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A Comparison of Tape Sampling and Microvacuum Procedures for the Collection of Surface Glass Fiber Contamination

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Currently, few published methods exist for assessing surface contamination of asbestos and other fibers. Several surface sampling procedures have been employed: the wipe sampling method, the tape sampling method, and a more recent procedure commonly known as the microvacuum or microvacing procedure. Wipe sampling is not appropriate for sampling fibers on a surface, and limited studies have been reported which describe the procedure and validation of the tape sampling method or the microvacing procedure with respect to quantitative recovery, repeatability, or methodology. Therefore, this laboratory study evaluated the relative efficiency and reproducibility of two tape sampling and two microvacing procedures in use at a large multibuilding government facility for assessing surface contamination of fibrous materials, and quantitatively compared the most efficient and reproducible tape sampling method with the most efficient and reproducible microvacing procedure. The one-pat and three-pat tape sampling procedures, as well as the one-area sweep and three-area sweep microvacing procedures, were all evaluated simultaneously within an aerosol chamber using micropulverized fiberglass (mean fiber dimensions of 19 × 0.9 μm) as the fibrous contaminant and smooth, painted metal as the sampling surface. Samples were analyzed by phase contrast microscopy and incorporated differential counting procedures which applied polarized light microscopy. The relative efficiency was evaluated by collecting repeat samples {relative efficiency = 100 − [(repeat/original) × 100]}. Reproducibility was evaluated by comparing adjacent samples (original/adjacent). The results demonstrated that the mean fiber concentration collected by the tape sampling method ranged from 40 to 176 times the mean fiber concentration collected by the microvacing procedure on a painted metal surface. The tape three-pat method was overall most efficient [mean relative efficiency of 93%, 95% confidence interval (CI) = 88.28, 97.87) and most reproducible (adjacent paired ratio of 1.14 ± 22%, 95% CI = 0.89, 1.39) when compared with the other tape or microvacing methods studied. CORRIGAN, C.A.; BLEHM, K.D.: A COMPARISON OF THE TAPE SAMPLING AND MICROVACUUM PROCEDURES FOR THE COLLECTION OF SURFACE GLASS FIBER CONTAMINATION. APPL. OCCUP. ENVIRON. HYG. 12(11):751–755; 1997.

An estimated 20 percent of buildings, including hospitals, schools, and other public and private structures, incorporate asbestos-containing building materials.[1] An even greater number of buildings contain fibrous glass insulation. Fibers released during disturbance (removal or maintenance operations, physical or water deterioration, natural decomposition) will eventually settle and deposit on building surfaces such as desktops, filing cabinets, and floors. Depending on the building activity and ventilation, these deposited fibers could become reentrained into the building air, posing a potential hazard to building occupants. At present, no standard method is followed by industrial hygienists in assessing surface contamination of asbestos and other fibers.

Regulatory action is primarily focused on airborne fibers, thus creating much debate on the hazard significance and the means for assessing surface contamination. The confusion concerning the hazard significance resolves around the theory that if the surface contamination is left alone, untouched, or undisturbed, so as not to render it airborne, it will not contribute to any health hazard. However, settled fibers contaminating surfaces can be easily disturbed by simple air currents (e.g., sneezing, coughing) and especially by cleaning and maintenance activities. Therefore, surface contamination presents a potential health hazard, although the extent of the hazard is unknown. The confusion concerning the means for assessing surface contamination is largely attributed to the absence of a standard method. Several methods have been employed for assessing surface contamination, including wipe sampling, tape sampling, and microvacuum sampling. However, there is much question concerning the quantitative nature of these methods.[2–11]

This research evaluated and compared a tape surface sampling method and the more recent microvacuum method for the assessment of surface contamination (commonly known as the microvacing procedure). Reproducibility and relative efficiency of two tape sampling methods and two microvacing procedures were determined. The most reproducible and efficient tape sampling method was quantitatively compared with the most reproducible and efficient microvacing procedure. The results of this research can be used to evaluate the utility of these two surface sampling methods for the assessment of fibrous surface contamination and supplementation of air monitoring data for hazard assessment.

