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A Study of Area and Personal Airborne Asbestos Samples during Abatement in a Crawl Space

J.H. Lange[a] B.D. Kuhn[a] K.W. Thomulka[b] S.L.M. Sites[c]

[a]Department of Environmental Science and Engineering, Gannon University, Erie, Pa., [b]University of the Sciences in Philadelphia, Pa., [c]Northeastern Environmental Associates, Inc., Chambersburg, Pa., USA

Key Words

Area sampling · Personal sampling · Occupational exposure · Asbestos abatement · Glove-bag

Abstract

Air sample data were collected during asbestos abatement of two buildings using area and personal sampling methods. Abatement involved removal of pipe insulation from crawl spaces. The two sampling methods were compared to determine if there was a relationship between them. A relationship was observed between area and personal airborne samples in building 2 as determined by correlation and regression but is most likely due to chance. One major outlier was detected for both area and personal measurement sample data sets in building 2. It was concluded that any relationship between area and personal sample measurements must be viewed with caution. Concentrations measured from personal sampling were statistically higher than those from area sampling. Also, the distributions of concentrations in the samples were calculated to be nonnormal (logarithmic form). It is proposed that area sampling under-estimates worker exposure compared to personal measurements and is not applicable for exposure and hazard assessment. It is suggested that area and personal samples measure two different population concentrations of airborne fibers. Use of area samples in lieu of personal measurements should only be employed with caution.

Introduction

During asbestos abatement exposure to airborne asbestos fibers is determined by air sampling. These data are subsequently used for evaluating the potential degree of hazard [1–14]. A number of studies of airborne occupational exposure [15–21] have suggested that personal air samples, as compared to area samples, exhibit a higher concentration which is not related to area (stationary or fixed location) samples [16–22]. Few studies have concluded that area and personal samples are comparable [8, 23]. The concentration to which workers are exposed is used for establishing effectiveness of engineering controls, employment of personal protective equipment (PPE) and determination of exposure and hazard assessment [8, 24–26]. Some specifications [27–30] and regulatory agencies [31] require employment of PPE without consideration of

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J.H. Lange
Envirosafe Training and Consultants
PO Box 114022
Pittsburgh, PA 15239 (USA)
Tel. +1 724 325 3360, Fax +1 724 325 3375, E-Mail john.pam.lange@worldnet.att.net

likelihood of exposure or historical data. Use of area sampling as compared to personal sampling is often a result of convenience [8, 21, 32]. Consequently the evaluation of an association, if any, between area and personal samples is important for the abatement industry since area samples are often used to estimate exposure to workers [8]. Several studies related to asbestos abatement [8, 33, 34] have evaluated an association between the two sampling methods (area and personal) and have suggested that there may be no difference in fiber concentrations [2, 8]. Other studies of airborne contaminants have suggested that a relationship may exist [15, 16, 18]. However, studies which reported no association between area and personal samples were conducted for nonabatement industries [17–20].

Airborne concentration studies in the occupational environment have been suggested to be nonnormal and are best represented by a logarithmic distribution [8, 19, 25, 26, 34–37]. An understanding of distribution for occupational contaminants, such as asbestos, is important since this will have a strong influence for evaluating exposure measurements, potential health effects, epidemiological findings, and variability of air samples [8, 36–40].

The present study collected matched area and personal air samples during asbestos abatement in two different buildings for the purposes of comparing concentration data and evaluating sample concentration distribution. Data collected in this investigation were taken to evaluate the relationship between the two sampling methods. Distribution of airborne asbestos was also evaluated. Comparison studies of this nature will assist regulatory agencies, contractors, industrial hygienists, epidemiologists, toxicologists, and others in establishment of sampling strategies for abatement projects and exposure determinations (exposure and hazard assessment) [8, 33, 34, 41].

