et al., 1999). Specifically, in 1968, Lynch reported no detectable fibers in clutch wear debris following normal driving conditions (Lynch, 1968). Other reported measurements of asbestos in clutch wear debris are < 1% (Boelter et al., 2007) and non-detect to 0.4% (R.J. Lee Group, 2004). This is consistent with the fact that airborne concentrations of asbestos during clutch repair are also quite low. Numerous studies have shown that the time-weighted average (TWA) airborne asbestos levels during removal/installation of asbestos-containing manual clutches on automobiles and heavy equipment are consistently below the current OSHA 8-hour permissible exposure limit (PEL) of 0.1 f/cc (Boelter et al., 2007, R.J. Lee Group, 2004; Yeung et al., 1999).

Workers who handle, unpack, and repack boxes of new clutches could also theoretically experience some degree of exposure to asbestos. Such workers would include the mechanics themselves, bystanders, "parts-pickers", and other staff at a distribution center or an auto parts store. Theoretically, residual asbestos fibers could be present inside a new clutch box, possibly as wear during product shipping or as a result of airborne fibers "settling" into the open box in the manufacturing or packaging facility. These residual fibers could become airborne when the boxes are handled or the clutches are removed from the box and installed, or when clutches are "repacked" into the original box or another container. To date, there are no studies that describe airborne asbestos concentrations associated with clutch or box handling or cleanup activities. We recently completed a study involving boxes of asbestos-containing brake pads and discs (Madl et al., 2007). In that study, we measured worker and bystander airborne asbestos levels during the unpacking and repacking of asbestos-containing brake pads and brake shoes. The results indicated that 1) airborne asbestos concentrations increased with the number of boxes unpacked and repacked, 2) handling brake pads resulted in higher asbestos concentrations than handling brake shoes, and 3) amphibole fibers were not detectable in bulk samples of the brake pads and shoes.

In this analysis, we employ a similar research protocol to characterize potential worker and bystander exposures to asbestos during the handling, unpacking, and repacking of asbestos-containing clutch discs. Short-term and 8-hour TWA concentrations were measured and calculated under a variety of worker scenarios. In addition, we evaluated: (1) potential asbestos exposures associated with clean-up and clothes handling activities, and (2) size and morphology of airborne asbestos fibers. The resulting data are compared to historical and current OSHA short-term and long-term asbestos standards and cumulative chrysotile exposures experienced by other cohorts. These comparisons are used to determine whether and to what degree handling, packing, and re-packing asbestos-containing clutch discs might contribute to asbestos-related pulmonary diseases.

METHODS

The protocol for the study was approved by Copernicus Group IRB (Research Triangle Park, NC), an accredited Institutional Review Board (IRB).

Description of Boxes of Clutch Discs

A total of 27 boxes of clutch discs were obtained from an automotive parts warehouse. The clutches were made prior to the mid-1980s for passenger vehicles and were therefore expected to contain chrysotile asbestos. The boxes had typically been in-stock and undisturbed for several years and were in good structural condition in the original packaging. The boxes were not taped together and did not appear to have been opened prior to the study. The boxes were not opened prior to sampling to ensure that the results would be consistent with a worker opening a new unused box of replacement clutches. Each box contained one clutch disc. The brands on the boxes of the clutches were used to identify the individual clutches (Table II). Figure 2A illustrates the worker with a stack of clutch boxes, and Figure 2B illustrates close-up photographs of representative brands of clutch discs and their respective boxes

Description of Study Setting

The automobile repair shop where the study was conducted has been previously described in detail in Paustenbach et al. (2006) (Paustenbach et al., 2006). The shop, which is located in Santa Rosa, CA, is a garage with an open floor plan with dimensions of approximately 101 ft wide by 48 ft deep with a 15-ft ceiling (Figure 3A). To prevent air sampling measurements from being confounded by other repair activities in the shop, no other automobile repair work was conducted on the testing days of this study. Additionally, the shop was not ventilated with heating or air conditioning. To simulate low ventilation conditions all entry and service doors were closed during the testing. Temperature and weather conditions were noted each day of the testing.

Description of Exposure Scenarios

The different tasks evaluated over the three days of study are summarized in Table I On January 20, 2007, discrete airborne asbestos measurements were obtained during the following tasks: 1) continuous repetitive stacking and handling 27 unopened boxes of clutches (one event): 2) unpacking and repacking 1 box (4 events); 3) unpacking and repacking 1 box with overhead disc manipulation and dry cloth wipe (2 events) or spray clean wipe (2 events); 4) counter cleanup (one event). On January 21, 2007, the tasks were 1) unpacking and repacking 1 box (4 events), 2) unpacking and repacking 2 boxes with overhead manipulation (2 events), and 3) counter cleanup (one event). On January 27, 2007, the tasks were 1) unpacking and repacking 1 box (4 events), 2) unpacking and repacking 2 boxes with overhead manipulation (2 events), 3) counter cleanup (one event), and 4) clothes handling (one event).

All box-handling work was performed by a single individual. The box and clutch handling activities were designed to be consistent with those described by career automotive mechanics and parts suppliers. The handling, unpacking and repacking of boxes of clutches was conducted at a 3.5 ft high counter open to the automotive repair section of the shop (Figure 3A). The counter was wiped thoroughly before each sampling event with a commercial cleaner and a rag. Boxes of clutches were stored on the counter within reach of the worker. The handling activity consisted of opening the box, comparing the new replacement clutch to a demonstrative clutch, and then repacking the clutch in the original box. This entire process required approximately 15-30 seconds. In some cases, the individual also cleaned the disc with a dry cloth or spray cleaner (30 seconds) and/or held the disc overhead (10-15 seconds) before returning the clutch to the box. Each box was unpacked and repacked only once. The repetitive box stacking task was conducted for the entire 30 minute period. Counter "cleanup" events occurred at the end of the day (for approximately 1 minute) and were performed using paper towels and wet wipes. The clothes-handling task (approximately 45 seconds in length) involved shaking and folding 3 different pairs of overalls (a fresh pair was worn by the individual during each day of testing) to simulate a person handling and laundering potentially "contaminated" work clothes. The overalls from the first 2 days were kept in a sealed bag until testing.

Collection and Analysis of Airborne Asbestos Samples

Airborne asbestos samples were collected in a manner consistent as previously described (Paustenbach et al., 2006). Briefly, samples were collected using mixed cellulose ester (MCE) filter membranes (25 mm, 0.45 μm pore size, Zefon International, St. Petersburg, FL, USA) using either portable SKC Universal PCXR (SKC-West, Inc., Fullerton, CA, USA) or Gilian Gilair pumps (Sensidyne Inc., Clearwater, FL, USA) or Dawson 1300 high-volume sampling pumps (Ashtead Technology Rentals, Hayward, CA, USA). The sampling pumps were noted with a Bios® DryCal DCLite primary flow calibrator (Bios International Corporation, Butler, NJ, USA) before and after sample collection. Portable SKC or Gilair pumps were used to collect asbestos samples at 2 liters per minute (LPM), whereas high-volume pumps were used to collect samples at air flow rates between 3 - 10 LPM. Collection of all airborne asbestos samples was consistent with NIOSH Methods 7400 and 7402 (NIOSH, 1994a; NIOSH, 1994c).

During each individual event, personal air samples were collected on the left and right lapels of the worker. Specifically, worker lapel samples were collected in both 15-minute (n=4, 2 consecutive samples on both the right and left lapel, 8 - 10 LPM respectively) and 60-minute (n=2, one sample on both the left and right lapel, 3 – 6 LPM respectively) time segments. In addition, during each event 30 minute area samples were collected at two bystander locations (5 feet from the main activity, 8 - 10 LPM), and a remote location (over 50 feet from the main activity, 10 LPM) at breathing zone height (5 feet) (Figure 3A). To assess background conditions inside the facility prior to testing, three consecutive 30-minute samples were collected at the beginning of each day of testing at both bystander locations. Three consecutive 120-minute ambient air samples were also collected each day of testing with a sampling rate of 10 LPM outside the south wall of the shop away from automobile traffic.