Background

A method that has traditionally been employed for evaluation of surface contamination is the collection of the wipe sample, typically with wet or dry cotton swabs, glass fiber filter disks,

paper filters, or commercial wet wipes.[2–7,9] While moist wipes have been reported to remove 85 to 90 percent of lead dust from formica surfaces,[5,7] the wipe method has been shown to have a poor level of detection or poor recovery for other surface contaminants.[2–4] Further, wipe sampling is not suitable for assessment of fiber contamination. The wipe sampling medium is composed of fibrous materials which would obscure or interfere with identification of the surface fibers. Further, wipe sampling disturbs the relative position and orientation of fibers on the surface. Thus, two other methods are usually employed for assessment of surface fiber contamination: tape sampling and microvacing.

In 1985 Nichols[8] reported on a tape method for asbestos surface sampling. Nichols noted that the main disadvantage of wipe sampling collection was that the sample had to undergo several stages of handling before commencing analysis. A method was needed that used an optically isotropic material to lift settled dust, enable safe transfer to the laboratory, and allowed examination of the various particle types. Nichols reported that translucent Scotch™ 810 Magic™ tape was a good candidate because it did not produce the bright interference colors characteristic of transparent tape when viewed between crossed polarizers.

Ryan[11] evaluated the ability of the tape sampling method as described by Nichols[8] to predict surface concentrations in a laboratory study. The method was evaluated by comparing asbestos concentrations as measured by scanning electron microscopy (SEM) directly from excised pieces of drywall surface with asbestos concentrations as measured from tape samples from the drywall. Ryan found that the tape samples, analyzed by polarized light microscopy (PLM) and SEM, predicted averages from 6.8 to 37.9 percent of the concentrations measured directly from the drywall surface. While the evaluation had limited success in demonstrating significant correlations between the tape and drywall samples, the cause of this failure was believed to be surface variability produced by the aerosol generations and not necessarily the method itself. Ryan concluded that the tape sample can provide a relative index of surface concentrations, thus providing more information than a traditional wipe sample; however, it should be regarded as a qualitative method.

A recent surface sampling method is the microvacing procedure. This method utilizes either a low or high flow sample pump fitted with an open- or closed-face cassette to vacuum fibers or contaminants from the surface. The Environmental Protection Agency has utilized a microvacing procedure for assessing lead dust on surfaces (referred to as the dust vacuum method).[6] The American Society for Testing and Materials Standard Test Method D5755-95 for Microvacuum Sampling and Indirect Analysis of Dust by Transmission Electron Microscopy for Asbestos Structure Number Concentrations describes one microvacing procedure for asbestos fibers.[10] However, various modifications of this procedure have been used by practitioners in the field.

The goals of this study were to (1) evaluate the efficiency and reproducibility of the tape one-pat and three-pat methods; (2) evaluate the efficiency and reproducibility of the microvac one-area sweep and three-area sweep methods; and (3) quantitatively compare both methods for assessing surface contamination of fibrous materials. The tape and microvac sampling methods evaluated were both in current use at a large, multi-building government facility. Thus, it was of interest to evaluate and compare the results of these procedures.

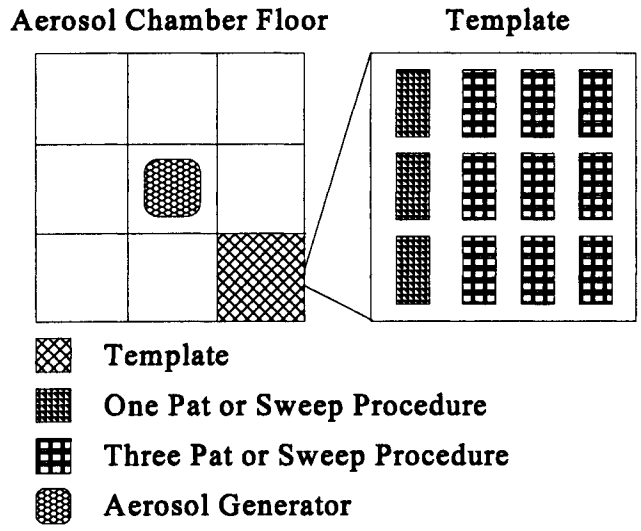

FIGURE 1. Visual illustration of aerosol chamber floor and template.