Materials and Methods

Both area and personal samples were collected at the same time and from the same location (matched or paired samples, within the work area) and are represented as fibers per cubic centimeter ($f \cdot cm^{-3}$) [8]. All personal samples were collected from the breathing zone and reported as a time-weighted average (TWA) as described by the US Occupational Safety and Health Administration (OSHA) [6]. Area samples were collected from the work area, inside the containment, using high-volume pumps that were 3–5 feet off the ground surface [42]. TWA methodology was used for calculating area sample concentration [6, 40, 43]. Area and personal samples were collected for 8 h a day, or as near as possible, using a flow rate of 10 and 2 liters$\cdot$ min^{-1}, respectively [3, 6]. All sampling was open face with the cassette in a downward facing position [1]. Flow rate was determined with a calibrated rotameter at the beginning and end of each sample period [8, 34, 35, 44]. Samples were collected on a 0.8 µm pore size mixed cellulose ester membrane filter with a 25-mm electrically conductive extension cowl cassette [6, 8]. Analysis was performed using phase-contrast microscopy as described by the National Institute for Occupational Safety and Health 7400 method [6, 45].

The type of abatement work involved removal of friable pipe insulation, contaminated dirt, encapsulation, and cleanup of asbestos-containing material (ACM). Approximate quantity of work for each day of sampling was estimated by observation. The program of work involved abatement in two different buildings. Building 1 consisted mostly of air cell pipe insulation and building 2 was primarily a mag pipe insulation. Nine samples were collected from building 1 and 13 samples from building 2. Abatement procedures followed the OSHA and Environmental Protection Agency (Asbestos Hazard Emergency Response Act, AHERA) protocols [3, 6]. The abatement time period for both buildings together was 22 days with one set of paired samples collected each day of work. Statistical analysis was conducted for each building separately. All samples were collected by one of the authors (B.D.K.).

Summary airborne asbestos concentrations are reported as arithmetic (AM) and geometric means (GM) [8, 34, 46]. Variation of these data is provided as standard deviation (SD) [46], geometric standard deviation (GSD) [26, 34] and range [8, 25]. For statistical comparison of matched area and personal samples, the Wilcoxon signed-rank and Z tests were employed for nontransformed and transformed data, respectively [47, 48]. Correlation coefficients were determined for sample values that were non-transformed and converted (transformed) to a logarithmic (common) value [34, 35]. For nontransformed and transformed data the Spearman rank order correlation and Pearson's product-moment correlation tests were used, respectively [48–51]. Regression analysis using ordinary least squares was performed for both nontransformed [52] and transformed data [21, 23, 53]. Correlation tests [54] and AM, SD, Wilcoxon signed-rank and regression [55] were determined using computer programs. GM and GSD were determined by converting values to a common logarithmic number, obtaining a summary statistic with the computer program, and calculating the descriptive statistic using an exponential conversion as described by Leidel et al. [40]. Statistical analysis was conducted with and without outliers.

Confidence intervals (CI), 95%, were determined for summary data using a technique for nonnormal populations [56]. Evaluation for distribution of data was conducted using the Shapiro-Wilk W test [8, 37, 57, 58]. For testing distribution, data were transformed using common logarithms (log-normality) [37, 58, 59, 60]. Determination of major outliers and coefficients of skewness and kurtosis was conducted for transformed and non-transformed (arithmetic concentration values) data using a computer program [55]. Statistical significance for the Wilcoxon signed-rank test, correlation, regression, distribution and outliers were determined at the 5% level. Bulk samples of the ACM were examined by polarized light microscopy and asbestos content reported as a percentage value [3].

The concentration detection limit was established as 0.01 $f \cdot cm^{-3}$. Sample concentrations that were reported as less than the detection limit were included in summary data and statistical calculations as 0.01 $f \cdot cm^{-3}$ [8].

Table 1. Building 1 descriptive data and summary statistics for results of fiber counts (f·cm^{-3} TWA)

Type	n	AM	SD	GM	GSD	Range	Sample distribution
Area samples	9	0.03	0.02	0.02	2.03	0.01–0.07	1 SD 77.8% 2 SD 88.9% 3 SD 100%
Personal samples	9	0.07	0.04	0.05	2.71	0.01–0.14	1 SD 77.8% 2 SD 100% 3 SD 100%

n = Number of samples; range = arithmetic range.

Table 2. Building 2 descriptive data and summary statistics for results of fiber counts (f·cm^{-3}-TWA)

Type	n	AM	SD	GM	GSD	Range	Sample distribution
Area samples	13	0.03	0.04	0.02	2.42	0.01–0.14	1 SD 84.6% 2 SD 92.3% 3 SD 100%
	12+	0.02	0.02	0.02	2.03	0.01–0.07	1 SD 83.3% 2 SD 91.7% 3 SD 100%
Personal samples	13	0.08	0.10	0.05	2.47	0.01–0.40	1 SD 92.3% 2 SD 92.3% 3 SD 92.3%
	12+	0.05	0.03	0.04	2.00	0.01–0.13	1 SD 75% 2 SD 91.7% 3 SD 100%

n = Number of samples; range = arithmetic range; + = samples without outlier.