All event sampling was completed with the entry and service doors of the repair shop closed. After each box handling, clothes handling, or counter cleanup event, the doors of the shop were opened to air-out the workspace. A summary of the airborne asbestos sampling events collected per exposure scenario is shown in Figure 3B.

Fibers were counted according to the NIOSH Methods 7400 and 7402, which define fibers as being greater than 5 μm in length and 0.25 μm in diameter and having at least a 3:1 aspect ratio (NIOSH, 1994a; NIOSH, 1994c). All airborne asbestos samples were sent to an American Industrial Hygiene Association accredited laboratory (EMS Laboratories, Pasadena, CA) for analysis of asbestos by Phase Contrast Microscopy (PCM, NIOSH Method 7400) and Transmission Electron Microscopy (TEM, NIOSH Method 7402) (NIOSH, 1994a; NIOSH, 1994c). Air samples were also analyzed according to the International Organization for Standardization (ISO) method for characterization of fiber type, size, and morphology of fibers greater than 5 μm in length (ISO, 1995).

Fiber Size and Morphology Analysis

Because OSHA specifies PCM analysis (with or without TEM analysis) for the evaluation of occupational exposures to airborne asbestos, most workplace measurements of asbestos utilize the NIOSH Method 7400. However, the NIOSH Method 7400 PCM analysis does not differentiate asbestos fibers from other structurally similar non-asbestos fibers, therefore OSHA has indicated that TEM analysis (NIOSH Method 7402) can be used to quantify the ratio of asbestos fibers to total fibers, which is then applied to the PCM fiber concentration result (OSHA, 1994). To assess occupational exposure to asbestos, one can compare either the PCM result or the PCM adjusted result to the OSHA PEL.

While the NIOSH methods 7400 and 7402 cannot be used to assess the fiber size (length and width) of any given fiber, the ISO Standard method is a refined technique using TEM that permits characterization of both fiber size and type, and it can differentiate between free fibers and fibers associated with a matrix (ISO, 1995). Using the ISO 10312 methodology, asbestos fiber morphology in the personal air samples was quantified by categorizing asbestos fibers greater than 5 μm in length as free fibers, free fiber bundles, fiber clusters, or matrix fibers (including matrix fibers, bundles, and dispersed arrangements). In those instances where asbestos fibers were associated with a cluster or matrix, the dimensions of the cluster or matrix structure, as well as those of the individual fibers within the cluster or matrix, were recorded The ISO methodology was also used to assess the presence of amphibole fibers in the personal air samples.

A number of studies have shown that fibers that are deposited in the pulmonary region of the lung are thinner than 0.7 μm and virtually all are thinner than 1 μm (Harris and Timbrell, 1975; Strom and Yu, 1994; Sussman et al., 1991a, Sussman et al., 1991b; Yu et al., 1995). Therefore, for the purposes of this analysis, respirable fibers (free and bundles) were designated as those with width of 0.7 μm or less.

Collection and Analysis of Bulk Asbestos Samples

Filings of the clutch lining material from each box and the dust that accumulated on the counter during the box handling activities were collected for bulk sample analysis for asbestos in a plastic bag which was then sealed and sent for analysis. Both types of bulk material were analyzed by EMS Laboratories (Pasadena, CA) using X-Ray Diffraction (XRD) according to NIOSH Method 9000 (NIOSH, 1994d), and Polarized Light Microscopy (PLM) according to NIOSH Method 9002 (NIOSH, 1994b). XRD analysis was used to determine the % composition (by weight) of the bulk samples that were comprised of asbestos while the PLM analyses were used to assess the presence of chrysotile or amphibole asbestos fibers. The limit of detection (LOD) for PLM analysis was 1%.

Air Exchange Measurements Using Tracer Gas

Sulfur hexafluoride (SF_6) was used as a tracer gas to estimate the air exchange rate within the garage as previously described by Paustenbach and coworkers (Paustenbach et al., 2006). In summary, measurements of the gas were taken according to ASTM Method E741-00 (ASTM International, 2001). A steady-state concentration of 1 ppm for SF_6 (Sigma-Aldrich, St. Louis, MO) was targeted for the tracer gas analysis. Based on the estimated volume of the repair shop, three Tedlar bags (Fisher Scientific, Hampton, NH) were filled with SF_6 outside of the garage to prevent leakage into the shop. The bags were then released in the garage with all doors closed. Fans on either end of the garage were used to facilitate dispersion of the gas After steady-state was reached, SF_6 measurements were taken in 30-sec intervals with a MIRAN SapphIRe-XL Analyzer (Thermo-Electron Corporation, Hayward, CA) for approximately 1 hr. The air exchange was calculated by the following equation:

$$A = |(\ln C_2 - \ln C_1)|(t_2 - t_1) \quad (1)$$

The air exchange in the garage was calculated using the concentration decay (optional regression) test method by plotting the natural logarithm of SF_6 concentration over time (ASTM International, 2001).

Data and Statistical Analyses

Descriptive statistics were calculated for both PCM and TEM measurements of airborne fiber concentrations. Analytical sensitivity limits were estimated based on the presumption that 1 fiber could be counted within 100 microscopic fields and the volume of air sampled (NIOSH, 1994a; NIOSH, 1994c) Results below the analytical sensitivity limit (LOD) were inputed using a value equal to one-half the sensitivity limit. PCM measurements were adjusted for asbestos fiber content according to the method outlined in NIOSH Method 7402, which specifies multiplying the ratio of asbestos fibers to total fibers observed in the TEM analysis by the PCM fiber concentration (NIOSH, 1994c). The ratios of asbestos to total fibers (asbestos and non-asbestos fibers) were based on TEM fiber counts for the same filters from which the PCM fiber counts were obtained. The PCM measurements adjusted by the ratio of asbestos versus total fibers were referred to as "PCM adjusted" (PCMadj) airborne asbestos concentrations in this study. In cases where the PCM result was below the analytical sensitivity limit but asbestos fibers were detected in the corresponding TEM measurement, a value of one-half the PCM analytical sensitivity limit was substituted and multiplied by the ratio of asbestos fibers:total fibers observed by TEM. In circumstances where PCM measurements were above the sensitivity limit (LOD), but asbestos fibers were not detectable by TEM, a PCM-adjusted asbestos concentration was not calculated. All of the reported measurements for the various activities are the actual measured values and have not been adjusted for contributions from background or ambient sources.

Thirty-minute TWA and 8-hr TWA airborne asbestos concentrations were calculated from the consecutive 15-min samples collected on the right and left lapel of the worker using the following equations, respectively:

$$\sum(C_i * t_i)/30 \text{ min} \quad (2)$$

$$\sum(C_i * t_i)/480 \text{ min} \quad (3)$$

where C_i is the average airborne concentration (f/cc) for the left and right lapel collected for each of the sampling segments and t_i is the duration of the task. For the 8-hr TWA calculation, the mean of all the measured background values was assumed to be present for the remaining 7.5 hours of the workday. The 15-min concentrations were compared to the historical OSHA 15-min ceiling limit of 10 f/cc (1972 – 1986) and the calculated 30-min TWA concentrations were compared to the current OSHA 30-min excursion limit of 1 f/cc (1988 – present). Eight-hour

TWA airborne asbestos concentrations were compared to the current OSHA PEL of 0.1 f/cc

RESULTS

Air exchange on the days of testing (measured with SF_6 tracer gas) indicated rates of 0.4 air exchanges per hour on January 20, 2007, 2.0 air exchanges per hour on January 21, 2007, and 0.3 air exchanges per hour on January 27, 2007. These air exchange rates are similar to those reported previously for this building by Paustenbach et al. (2006) and are low compared to the rates expected in most auto repair facilities (ASHRAE, 1991; Paustenbach et al., 2006). This is not surprising, given that no active ventilation system was present in the building and all doors and windows were kept closed during sampling.