Methods

A Mettler® (H54AR) analytical balance was used to weigh 30 mg (weight was based on precision and accuracy considerations for fiber counting) of micropulverized fiberglass (mean fiber dimensions of 19 × 0.9 μm) provided by the TIMA/NAIMA Fiber Repository.[12] After the fiberglass was weighed, it was placed in a Misto® II aerosol generator which was located in the center of a 0.65-m^3 plexiglass aerosol chamber (inside dimensions of 34 × 34 × 34 inches). Fiber aerosolization and dispersion was performed by use of compressed air generated by a Speedaire (5Z032) portable air compressor. To facilitate fiber breakup and dispersion, 80 pounds per square inch (psi) was initially introduced into the aerosol generator followed by a gradual decrease to 30 psi. After approximately 5 minutes the air compressor was shut off and the fibers were allowed to settle for 24 hours.

Tape Sampling Methods

Four 28.3-cm^2 (slightly less than 1 ft^2) templates were secured onto smooth, painted metal plates (28.3 cm^2) on the chamber floor. Each template was composed of twelve 2¼ × 3¾-inch rectangular cutout shapes, which facilitated easy tape sampling on the metal plates, and a consistent surface area (Figure 1).

A tape sampling method similar to the method described by Nichols[8] was performed. Two-inch wide 3M Scotch super performance mailing tape was mounted onto Esco precleaned, frosted microscope slides No. 2951 prior to entering the sampling area to prevent cross-contamination. The tape was cut to 1 × 4-inch dimensions. Approximately 0.5 inches of the tape was attached to the underside of the frosted microscope slide, which served strictly as an anchor to the slide. The tape was then run up over the top of the slide lengthwise. The second end of the tape, approximately 0.5 inches, was folded back onto itself, forming a lip for easy removal from the slide.

During sampling, only the tape attached to the top of the slide was removed (approximately 1 × 3 inches). The tape samples were pressed on the metal surfaces with medium, uniform hand pressure. The tape was then removed and pressed sticky side down back onto the microscope slide until analysis. Tape method 1 consisted of one pat: the tape was applied to only one single rectangle. Tape method 2 consisted of three pats: the same piece of tape was applied to three different rectangles. Each template contained adequate excised rectangular space to allow for three one pats and three pats to be performed on each metal plate.

The purpose behind tape methods 1 and 2 was to determine the tape method that possessed the most reproducibility and relative efficiency. Reproducibility of the tape sampling method was evaluated by comparing fiber count results obtained between adjacent samples; the concentration of each original sample was divided by its paired adjacent sample, yielding a ratio (method reproducibility = original/adjacent). Relative method efficiency (percent recovery) was determined by collecting a tape sample and immediately collecting a second tape sample in the same location and using the same methodology {relative method efficiency = 100 − [(repeat sample/original sample) × 100]}. Since each excised rectangle was slightly larger than the dimensions of the tape, the tape was always placed in the upper, flush right side of the excised rectangle. This method of collection ensured that the repeat tape samples were collected in the same location as the original. To increase the probability of an exact match in location, only the center section of each piece of tape (original and repeat) was analyzed, instead of analyzing the edges, which might not be matched as closely in location due to human error.

Microvacing Procedures

The sampling train consisted of a Little Giant pump set at a nominal flow rate of 16 L/min and a face velocity of approximately 69 cm/s; 3 ft of tygon tubing; and an open-face, 25-mm diameter cassette with a 50-mm extension cowl and mixed cellulose ester filter having a pore size of 0.8 μm. The cassette was held approximately 0.25 inches from the surface while vacuuming, and a very slow, methodical motion was used over the surface area sampled.