Results

Asbestos abatement procedures in this study involved the removal of pipe insulation, contaminated dirt from a crawl space and encapsulation of surfaces and pipes. The location of this work was in central Pennsylvania, USA. Procedures followed the OSHA and EPA regulations for abatement of ACM [3, 6]. All samples were collected as matched pairs, one personal and one area, each work day in the same work (containment) location. Tables 1 and 2 provide descriptive data and summary statistics for samples collected and analyzed. Sample data, type and estimated quantity of work, at each building, for each day, in f·cm^{-3} TWA, for area and for personal measurements are shown in table 3. Confidence intervals of the AMs of buildings 1 and 2 for area and personal sample data were ±0.01 (area building 1) and ±0.02 (personal building 1), and ±0.03 (area building 2) and ±0.05 (personal building 2), respectively.

OSHA established a maximum exposure level of airborne asbestos for abatement workers before they are required to employ respiratory devices and other PPE [6]. This airborne limit is defined as the permissible exposure limit (PEL) and is 0.1 f·cm^{-3} TWA for airborne asbestos [6, 43]. Most of the sample results were below the OSHA PEL. Both the AM and GM for area and personal samples were below the OSHA PEL for buildings 1 and 2. The approximate concentration of asbestos in both types of insulation was 40% as determined by polarized light microscopy. Soil samples had asbestos debris from the pipes and some samples had a concentration greater than 1%.

Both populations of area samples from buildings 1 and 2 and personal samples from building 2 were determined

Table 3. Area and personal sample results (in f·cm^{-3} TWA) and type/quantity of work performed for each study day

Time	Fiber concentration	Type of activity/quantity of material abated
Building 1		
Day 1	Area 0.01 Personal 0.01	glove-bag 300 lf
Day 2	Area 0.02 Personal 0.14	glove-bag 800 lf
Day 3	Area 0.02 Personal 0.11	glove-bag 700 lf, dirt removal 7,400 sf and bag-out
Day 4	Area 0.07 Personal 0.07	glove-bag1,200 lf and dirt removal 4,800 sf
Day 5	Area 0.05 Personal 0.10	glove-bag 500 lf and dirt removal 2,000 sf
Day 6	Area 0.03 Personal 0.10	glove-bag 600 and dirt removal 2,400 sf
Day 7	Area 0.01 Personal 0.06	Dirt removal 1,000 sf and bagging of material (double bagging)
Day 8	Area 0.02 Personal 0.06	glove-bag 400 lf, dirt removal 1,600 and bag-out
Day 9	Area 0.01 Personal 0.01	encapsulation
Building 2		
Day 1	Area 0.01 Personal 0.01	glove-bag 1,000 lf and dirt removal 4,500 sf
Day 2	Area 0.01 Personal 0.02	glove-bag 800 lf and dirt removal 3,200 sf
Day 3	Area 0.07 Personal 0.08	glove-bag 400 lf, dirt removal 1,600 sf and bag-out
Day 4	Area 0.05 Personal 0.13	glove-bag 300 lf and dirt removal 1,200 sf
Day 5	Area 0.01 Personal 0.04	dirt removal 900 sf
Day 6	Area 0.01 Personal 0.04	glove-bag 400 lf and dirt removal 1,600 sf
Day 7	Area 0.02 Personal 0.04	glove-bag 500 lf and dirt removal 2,000 sf
Day 8	Area 0.14 Personal 0.40	glove-bag 1,200 lf
Day 9	Area 0.03 Personal 0.04	glove-bag 500 lf and dirt removal 2,000 sf
Day 10	Area 0.01 Personal 0.05	dirt removal 2,000 sf, bag material (double bag) and bag-out
Day 11	Area 0.02 Personal 0.06	dirt removal 2,000 sf and bag-out
Day 12	Area 0.03 Personal 0.10	dirt removal 2,000 sf
Day 13	Area 0.01 Personal 0.03	bag-out, final clean and encapsulation

lf = Linear feet; sf = square feet.

to be nonnormally (logarithmic) distributed. The population of personal samples from building 1 was normally distributed. If a 1% level is employed both area and personal sample data from building 1 were normally distributed. Building 2 data remained nonnormally distributed at 1%. These distributions for building 1 are supported by the percentage of values associated with the SD shown in table 1.