Asbestos Bulk Sample Analyses

The chrysotile content of each clutch is summarized in Table II. Bulk sample analysis (via X-ray diffraction, XRD) indicated that all of the clutches contained asbestos and the mean chrysotile asbestos content was 33.7% ± 2.0, with a range of 20 - 52%. PLM analysis (LOD 1%) did not indicate the presence of amphibole asbestos fibers in any of the clutches. Bulk sample analysis (XRD) of dust which had accumulated on the countertop during the unpacking and repacking of boxes of clutches indicated an average chrysotile asbestos concentration of 6.8% ± 2.2, and a range of 1 - 14% (Table III)

Airborne Asbestos Sample Analyses

Table IV presents the mean, minimum and maximum airborne PCM, TEM, and PCMadj data for the different activities and sampling periods. Average sensitivity limits for airborne asbestos samples ranged between 0.0004 and 0.0042 f/cc for PCM and 0.003 and 0.009 f/cc for TEM (data not shown).

As summarized in Table IV, the mean of the 1st 15-minute PCMadj values for unpacking/repacking a single box were very similar in all handling scenarios: 0.051 f/cc with no manipulation, 0.050 f/cc with dry wipe and overhead handling, 0.046 f/cc with spray clean wipe and overhead handling. As is also summarized in Table IV, for each of these activities. the means of the 2nd 15-minute PCMadj values were far lower (means of 0.002, 0.005 and 0 001 f/cc, respectively) than the 1st 15-minute means. The mean of the 1st 15-minute asbestos concentrations associated with unpacking/repacking two boxes (0.196 f/cc) was higher than the means measured with one box; however the concentrations measured during the 2nd 15-minutes were far lower (mean of 0.001 f/cc) and similar to the values measured with one box . The relatively higher personal measurements during the 1st minute sample (2 boxes) were not evident at the bystander and remote locations (Table IV). Repetitive stacking and handling of 27 unopened boxes generated the highest mean concentrations in this study (1st- and 2nd 15-minute PCMadj means of 0.231 and 0.194 f/cc respectively). Again, however, airborne concentrations of asbestos above background were not present at the bystander or remote locations (Table IV) The trends observed in the 60 minute samples were generally consistent with those discussed above (Table IV).

Cleanup and clothes handling activities did not generate significant concentrations of airborne asbestos (maximum PCMadj value of 0.006 f/cc on personal lapel samples, no measurable asbestos fibers at remote or bystander locations). Samples collected at the bystander locations (5 feet away from the box activities) were less than 0.02 f/cc regardless of activity, while all of the samples collected at the remote location contained zero PCMadj values. Similarly, all background PCMadj samples collected between testing events and ambient measurements were calculated to be 0.000 f/cc (Table IV).

As can be seen in Table IV, every individual 15 minute sample was less than the historical OSHA short term 15-min ceiling limit of 10 f/cc (1972 – 1986). As shown in Figure 5, the calculated 30-minute TWAs for all activities were less than the current (1988-present) short term 30-minute OSHA standard of 1 f/cc. As shown in Figure 6, the calculated 8-hr TWAs for all activities were far below the current 8-hour OSHA PEL of 0.1 f/cc.

Fiber Size and Morphology

Fiber size and morphology were assessed for personal worker samples collected during box handling, cleanup, and clothes handling activities. For the purposes of this analysis, the limit of detection of fiber length was 5 μm. When all the data are considered in aggregate (all activities combined) the results indicate that 57% of the fibers counted were free fibers or bundles, 19% were fiber clusters, and 24% were associated with a matrix (Table V). Approximately one-third (29%) of the free fibers/bundles were of a respirable width (less than 0.7 μm). Very few (3%) of the fibers/bundles longer than 20 μm were less than 0.7 μm in width It should also be noted that 17% of the "respirable fibers" (fibers of widths less than 0.7 μm) were actually bound in a matrix. Using a respirable particle definition of < 10 μm in diameter yielded similar values for the clusters and matrix-bound fibers. None of the personal air samples contained detectable amphibole fibers

DISCUSSION

The results of this study indicate a number of activity patterns and data trends that should permit an accurate evaluation of potential asbestos exposures associated with a variety of clutch-handling scenarios. First, unpacking and repacking unused asbestos-containing manual clutches results in brief "peak" asbestos levels that rapidly return to concentrations at or near background levels. As a result, asbestos levels associated with unpacking/repacking one or two boxes did not exceed any of the historical or current short- or long-term occupational standards (Table IV and Figures 2 and 3). Cleaning the clutch face with a dry wipe or spray cleaner did not influence the airborne asbestos levels (Figure 4). Airborne concentrations at bystander locations (5 feet from the work activities) were even lower and often indistinguishable from background. Given the fact that garage mechanics rarely conducted more than one clutch change a week (Cohen and Van Orden, 2008; Kauppinen and Korhonen, 1987; Yeung et al., 1999), it can be concluded that clutch box handling did not result in exceedances of workplace standards for garage mechanics or co-workers at any point in time.

Interestingly, the results of the "box-stacking" activity suggest that handling numerous unopened boxes in a short amount of time can result in higher asbestos levels than actually opening the boxes and handling the clutch. In this study, 27 unopened boxes were repetitively stacked/unstacked and otherwise moved about on the work counter throughout the first and second 15 minute periods (approximately 4 cycles of stacking/unstacking during each 15 minute period). The bystander (but not remote) concentrations were also elevated relative to all other activities. The box stacking activity constituted the first sampling event on the first day and therefore the results are not due to suspension of residual fibers from previous activities. Hence, the results indicate that repetitive handling of numerous unopened boxes (as might be conducted by a distribution warehouse parts picker, or occasionally by an auto parts dealer or counterman) could result in higher short-term exposures than might be experienced by a mechanic who would typically open one or two boxes a week at most. Nonetheless, the 15 minute samples were all below the historical 15 minute STEL (10 f/cc) (Table IV, Figure 4), the calculated 30-minute TWAs were all below the current OSHA 30 minute STEL of 1 f/cc (Figure 5), and the calculated 8-hour TWAs (assuming background exposure levels for the remainder of the day) were also below the current 8-hour PEL (0.1 f/cc) (Figure 6).

Personal airborne samples collected during counter cleanup and clothes handling were all low and often non-detectable, suggesting that these activities would contribute little if any to the total asbestos exposure experienced by a mechanic, parts picker, or auto parts dealer. The data also suggest that "take home" exposures, as might be experienced by a person(s) laundering the clothes of the worker, would be minimal. It is interesting to note that the personal TEM results were higher than the personal PCM results for all activities except cleanup and clothes handling, which indicates that non-asbestos fibers from the cleanup activities and clothing contributed to the PCM values. This is consistent with the findings of Weir et al. in which airborne asbestos levels were measured during the agitation of a brake mechanic's clothing to determine the quantity of fibers remaining on the clothing (Weir et al., 2001). The majority of fibers were not asbestos fibers, but other benign fiber types such as cotton fibers; the small amount that was asbestiform was composed of chrysotile fibers (Weir et al., 2001). Similarly, analysis of the counter top bulk samples (collected at the end of each day) indicated a chrysotile content of 6.8% ± 2.2. This is much lower than the chrysotile content of the original clutch material (33 7% ± 2.0), suggesting the presence of non-asbestos material in the dust that accumulated on the counter (possibly from the box itself). It is also worth noting that the PCM results of the bystander and remote samples were consistently higher than TEM results, again indicating the presence of a significant number of non-asbestos fibers at these locations.

The low airborne asbestos levels measured in this study are consistent with recent studies of clutch handling and repair activities. Yeung et al. (1999) reported no detectable airborne asbestos at a detection limit of 0.05 f/cc (PCM) during a single clutch repair in an Australian passenger car service garage (Yeung et al., 1999). RJ Lee (2004) measured airborne asbestos concentrations (PCM) during clutch servicing activities that included opening of the bell housing, removing the clutch plate and scraping debris from inside the housing (R.J. Lee Group, 2004). All 8-hour TWAs were below the current 8-hour OSHA PEL of 0.10 f/cc (the highest reported concentration was 0.0363 f/cc) and in fact most samples did not contain any detectable asbestos fibers (R.J. Lee Group, 2004). Boelter et al (2007) reported 8-hr TWAs ranging from 0.007 to 0.013 f/cc during clutch-specific repair from heavy equipment (Boelter et al., 2007). In many instances, the previous studies also involved brake servicing activities which may have influenced the airborne asbestos fiber concentrations. Hence, even if it was assumed that all of the asbestos measured in those studies was derived solely from clutches (i.e., brakes and gaskets made no contribution), the results would still clearly indicate that clutch repair does not result in asbestos levels in excess of workplace standards.