As with the tape sampling, four templates that consisted of twelve 2 × 3.5-inch excised rectangles were positioned on smooth, painted metal plates on the chamber floor (Figure 1). The entire excised rectangular shape was vacuumed with three lengthwise zigzag sweeps using a smooth uniform motion that started at the top right corner of the rectangle and finished at the bottom left. Microvac procedure 1 consisted of vacuuming only one 2 × 3.5-inch rectangle. Microvac procedure 2 consisted of vacuuming three separate rectangles with the same cassette. Each template contained adequate excised rectangular space to allow for three one-area sweeps and three three-area sweeps to be performed on each metal plate.

The purpose behind microvacing methods 1 and 2 was to determine the microvacing procedure with the greatest reproducibility and relative efficiency. The reproducibility of the microvacing procedure was evaluated in the same way as the tape sampling method: by comparing fiber count results obtained between adjacent samples. The concentration of each original sample was divided by its paired adjacent sample, yielding a ratio. Method relative efficiency (percent recovery) of the microvacing procedure was determined by collecting both microvac repeat samples and tape repeat samples immediately following the original microvac sample. The repeat microvac and tape samples were randomly allocated to location. In the case of the tape sample repeat, immediately following the microvac sample, a piece of 1 × 3-inch 3M Scotch super performance mailing tape was pressed with uniform, medium hand pressure over the flush right side of the rectangle. Relative efficiency for the microvac originals followed by the tape repeats was evaluated by comparing the ratio of tape repeat/microvac original to microvac original. In the case of the microvac repeat, relative efficiency was determined by the following equation: (relative method efficiency = 100 − [(repeat sample/original sample) × 100]). The concentration of fibers collected by both the tape and microvac repeats was used to evaluate the relative efficiency of the microvacing procedure.

The tape and microvacing procedures were simultaneously evaluated for reproducibility and relative efficiency in the chamber to reduce the variability that would occur between runs if each were evaluated separately. The aerosol chamber held a total of eight templates, and two chamber runs were performed for this study. Therefore, 48 original tape samples with 48 repeat tape samples, and 48 original microvac samples with 24 tape repeats and 24 microvac repeats were collected, totaling 192 surface samples.

Analysis of Samples

A modified version of Occupational Safety and Health Administration Method ID-160[13] was used in conjunction with a modified version of National Institute for Occupational Safety and Health (NIOSH) Method 7400 counting rules[14] for the analysis of all microvac samples. For example, the NIOSH recommended sampling rate, air volume, and sampling placement were not applicable to surface sampling. In addition, PLM instead of electron microscopy was used for differential counting, and since method efficiency was being calculated, the laboratory counted all fibers greater than 0.25 μm in diameter. Tape samples were analyzed using the same modification of the NIOSH Method 7400 counting rules and a modification of the analytical technique described by Nichols.[8] The use of 2-inch wide 3M Scotch super performance mailing tape eliminated the interference (characteristic reticulate pattern–strings) commonly observed during analysis with other tapes. Discrimination between nonfiberglass and fiberglass fibers (differential counting by use of PLM) was accomplished with these hybrid analytical methods. The analyses of both methods were expressed in the same units (fibers/square millimeter of tape or filter) and then adjusted to fibers/square millimeter of chamber floor surface area to allow for the direction comparison of fiber concentrations between all methods. In addition, blind recounts were performed on 10 percent of all samples.

Results

The coefficient of variation (CV) and the limit of detection (LOD) for the hybrid analytical technique used for the analyses of all samples were 0.12 (at 100 fibers/mm^2) and 5.5 fibers/mm^2, respectively. This LOD equates to 5.5 fibers/mm^2 of

TABLE 1. Relative Efficiency of the Tape and Microvacing Procedures

Method	Sample Size	Mean f/mm²	Mean % Relative Efficiency (%E)	SD (of %E)	95% CI (of %E)
Tape one-pat	24	24.81	85.81	20.43	(77.19, 94.44)
Tape three-pat	24	24.36	92.58	9.93	(88.28, 96.87)
Microvac one-sweep	24	0.60	−90.8*	296.0	(−318.4, 136.8)
Microvac three-sweep	24	0.38	19.9	120.0	(−56.3, 96.2)