One major outlier was identified for both area and personal samples of building 2 when represented as nontransformed values. No outliers were identified for building 1 sample data. No outliers, in either building 1 or 2 samples, were identified when these data were transformed. Coefficients of skewness and kurtosis for area and personal samples for nontransformed values from building 1 were 1.20 and 3.16, and –0.19 and 2.03, respectively. Personal sample data from building 1 suggests normality based on skewness at a 5% probability level [60]. If this probability level is evaluated at 1%, both area and personal samples are suggested to be normal in distribution. For building 2, skewness and kurtosis for area and personal samples for nontransformed values were 2.08 and 6.49, and 2.64 and 8.92, respectively. Using probability levels for skewness, both area (2.08) and personal (2.64) data are at a level of greater than 1% from a normal distribution, suggesting nonnormality [61]. When these data are transformed, for skewness and kurtosis [62], area and personal data from building 1 are 0.43 and 2.02, and –1.62 and 4.87, and building 2 are 0.83 and 2.55, and 0.49 and 3.57, respectively.

Data, with and without the outliers, represented as both nontransformed and transformed values, were statistically different as determined by the Wilcoxon signed-rank and Z tests. Both the arithmetic and geometric means were larger for personal samples than area samples. Personal sample data also have a larger range than area samples. GSD were similar for building 2, but descriptively different for building 1. GSD for area and personal sample data suggest a relatively high variation [8, 40], but within the range of variation reported for occupational exposure [8].

Building 1 nontransformed and transformed matched (paired) data were not statistically correlated as evaluated by the slope of the line. There were statistical correlations for matched samples with and without inclusion of the outliers for both the nontransformed and transformed data of building 2. For building 2 testing for the slope of the line was found not to be equal to zero ($p < 0.05$). Correlation coefficients (R2) for building 1 nontransformed and transformed data were 0.60 and 0.10, and for building 2 were 0.82 and 0.88, respectively.

Regression analysis for building 1 nontransformed and transformed sample data had coefficient of determination values (R2) of 0.10 and 0.25, respectively, and both were statistically unrelated (significantly different). Building 2 sample data, nontransformed and transformed, with and without an outlier, were statistically related. Coefficient of determination values of building 2 for nontransformed and transformed data, with the outlier, were 0.49 and 0.71, respectively.

Discussion

This study evaluated the relationship between area and personal airborne fiber concentrations of matched samples that were collected during an asbestos abatement project. Previous occupational publications have reported both a relationship [8, 23] and no relationship [15–18, 20, 21, 34, 40] between these two sample collection methods. It has also been reported [8] that there is no statistical difference for concentration values between asbestos airborne area and personal measurements, although other studies have not supported such findings [16–18, 20, 34]. OSHA requires employers to collect personal samples for assessing potential exposure to workers of airborne asbestos [6]. There is no reference in the regulatory standards discussing use and application of area samples for determining individual exposure or for supporting this method as a mechanism of occupational (personal) sampling for asbestos. However, area sample data are often used for determining exposure of workers in lieu of personal sample data in the abatement industry [8]. Information regarding associations between area and personal airborne asbestos samples is important for evaluating exposure criteria and determination of the hazard assessment, as well as the underlying sample distribution [8, 18, 20, 21, 26, 37]. Generally, area samples are employed for environmental and public health protection, evaluation of emission controls and general concentrations of fibers in the work location, including inside and outside the regulated area (containment area) [2, 9]. Personal samples can also be used for decision criteria beside those of occupational exposure [8, 34].

A previous study [8] found a relationship between the two sample collection methods, however, sample collection in this published investigation did not evaluate concentrations that were of a TWA. The investigation presented here, which employs samples that are TWA measurements, does partially support an association between area and personal samples based on correlation coefficients. However, any association between area and personal samples must be viewed with caution since previous investigators have suggested a lack of association [17, 18, 21, 34, 63]. Correlation for area and personal sample data from building 2 suggests that these results vary together. However, there was no correlation for building 1 data.