The airborne asbestos concentrations measured in this study are likely biased high for most settings. First, the data were collected under conditions of very little ventilation. Second, the boxes and the clutches used in this study were at least 30 years old and therefore the data are probably conservative for potential exposures that occurred when relatively new clutch boxes were handled or opened. Third, while it is reasonable to expect that a mechanic or parts picker would open (and possibly repack) clutch boxes on a fairly consistent basis, it is unlikely that an auto parts counterman would actually repetitively shuffle and stack 27 clutch boxes on a counter in a 30-minute period. The same individual conducted all of the tasks in this analysis and therefore the influence of worker-to-worker variability is unknown. Given the fairly simplistic nature of the tasks conducted in this study (e.g., opening/repacking or shuffling clutch boxes), the influence of worker-to-worker variability should be minimal. Future studies evaluating more complex tasks (e.g., performing a complete clutch change) should address this potential variability factor.

The clutches used in this study contained 33.3% ± 2.0 chrysotile asbestos by weight, as determined by X-ray diffraction. Although chrysotile fibers were used to manufacture asbestos-containing automotive friction products such as brakes and manual clutches, it has been known for some time that certain chrysotile mines contained trace amounts of tremolite, a non-commercial amphibole fiber. Accordingly, it is theoretically possible that small amounts of tremolite may have been present in some asbestos-containing friction products at different points in time. However, the weight of evidence is largely negative in this respect. For example, Sheehy et al. (1989) found that fibers in 40 vehicles with asbestos-type brake shoes contained mostly chrysotile fibers, and that fibers in the wheel drum bulk samples represented less than 1% of the brake dust, and were generally 60-100% chrysotile (Sheehy et al., 1989). Weir et al. demonstrated that an overwhelming majority of samples from dust collected from the brake drum where air was not used to blow out the drum contained non-fibrous material (cotton), and that most fibers were attached to phenolic residue deposits (Weir et al., 2001). Weir et al further demonstrated that fibrous asbestos-containing material, determined to be chrysotile by morphology, could be removed from brake pads by grinding or drilling processes, but they remained bound to the matrix of the underlying material (Weir and Meraz, 2001). Blake et al.

determined that air samples contained only chrysotile asbestos and an absence of other types of asbestos following brake changes in 4 different vehicles (Blake et al., 2003). In a recent study, we found that 121 asbestos-containing brakes had no detectable amphibole fibers (polarized light microscopy analysis with a limit of detection of 1%) (Madl et al., 2007). Similarly, in the current study, we found that none of the 24 asbestos-containing clutches contained amphibole fibers (polarized light microscopy analysis with a limit of detection of 1%).

It has been understood since the 1970's that the disease-producing potential of an inhaled fiber is governed in part by the fiber dimension (Stanton and Wrench, 1972; Stanton et al., 1972) Recent government expert panel evaluations have concluded that asbestos fibers < 5 μm in length (ATSDR) or up to 20 μm in length (EPA) probably do not contribute to disease (ATSDR, 2001; USEPA, 2003). Fiber widths of > 0.7 μm are rarely found in the lung (Stanton et al., 1972; Sussman et al., 1991a; Sussman et al., 1991b; Timbrell, 1980; Timbrell, 1982) and for the purposes of this analysis 0.7 μm is assumed to represent the upper bound of a respirable width. Hence, fibers of > 5 μm and > 20 μm in length, both with respirable widths < 0.7 μm, are of particular interest in this study. The fiber size and morphology analyses of the air samples demonstrated that only 29% of the airborne free fibers > 5 μm in length were of a respirable width (<0.7 um). Very few (3%) of the free fibers > 20 μm in length were of a respirable width (Table V). It is worth noting that a significant fraction of the respirable OSHA fibers (<0.7 um width, >5 um in length) measured in this study were present either in clusters (11%) or were bound in a matrix (17%). The current understanding of lung deposition characteristics of fibers is based primarily on free fibrous structures; the behavior of more complex fibrous structures, such as those attached to a matrix or resin, is less clear (Gross et al., 1971; Harris and Timbrell, 1977; ISO, 1995; Morgan and Holmes, 1980; OSHA, 1994; Strom and Yu, 1994; Sussman et al., 1991a; Sussman et al., 1991b; Timbrell, 1980; Timbrell, 1982; Yu et al., 1995). Presumably, at least some of these fibers would not be respirable due to a large aerodynamic diameter (of the cluster or matrix) and/or would not biologically active due to their encapsulation in a solid matrix. The PCM analytical methods typically used to monitor asbestos concentrations in the workplace cannot distinguish between free fibers vs. fiber clusters vs. matrix-bound fibers and, therefore, these results suggest that the PCMadj values reported in this paper are likely to overestimate actual respirable concentrations of OSHA fibers associated with different clutch handling activities.

Since the late 1960's, numerous industrial hygiene studies involving service and repair of asbestos-containing brakes have consistently found that the airborne asbestos levels were below contemporaneous and current occupational standards (Agudo et al., 2000; Goodman et al., 2004; Hessel et al., 2004; McDonald and McDonald, 1980; Paustenbach et al., 2004; Paustenbach et al., 2003; Spirtas et al., 1994; Spirtas et al., 1985; Teschke et al., 1997; Teta et al., 1983; Woitowitz and Rodelsperger, 1994; Wong, 2001). We recently developed estimates of cumulative asbestos exposures for brake mechanics based on industrial hygiene data and assumptions regarding the number of brake jobs a career mechanic might perform (Finley et al., 2007). We reported that the median and upper-bound cumulative exposures for U.S. automobile and light truck brake mechanics who worked prior to the installation of dust-control technologies (i.e., before the mid-1970's) were 0.41 and 2.79 f/cc-years, respectively (Finley et al., 2007) Similarly, estimates of lifetime cumulative asbestos exposuress associated with clutch box handling can be developed for a variety of individual work scenarios using the data presented in this paper (the product of the 8-hr TWA of a task and the number of years performing the task). For example, based on the 8-hr TWA estimate of 0.0016 f/cc for opening one clutch box (Figure

6), a 40-year career mechanic who performs one clutch change per week would experience a cumulative chrysotile asbestos dose of 0.065 f/cc-years as a result of taking the clutch out of the box (0.0016 f/cc x 40 years). A counterman unpacking/repacking 10 boxes a week for 20 years would have a cumulative exposure of 0.62 f/cc-years (8-hr TWA estimate of 0.0062 f/cc for unpacking/repacking 2 boxes x 5 x 20 years), while a parts picker stacking and shuffling 200 boxes per week for 5 years would have a cumulative exposure of 0.066 f/cc-years (8-hr TWA estimate of 0.0133 f/cc for stacking boxes x 5 years). In all cases, background values were used for the "non-exposure" periods. These exposures, and generally any plausible exposures associated solely with clutch box handling, are similar to or less than the aforementioned estimated exposures for mechanics conducting brake repair (Finley et al., 2007). Because it has been well-established that garage mechanics conducting brake repair are not an increased risk of developing asbestos-related diseases (Finley et al., 2007), it can be inferred that the cumulative asbestos doses associated with clutch box handling do not pose a health risk. Also, any estimated exposures from clutch box handling would be far below the cumulative "no-effect" exposures that have been reported for chrysotile-exposed cohorts: 25-1,000 f/cc-years for lung cancer (Albin et al., 1990; Berry and Newhouse, 1983; Brown et al., 1994; Hughes et al., 1987; Lacquet et al., 1980; Liddell and Armstrong, 2002; McDonald et al., 1983a; McDonald et al., 1983b; McDonald et al., 1984; McDonald et al., 1993; Neuberger and Kundi, 1993; Peto et al., 1985; Pierce et al., 2007; Piolatto et al., 1990) and 15-500 f/cc-years mesothelioma (Albin et al., 1990; Lacquet et al., 1980; McDonald et al., 1984; Pierce et al., 2007; Piolatto et al., 1990). In short, our findings suggest that individuals opening, repacking, or otherwise handling clutch boxes are not at an increased risk of asbestos-related disease. "Bystander" or "take-home" exposures would be even lower and would also pose no health risk.