Relative efficiency = 100 − [(repeat sample/original sample) × 100].
*Less than 0 percent method efficiency resulted when several repeat samples collected greater fiber concentrations than the original samples.

chamber floor surface area for the tape one-pat method, 1.8 fibers/mm² chamber floor surface area for the tape three-pat method, 0.47 fibers/mm² chamber floor surface area for the microvac one-sweep method, and 0.16 fibers/mm² chamber floor surface area for the microvac three-sweep method. The two-sample *t*-test showed no statistically significant difference at the 0.01 significance level between original and blind recount data.

The tape sample one-pat originals collected a mean fiber concentration of 24.81 fibers/mm² of chamber floor surface area [standard deviation (SD) 16.87, range 7.64 to 77.71]. The tape sample one-pat repeats collected a mean fiber concentration of 2.73 (SD 3.31, range 0.00 to 12.74). This method resulted in an overall tape sample original to repeat ratio of 9:1, mean relative efficiency of 86 percent (SD of 20.4), and increased efficiency at higher fiber concentrations (Table 1). The overall CV for the tape one-pat method for both chamber runs combined was 68 percent. When the concentration of each original sample was divided by its paired adjacent sample, data showed that 50 percent (the 25th to 75th percentiles) of the pairs had ratios between 0.65 and 1.27. The mean ratio was 1.32 [95% confidence interval (CI) 0.85, 1.79] or equivalently, 1.32 ± 36 percent (Table 2).

The mean fiber concentration collected by the tape sample three-pat originals was 24.36 fibers/mm² of chamber floor surface area (SD 11.16, range 6.79 to 48.40). The tape sample three-pat repeats collected a mean fiber concentration of 1.52 (SD 1.75, range 0.00 to 5.94). This method resulted in an overall tape sample original to repeat ratio of 16:1, mean relative efficiency of 93 percent (SD 9.9), and increased efficiency at higher fiber concentrations (Table 1). The overall CV for the tape three-pat method for both chamber runs combined was 46 percent. When the concentration of each original sample was divided by its paired adjacent sample, data showed that 50 percent (25th to 75th percentiles) of the pairs had ratios between 0.74 and 1.36. The mean ratio was 1.14 (95% CI 0.89, 1.39) or equivalently, 1.14 ± 22% (Table 2).

TABLE 2. Reproducibility of the Tape and Microvacing Procedures

Method	Sample Size	Mean Ratio of Adjacent Sample Pairs	SD	95% CI
Tape one-pat	24	1.32	1.11	(0.85, 1.79)
Tape three-pat	24	1.14	0.59	(0.89, 1.39)
Microvac one-sweep	24	3.28	5.13	(1.11, 5.44)
Microvac three-sweep	24	1.37	1.19	(0.86, 1.87)

Each original sample fiber concentration was divided by its adjacent sample fiber concentration, yielding a ratio.

The mean fiber concentration of the microvac one-sweep sample originals was 0.60 fibers/mm² of chamber floor surface area (SD 0.72, range 0.00 to 2.77). The microvac one-sweep sample repeats collected a mean fiber concentration of 0.46 (SD 0.58, range 0.00 to 1.91). This method resulted in an overall microvac sample original to repeat ratio of approximately 1:1, and mean relative efficiency of less than 0 percent (Table 1). The overall CV for both chamber runs combined was 120 percent. Data showed that 50 percent of the paired adjacent samples had ratios between 0.18 and 4.26. The mean ratio was 3.28 (95% CI 1.11, 5.44) or equivalently, 3.28 ± 66 percent (Table 2).