Regression analysis suggests that a statistical relationship does exist for samples taken in building 2, but not for building 1. Building 2 nontransformed and transformed data suggest that approximately 49 and 71% of the variation, respectively, 'account for' variability of area or personal samples [47, 48]. Data from building 2, particularly when transformed, suggested area and personal samples exhibited a relationship to each other and a possible regression equation could be developed. However, the lack of relationship for building 1 data, a statistical difference for concentration values in both building samples, area vs. personal, and previous findings [18, 34] of no relationship must temper any reported association. When these factors are considered for this study data, there may be no true relationship between measurements; area and personal exposure concentrations [8, 34, 40].

The concentration means for the two sampling methods, area vs. personal, for buildings 1 and 2 were both descriptively and statistically different. When CI values were evaluated for samples from both buildings, there was no overlap of the arithmetic range of either area or personal samples for building 1, but an overlap of range existed for building 2 (tables 1, 2). For building 2 the upper CI for area samples is 0.05 $f \cdot cm^{-3}$ and the lower CI for personal samples is 0.03 $f \cdot cm^{-3}$. These analyses support the observation that personal samples show a higher airborne concentration than area samples as has been reported in other publications [17, 18, 20–22, 34, 40].

Since data reported in this investigation are TWA and matched, the confounders of workers leaving the general location, episodic releases, continuous operation of area samplers at a fixed location, and other related workplace practices are somewhat minimized. However, these various work practice factors, the type of material abated, engineering controls, and variations of sample data must be considered in any reported relationship of area and personal measurements [8, 20, 21, 24, 43, 64, 65]. Such factors and activities may explain the previously reported relationship for area and personal samples [8], and the partial relationship observed in this study.

Area samplers may give higher concentrations since these stationary devices can be placed at fixed locations where the highest 'exposure' levels are expected [8, 19, 24]. Employment of this type of sampling is suggested by the authors to be inappropriate since an overestimate of exposure would result when the data are compared to personal measurements [8]. However, based on the data presented in this study and the work of others [18, 20, 21] area samplers will more likely underestimate exposure and subsequent respiratory requirements [8, 15–18, 20, 21, 63].

The present investigation has determined, as had previous studies [8, 20, 21, 23–25, 34–36, 40, 66–69] of distribution for asbestos and other airborne dusts/contaminants, that workplace (occupational) airborne concentrations are nonnormally distributed [70]. A difference in distribution upon transformation finds, as in previous studies [8, 34, 35], that asbestos airborne dust is best represented as a logarithmic form. As a result of this observed distribution, summary data would be best represented as GM and GSD [34, 35, 40]. However, some studies have suggested and reported data as the AM and SD rather than nonnormal summary data descriptors [46, 59, 71].

It has been suggested that AM is more representative of the health outcome following long term and chronic exposure to occupational hazards [72]. Use of an arithmetic value may also better represent the average dose and provide a less biased summary statistic that can be employed for occupational epidemiological studies [8, 73–75]. Reporting data only in parametric descriptors does not provide information of the underlying distribution and associated trends. Therefore, its has been suggested by some that both parametric and nonparametric descriptors should be included for representing sample location and dispersion [8].

The GSD and range suggest that the data are highly variable. Other studies [8, 15, 65, 76, 77] have also reported that occupational contaminants are highly variable. Personal sample measurements appear to have the largest variability in this study as evaluated by SD, GSD and range.

Summarizing the air sample data, as evaluated by AM and GM, indicated that the work practices used generally maintained an airborne concentration of asbestos below the OSHA PEL. The range for personal samples taken in both buildings 1 and 2 suggests that numeric excursions above the OSHA PEL do occur. However, for compliance purposes, sample data from building 1 cannot be demonstrated to exceed the OSHA PEL [39]. When evaluation of individual sample CI, the largest value, and means (AM and GM) were considered for building 2, there appeared to be some sample values that exceeded the OSHA PEL. For building 2, when the summary CI value of ± 0.05 was considered, one value (0.40 $f \cdot cm^{-3}$ TWA) clearly exceeded the OSHA PEL. This value is a major outlier warranting caution before concluding that the OSHA PEL had been exceeded, especially when compared to other exposure values collected that involved performing the same activity (glove-bag), mean (AM and GM) values, and sample variability [8,39]. Evaluation of outliers must also be viewed in regard to interpretation of regulatory compliance with the OSHA PEL, particularly as to whether exceedance is determined by an individual measurement (single shift) or cumulative exposure [39]. Decisions regarding exposure based on the highest concentration value, especially when considering outliers, may result in 'fallacious interpretation' and inappropriate actions, such as employment of respiratory protection [8]. When the outliers are removed summary and individual data suggest for building 2 that the exposure concentration is likely below the OSHA PEL. Thus, a hazard assessment of these data does not support a requirement for workers to use respirators for activities described, especially when the method of analysis (phase-contrast microscopy) for fibers is considered not to be specific for asbestos [2, 43]. Data presented could be considered historical in nature (historical data) [8], however, the variation reported for asbestos exposure concentrations must caution application of this information without additional site-specific monitoring data [8].