In conclusion, we have assessed airborne asbestos concentrations associated with several automotive clutch disc handling exposure scenarios not previously characterized in the literature A broad range of both typical and worst-case clutch box handling scenarios was studied, in addition to evaluating potential exposure associated with handling work clothes or performing clean-up activities following these scenarios. While this study characterizes potential exposures associated with handling boxes of clutches, a scenario not previously assessed in the historical exposure studies of automobile mechanics, the results of this study should not be extrapolated beyond what was tested. In summary, the short-term and 8-hr TWA airborne asbestos concentrations measured and calculated for a mechanic or bystander unpacking and repacking boxes of asbestos-containing clutches were below the current OSHA excursion limit and PEL for asbestos, as well as below all previous U.S occupational standards for asbestos.

ACKNOWLEDGEMENTS

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LIST OF TABLES AND FIGURES

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Table I Summary of clutch handling and associated activities performed throughout the simulation study

Activities	Day 1	Day 2	Day 3	Activity replicates	# personal worker samples
Stack boxes	1	---	---	1	4
U/R 1 box	4	4	4	12	48
U/R 1 box, DW, OH	2	---	---	2	8
U/R 1 box, SC, OH	2	---	---	2	8
U/R 2 boxes, OH	---	2	2	4	16
Clean counter	1	1	1	3	12
Clothes handling	---	---	1	1	4

U/R – Unpack/Repack DW – Dry wipe SC – Spray cleaner OH – Handle overhead

Table II Chrysotile content of the 24 clutch linings used in the simulation study.

Brand	XRD Result (Chrysotile %)	PLM Result (Amphibole %)
Brand 1	27	ND
Brand 2	29	ND
Brand 3	39	ND
Brand 4	52	ND
Brand 5	48	ND
Brand 6	48	ND
Brand 7	23	ND
Brand 8	43	ND
Brand 9	44	ND
Brand 10	39	ND
Brand 11	26	ND
Brand 12	35	ND
Brand 13	43	ND
Brand 14	28	ND
Brand 15	33	ND
Brand 16	27	ND
Brand 17	33	ND
Brand 18	20	ND
Brand 19	25	ND
Brand 20	21	ND
Brand 21	20	ND
Brand 22	47	ND
Brand 23	28	ND
Brand 24	31	ND

Note: ND - non-detectable, XRD - X-ray diffraction, PLM - Polarized light microscopy, Non-detectable samples entered as one-half the limit of detection or sensitivity limit Limit of detection = 1%

Table III Chrysotile content of the counter dust from the simulation study

Sample ID	Sample	XRD Result (Chrysotile %)	PLM Result (Amphibole %)
All boxes	Counter Dust	2	ND
Counter 012007	Counter Dust	5	ND
Counter 012107-A	Counter Dust	5	ND
Counter 012107-B	Counter Dust	1	ND
Counter 012707-A	Counter Dust	14	ND
Counter 012707-B	Counter Dust	9	ND

Note: ND - non-detectable, XRD - X-ray diffraction, PLM - Polarized light microscopy; Non-detectable samples entered as one-half the limit of detection or sensitivity limit LOD = 1%

Table IV. Summary of airborne asbestos concentrations (f/cc) during different handling scenarios

			PCM					TEM					PCMadj			
Location	Task	Replicates	N	Mean	Min	Max	%ND	N	Mean	Min	Max	%ND	N	Mean	Min	Max
Worker (1st 15 min)	One box	12	24	0.057	0.006	0.138	0	24	0.132	0.010	0.400	0	24	0.051	0.004	0.138
	One box, DW, OH	2	4	0.058	0.035	0.120	0	4	0.115	0.060	0.200	0	4	0.050	0.027	0.109
	One box, SC, OH	2	4	0.055	0.034	0.073	0	4	0.078	0.060	0.100	0	4	0.046	0.034	0.063
	Two boxes	4	8	0.209	0.110	0.370	0	8	0.413	0.100	0.700	0	8	0.196	0.102	0.366
	Stacking boxes	1	2	0.294	0.278	0.310	0	2	0.600	0.500	0.700	0	2	0.231	0.217	0.245
	Cleanup	3	6	0.012	0.006	0.021	0	6	0.006	0.004	0.008	50	6	0.002	0.000	0.006
	Clothes handling	1	2	0.110	0.090	0.130	0	2	0.006	0.004	0.007	50	2	0.003	0.000	0.005
Worker (2nd 15 min)	One box	12	24	0.011	0.005	0.019	0	24	0.006	0.003	0.020	71	24	0.002	0.000	0.008
	One box, DW, OH	2	4	0.014	0.008	0.019	0	4	0.010	0.005	0.020	0	4	0.005	0.003	0.008
	One box, SC, OH	2	4	0.007	0.005	0.010	0	4	0.011	0.004	0.030	75	4	0.001	0.000	0.005
	Two boxes	4	8	0.013	0.008	0.024	0	8	0.005	0.004	0.010	75	8	0.001	0.000	0.007
	Stacking boxes	1	2	0.230	0.207	0.253	0	2	0.450	0.400	0.500	0	2	0.194	0.180	0.207
	Cleanup	3	6	0.010	0.004	0.018	0	6	0.005	0.004	0.007	67	6	0.002	0.000	0.006
	Clothes handling	1	2	0.047	0.039	0.054	0	2	0.004	0.004	0.005	100	2	0.000	0.000	0.000
Worker (60 min)	One box	12	24	0.021	0.007	0.041	0	24	0.025	0.003	0.090	2	24	0.014	0.000	0.031
	One box, DW, OH	2	4	0.035	0.019	0.046	0	4	0.035	0.030	0.050	4	4	0.016	0.003	0.034
	One box, SC, OH	2	4	0.017	0.007	0.026	0	4	0.017	0.006	0.030	2	4	0.013	0.002	0.022
	Two boxes	4	8	0.061	0.027	0.097	0	8	0.121	0.050	0.300	12	8	0.054	0.024	0.091
	Stacking boxes	1	2	0.172	0.118	0.225	0	2	0.250	0.200	0.300	25	2	0.149	0.097	0.200
Bystander	One box	12	24	0.010	0.004	0.032	0	24	0.003	0.002	0.006	54	24	0.001	0.000	0.008
	One box, DW, OH	2	4	0.011	0.005	0.019	0	4	0.004	0.002	0.010	50	4	0.004	0.000	0.015
	One box, SC, OH	2	4	0.009	0.006	0.015	0	4	0.003	0.002	0.004	50	4	0.001	0.000	0.003
	Two boxes	4	8	0.009	0.002	0.019	0	8	0.007	0.002	0.020	38	8	0.004	0.000	0.019
	Stacking boxes	1	2	0.030	0.027	0.032	0	2	0.007	0.004	0.009	0	2	0.010	0.003	0.016
	Cleanup	3	6	0.006	0.001	0.015	0	6	0.002	0.002	0.004	83	6	0.000	0.000	0.000
	Clothes handling	1	2	0.010	0.006	0.013	0	2	0.004	0.004	0.004	100	2	0.000	0.000	0.000
Remote area	One box	12	12	0.008	0.003	0.022	0	12	0.004	0.004	0.007	92	12	0.000	0.000	0.003
	One box, DW, OH	2	2	0.005	0.001	0.008	0	2	0.004	0.004	0.004	100	2	0.000	0.000	0.000
	One box, SC, OH	2	2	0.005	0.003	0.007	0	2	0.004	0.004	0.004	100	2	0.000	0.000	0.000
	Two boxes	4	4	0.003	0.001	0.006	0	4	0.004	0.004	0.007	100	4	0.000	0.000	0.000
	Stacking boxes	1	1	0.008	0.008	0.008	0	1	0.004	0.004	0.004	100	1	0.000	0.000	0.000
	Cleanup	3	3	0.006	0.004	0.010	0	3	0.004	0.004	0.004	100	3	0.000	0.000	0.000
	Clothes handling	1	1	0.009	0.009	0.009	0	1	0.004	0.004	0.004	100	1	0.000	0.000	0.000
Background		3	9	0.007	0.002	0.014	0	9	0.004	0.004	0.004	100	9	0.000	0.000	0.000
Ambient		3	9	0.001	0.000	0.001	0	9	0.004	0.004	0.007	89	9	0.000	0.000	0.000