The microvac three-sweep sample originals collected a mean fiber concentration of 0.38 fibers/mm² of chamber floor surface area (SD 0.34, range 0.04 to 1.11). The microvac one-sweep sample repeats collected a mean fiber concentration of 0.13 (SD 0.08, range 0.04 to 0.29). This method resulted in an overall microvac sample original to repeat ratio of approximately 3:1 and mean relative efficiency of less than 20 percent (Table 1). The overall CV for both chamber runs combined was 89 percent. Data showed that 50 percent of the paired adjacent samples had ratios between 0.64 and 1.57. The mean ratio was 1.37 (95 percent CI 0.86, 1.87) or equivalently, 1.37 ± 37 percent (Table 2).

The efficiency of both microvac methods was also evaluated according to tape repeat samples. The tape one-pat repeat samples collected an average of 115 times (range 5.5 to 324 times) the microvac one-sweep original sample fiber concentration. The tape three-pat repeat samples collected an average of 187 times (range 0 to 637 times) the microvac three-sweep original sample fiber concentration.

Discussion

The mean fiber concentration collected by any tape method ranged from 40 to 176 times the mean fiber concentration collected by any microvacing procedure; thus, both tape methods were significantly more efficient than both microvacing procedures. The tape three-pat method was overall more efficient (mean relative efficiency of 93% for both chamber runs combined) and more reproducible (adjacent sample ratio of 1.14 ± 22 percent) than the tape one-pat method (mean relative efficiency of 86 percent for both runs combined, adjacent sample ratio of 1.32 ± 36 percent). However, at $\alpha =$

0.01 there was no statistically significant difference between the mean efficiencies of the tape one- and three-pat methods [CI = (−10.7, 11.6); p = 0.91]. The large CIs were probably due to uneven fiber distribution on the chamber floor. Both microvacing methods not only resulted in extremely poor levels of relative efficiency, but also exhibited poor levels of reproducibility.

This study had several limitations. First, the sampling and analytical methods employed were modifications of published methods. The tape sampling was a modification of Nichols.[8] The microvacing method was a modification of ASTM Standard Test Method D5755-95.[10] However, these were modifications being utilized by industrial hygienists in a large, multibuilding government complex.

Only one type of surface, painted metal, was studied. This would seem to be an ideal surface for collection of fibers by both sampling methods. Relative efficiency and reproducibility are likely to be very different on other surface types. On porous or uneven surfaces, the microvacing technique could well prove superior to tape sampling. Further, different microvacing techniques, such as scraping the surface with the cassette, would influence collection efficiency.

The study did not explore the effect of operator dependency, especially with regard to the amount of pressure applied during tape sampling. All sampling was conducted by the same person.

A final limitation was that the efficiency of the fiber collection was based on repeat sampling rather than known surface fiber concentrations. Unfortunately, the actual surface concentrations were not determined. Based on previous work of this type,[15] a gross calculation which assumed that twice as many fibers fell to the floor as adhered to the walls or the top of the chamber, the dimensions of the mean fiber were 19×0.9 μm, and 100 percent of the mass of fiberglass used was fibrous, resulted in an estimate of 115 fibers/mm^2 for the chamber floor. This would suggest an absolute collection efficiency in the range of 21 percent for tape sampling and 0.5 percent for microvacing.

Most horizontal surfaces collect varying quantities of fibrous dust depending on the location of the surface, the scheduled cleaning activities, and general office paper shuffling. The uneven fiber distribution phenomenon automatically limits the ability of the industrial hygienist to detect an absolute quantity of fiber on a horizontal surface by surface sampling. Thus, the primary benefit gained by surface sampling, at this point in time, is the simple detection (absence or presence) of a fibrous material. Therefore, when surface sampling is performed on smooth surfaces to supplement the hazard assessment made by airborne sampling, the tape sampling three-pat method is recommended. This method should be considered strictly qualitative, and should only be used when the objective is to determine the absence or presence of the fibrous material on the horizontal surface.

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Disclaimer

The opinions, findings, and conclusions contained in this publication do not necessarily reflect the views or policies of the U.S. Department of Labor, Occupational Safety and Health Administration, nor does mention of trade names, commercial products, or organizations constitute endorsement by the U.S. government.

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