There does not appear to be a descriptive association with the amount of work performed and the exposure concentration. Level of exposure may be a function of engineering controls, condition of material, work area, mobility of the worker, work practices by the individual and variation of concentration day-to-day (within) and between workers [8, 21, 25, 26, 39, 43, 65, 78–82]. The lowest exposure concentration is associated with cleanup. Bag-out appears to be generally the second lowest activity for exposure with glove bag procedures being the highest.

In evaluation and formation of a hazard assessment from exposure data, other factors such as the analysis methodology must be considered. The method recognized by OSHA for analysis of fiber concentration, PCM, is not specific to asbestos fibers, but rather is a measure of all airborne fibers [43, 80]. Since most ACM are usually less than half asbestos, the majority of fibers identified by phase-contrast microscopy are non-asbestos [2, 43]. The PEL as established by OSHA is designed to protect a majority of persons employed in the 'asbestos industry' for 45 years on the basis that their exposure is 40 h a week, with 50 weeks of work per year [43]. If this scenario is extrapolated to asbestos abatement workers, most, if not all, will not achieve the entire time period of exposure for the upper limit of the OSHA PEL. Much of the worker's time is spent in setup and teardown, which has been suggested to have exposure that is better represented by ambient concentrations of asbestos [2, 43]. Thus, periodic exceedances above the OSHA PEL may not be of critical importance to potential health outcomes [39], although they cannot be totally ignored or overlooked from an industrial hygiene and toxicological perspective.

Primary questions related to occupational exposure and measurements are in regard to respiratory protection, other forms of PPE and applicability of engineering controls, including work practices. OSHA through this respirator standard has stated that respirators should not be employed if their use creates a hazard [29 CFR 1910.134 (c)(2)(i)]. From the present investigation and other studies [1, 8, 34, 35, 43, 80, 81], if reasonable engineering controls are employed and appropriate work practices instituted fiber concentrations will most likely be below the OSHA PEL and so eliminate the regulatory requirements of respirator use. However, some have considered that respirators should be used regardless of airborne concentration [27–30]. This practice does not consider factors related to interpretation of the OSHA PEL [39], importance and applicability of engineering controls [8, 24, 25] and physiological stressors of respirator use [83]. Use of respirators at exposure concentrations below the OSHA PEL may actually be more harmful than beneficial when all factors are considered [34, 80, 83–85]. Physiological and related factors must be considered when conducting and formulating a hazard assessment and deciding respiratory requirements [80].

The value of the limit of detection was used for data values at or below the limit of detection for statistical calculations in this study [34, 70]. Some investigators [50, 86] have suggested that one half of the detection limit value should be used for statistical calculations. Use of the detection limit value provides the highest numerical exposure and may be more applicable for some studies as a method of incorporating a safety factor and in determining exposure and hazard assessment criteria.

Conclusion

This study has provided data on area and personal samples that were collected during asbestos abatement. These data suggest that if engineering controls and appropriate work practices are employed fiber levels of asbestos can be generally maintained below the OSHA PEL. Airborne concentration of asbestos appears to differ according to the type of activity performed [8]. A previously suggested relationship between area and personal samples as associated with asbestos abatement [8] is not fully supported by this study. Data presented in this investigation suggest that personal samples were statistically higher in concentration as compared to area samples. It is suggested that personal sampling gives the best measure for exposure evaluation and subsequent hazard assessment of the occupational environment [18, 21, 24, 34, 63, 80]. Use of area sampling for predicting occupational exposure should be employed with caution. As reported in previous studies [8, 34, 35] airborne asbestos concentrations are nonnormally distributed and have high variability. Additional studies are warranted for evaluating exposure of asbestos during abatement and concentration relationships between area and personal sample measurements.

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