Table V Size and morphology distribution of fibers detected in personal worker samples collected during various clutch handling and associated activities

			Percent Fibers (%) Classified as Fiber or Particle with Dimensions of:					
			Respirable Fiber				Respirable Particle*	
			<0.7 μm width		<3 μm width		<10 μm width	
Fiber Structure Classification	N	Total Fibers (%)	>5 μm length	>20 μm length	>5 μm length	>20 μm length	>5 μm length	>20 μm length
Total Fibers	1424	---	---	---	---	---	---	---
Free Fiber/Bundle	816	57%	29%	3%	41%	6%	---	---
Fiber Clusters	267	19%	11%	1%	15%	2%	15%	2%
Matrix Disperse	341	24%	17%	2%	21%	3%	21%	3%

Figure 1

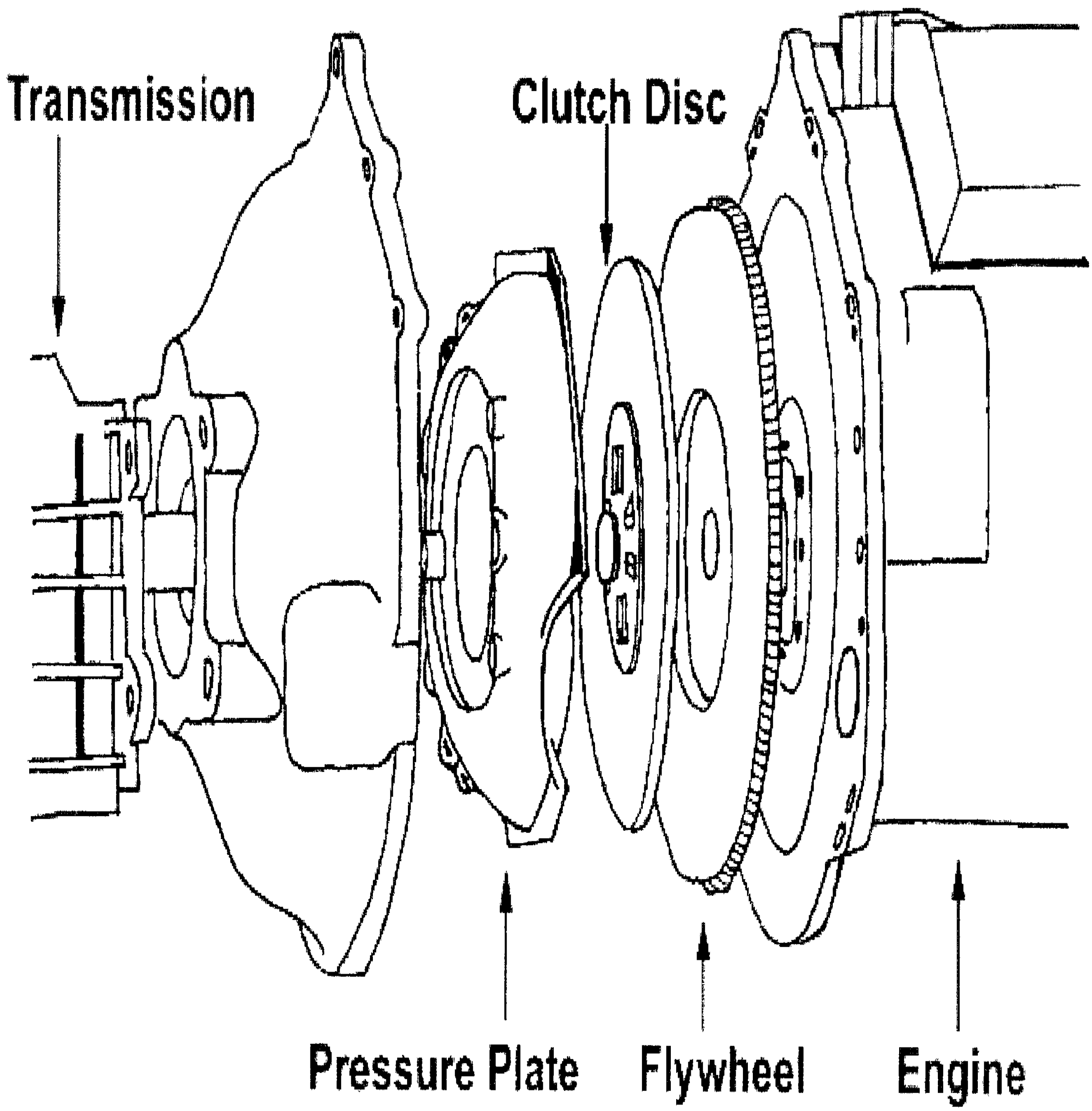


Figure 2A

Figure 2B

Figure 3A

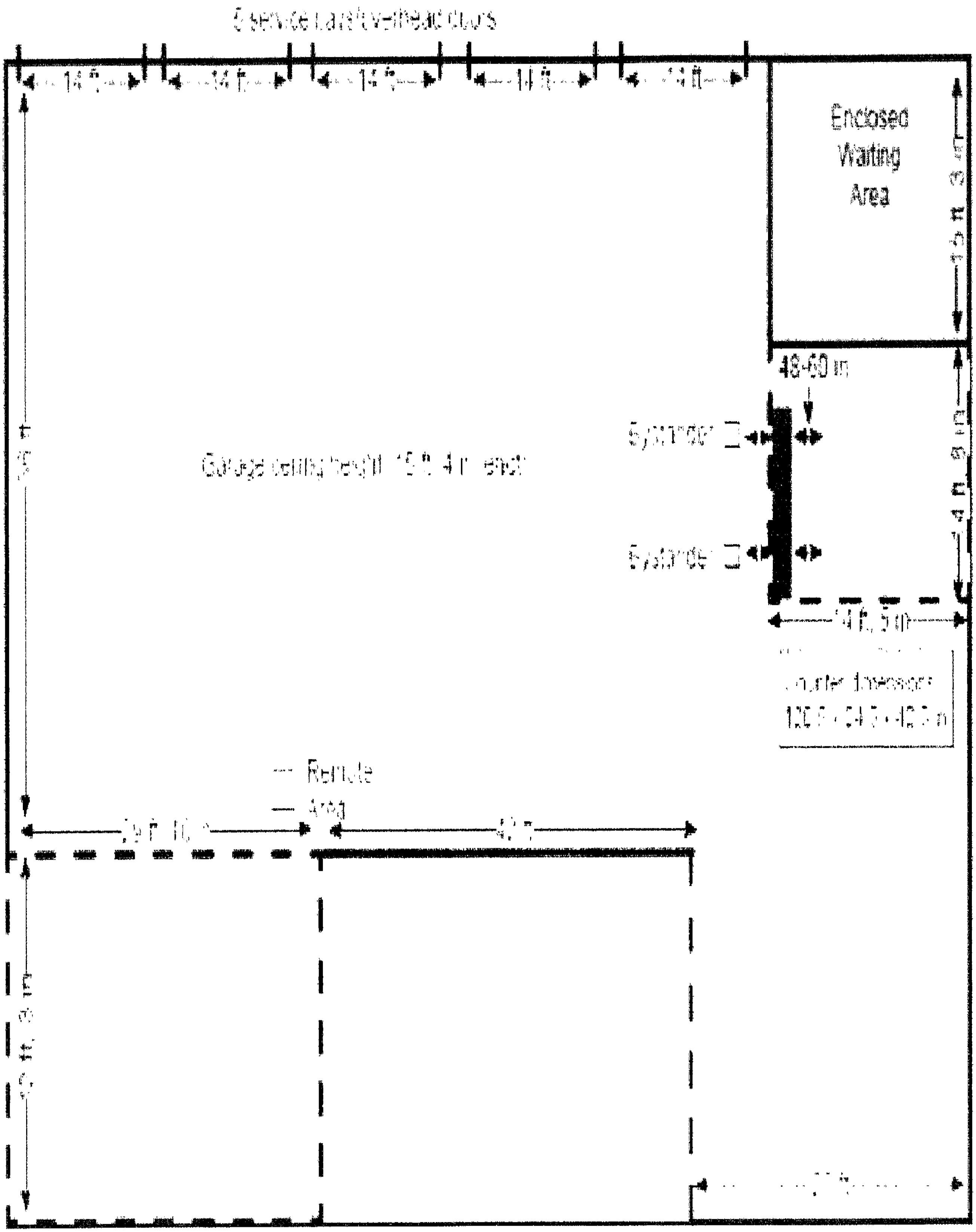


Figure 3B

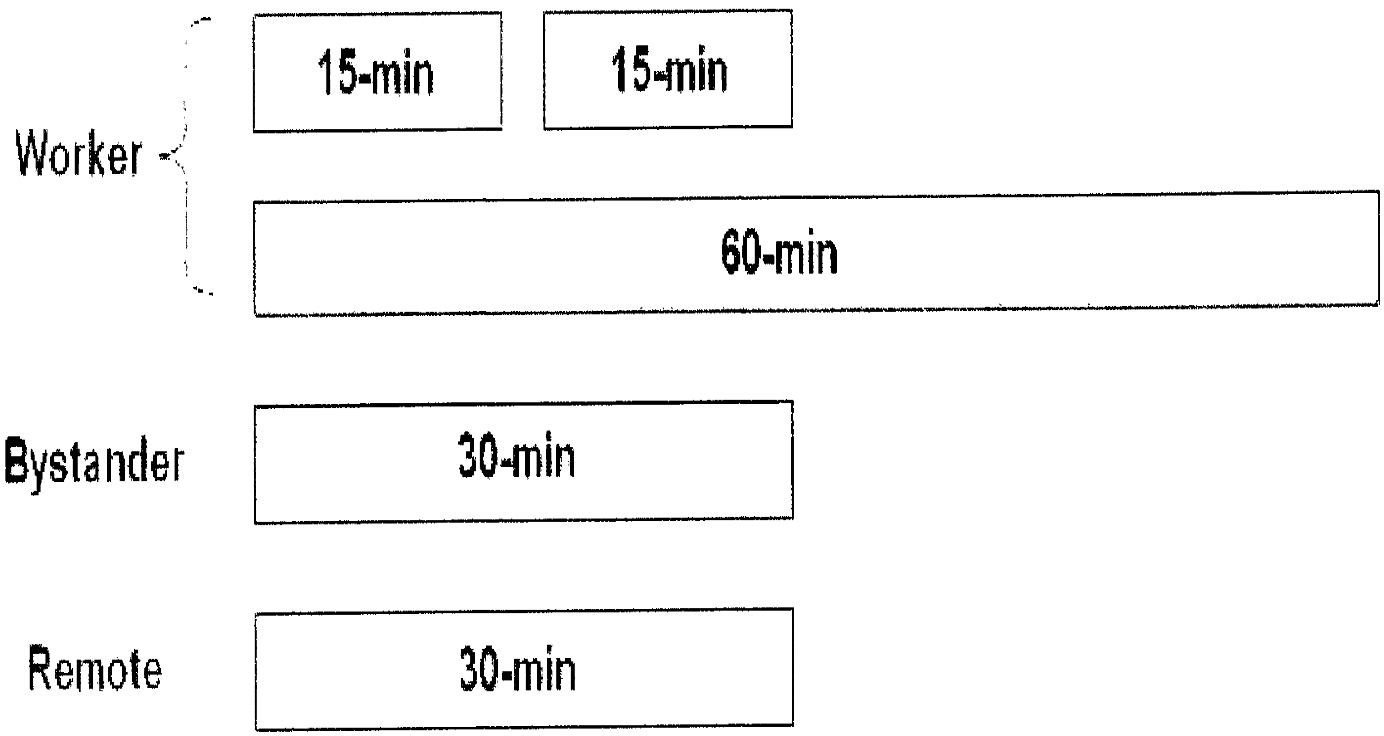


Figure 4

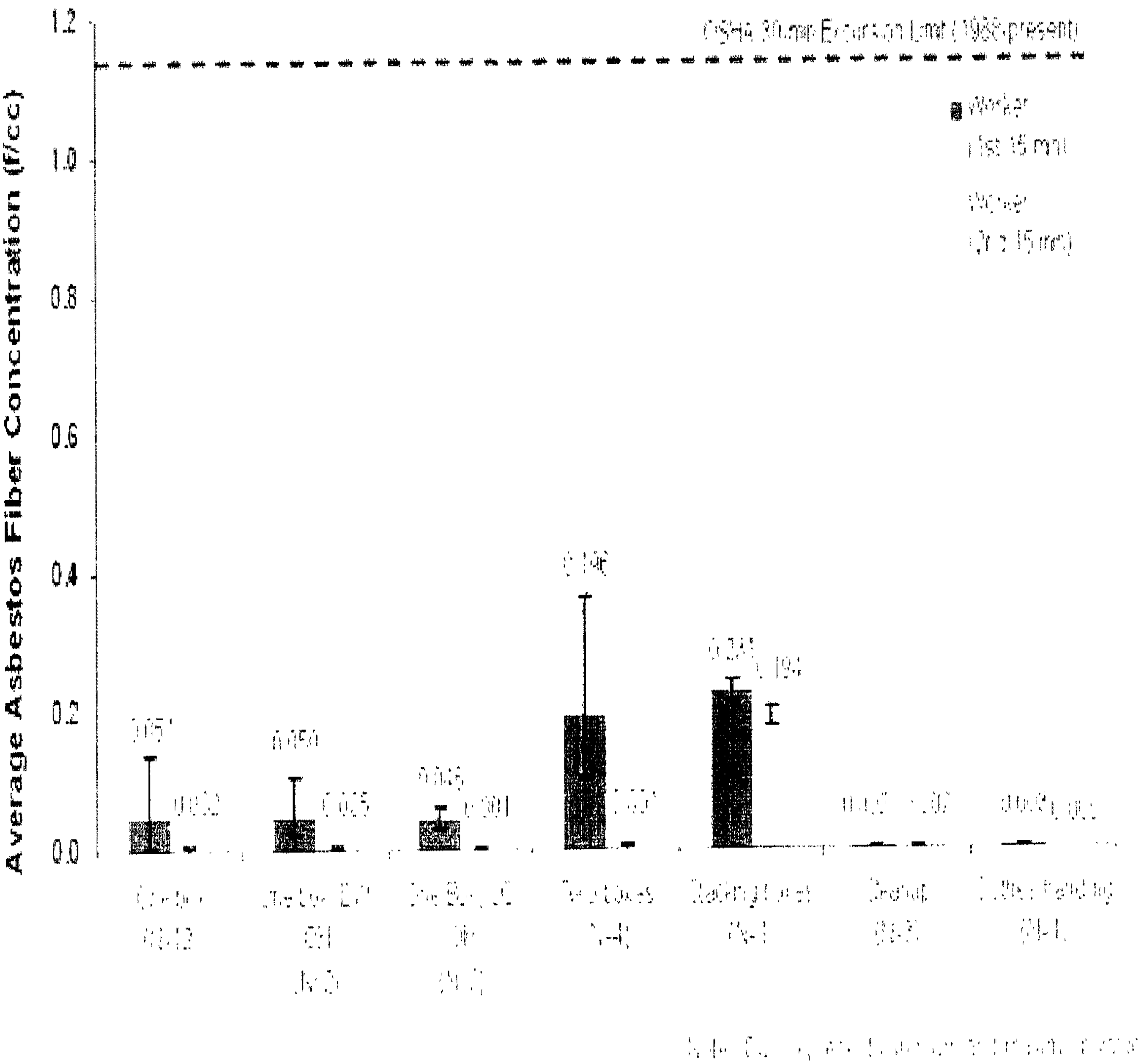

Average Asbestos Fiber Concentration (f/cc)
1.2
1.0
0.8
0.6
0.4
0.2
0.0

Figure 5

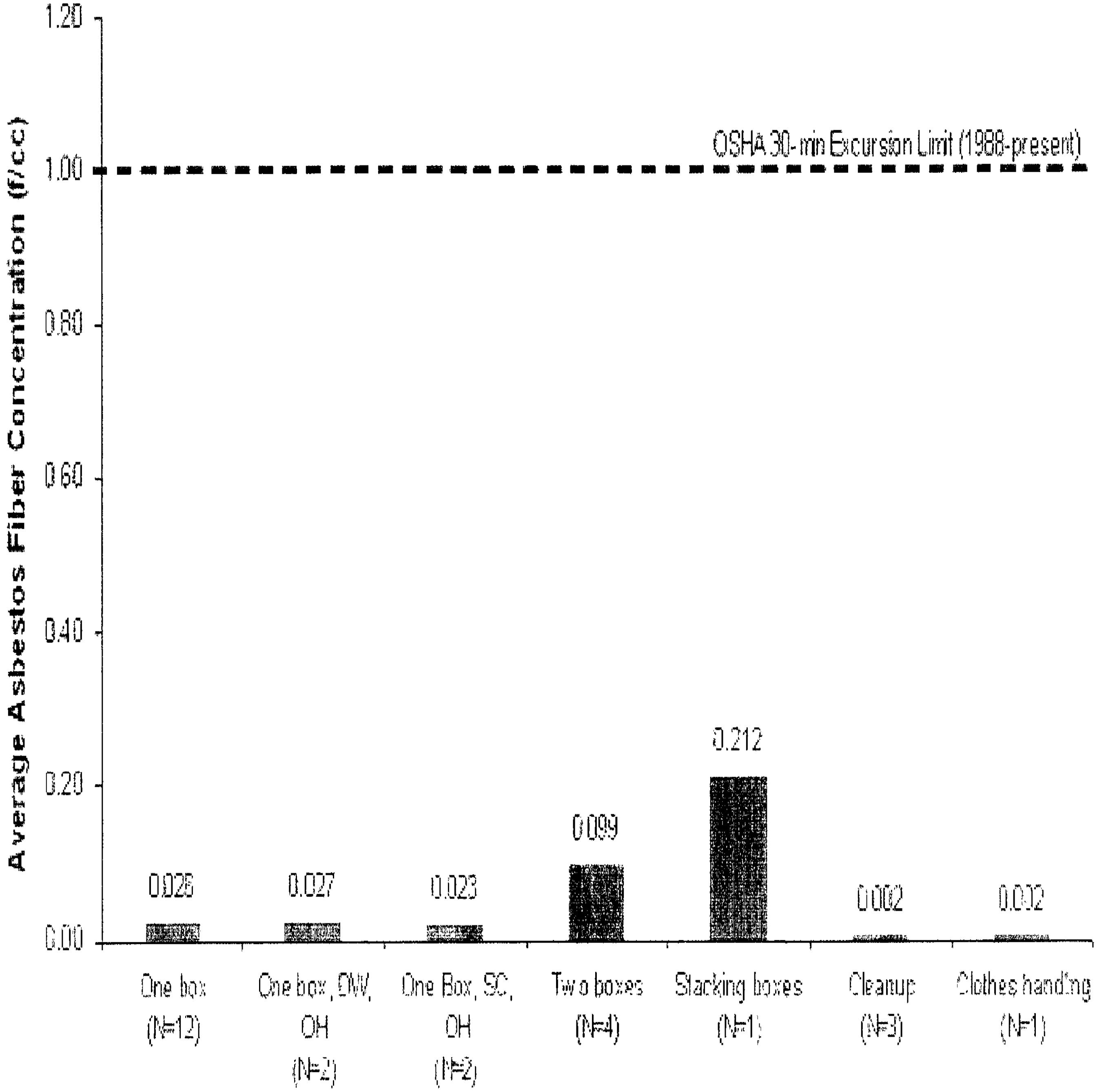
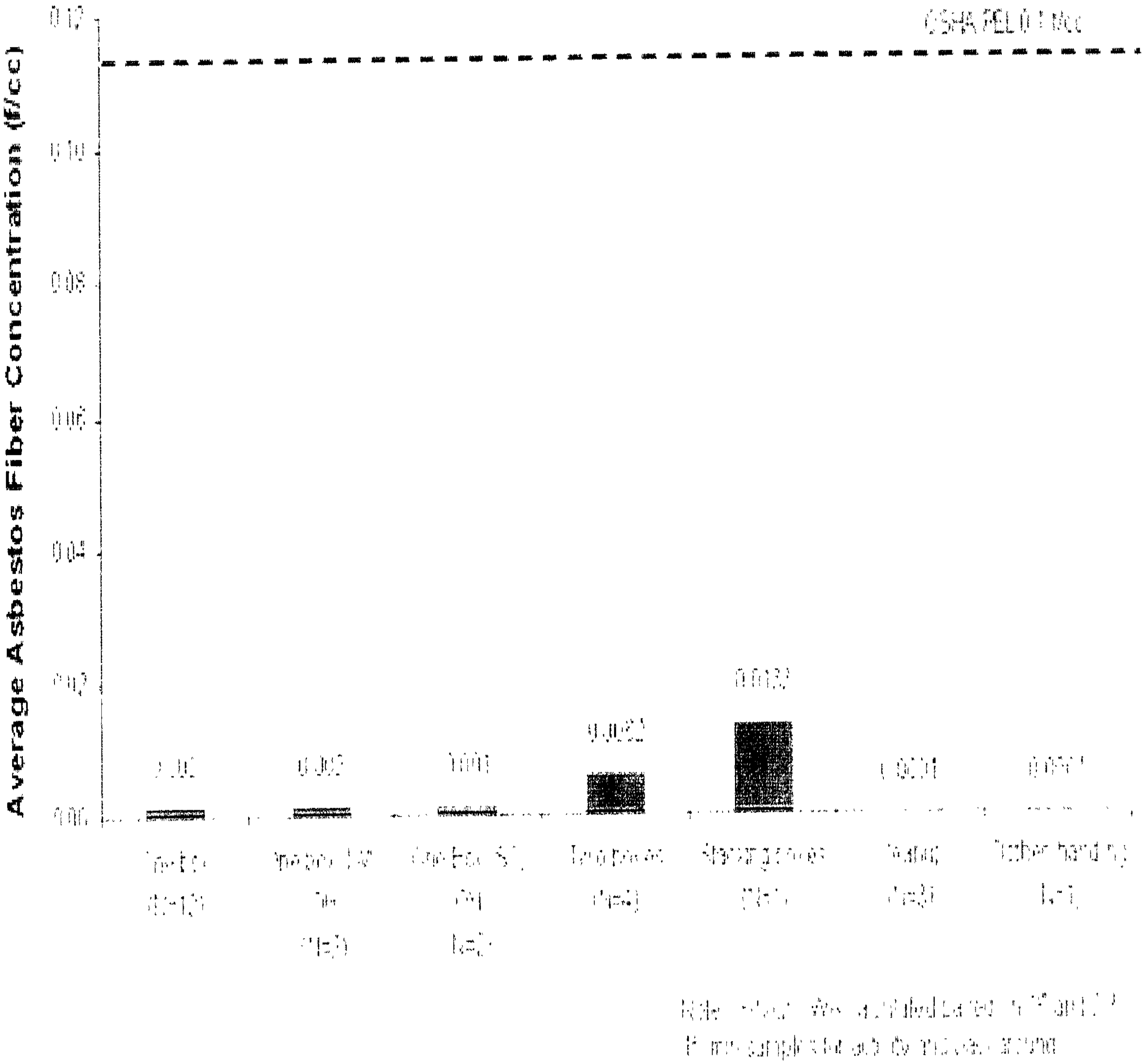

Average Asbestos Fiber Concentration (f/cc)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
OSHA 30-min Excursion Limit (1988-present)
0.026
0.027
0.023
0.099
0.212
0.002
0.002
One box (N=12)
One box, DW, OH (N=2)
One Box, SC, OH (N=2)
Two boxes (N=4)
Stacking boxes (N=1)
Cleanup (N=3)
Clothes handling (N=1)

Figure 6


Average Asbestos Fiber Concentration (f/cc)
0.12
0.10
0.08
0.06
0.04
0.00
OSHA PEL 0.1 f/cc
0.0022