

Evaluation of a Standardized Micro-Vacuum Sampling Method for Collection of Surface Dust

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A standardized procedure for collecting dust samples from surfaces using a micro-vacuum sampling technique was evaluated. Experiments were carried out to investigate the collection efficiency of the vacuum sampling method described in ASTM Standard D7144, "Standard Practice for Collection of Surface Dust by Micro-Vacuum Sampling for Subsequent Metals Determination." Weighed masses (≈ 5 , ≈ 10 and ≈ 25 mg) of three NIST Standard Reference Materials (SRMs) were spiked onto surfaces of various substrates. The SRMs used were: (1) Powdered Lead-Based Paint; (2) Urban Particulate Matter; and (3) Trace Elements in Indoor Dust. Twelve different substrate materials were chosen to be representative of surfaces commonly encountered in occupational and/or indoor settings: (1) wood, (2) tile, (3) linoleum, (4) vinyl, (5) industrial carpet, (6) plush carpet, (7,8) concrete block (painted and unpainted), (9) car seat material, (10) denim, (11) steel, and (12) glass. Samples of SRMs originally spiked onto these surfaces were collected using the standardized micro-vacuum sampling procedure. Gravimetric analysis of material collected within preweighed Accucap inserts (housed within the samplers) was used to measure SRM recoveries. Recoveries ranged from 21.6% ($\pm 10.4\%$, 95% confidence limit [CL]) for SRM 1579 from industrial carpet to 59.2% ($\pm 11.0\%$, 95% CL) for SRM 1579 from glass. For most SRM/substrate combinations, recoveries ranged from $\approx 25\%$ to $\approx 50\%$; variabilities differed appreciably. In general, SRM recoveries were higher from smooth and hard surfaces and lower from rough and porous surfaces. Material captured within collection nozzles attached to the sampler inlets was also weighed. A significant fraction of SRM originally spiked onto substrate surfaces was captured within collection nozzles. Percentages of SRMs captured within collection nozzles ranged from $\approx 13\%$ ($\pm 4 - \pm 5\%$, 95% CLs) for SRMs 1579 and 2583 from industrial carpet to $\approx 45\%$ ($\pm 7 - \pm 26\%$, 95% CLs) for SRM 1648 from glass, tile and steel. For some substrates, loose material from the substrate itself (i.e., substrate particles and fibers) was sometimes collected along with the SRM, both within Accucaps as well as collection nozzles. Co-collection of substrate material can bias results and contribute to sampling variability. The results of this work have provided performance data on the standardized micro-vacuum sampling procedure.

Keywords dust, gravimetric analysis, reference materials, substrates, surfaces, vacuum sampling

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INTRODUCTION

Human exposures to toxic substances that are present in surface dust can result from dermal contact with or ingestion of contaminated particulate matter. Chromium and beryllium are examples of dermal contaminants that have been associated with occupational dermatitis⁽¹⁾ and skin sensitization,⁽²⁾ respectively. Worker exposures to lead through ingestion from contact with contaminated surfaces have also been reported.⁽³⁾ Additionally, inhalation exposure can result from disturbing dust particles on surfaces. For example, exposure to dust mite allergens via inhalation, due to disruption of contaminated surfaces, has been suggested as a route of exposure.⁽⁴⁾ Dust containing toxicants such as lead can also be transported to the home via contamination in workers' clothes, automobiles, tools, etc., and can result in exposures to children and other family members.⁽⁵⁾ To evaluate the potential for human exposures to toxic substances in surface dust, and to compare and contrast exposure data, standardized methods for the collection of surface dust samples are needed.

Historically, wipe sampling methods have been used to obtain estimated measures of surface contamination levels⁽⁶⁾ and to approximate the potential for dermal exposures.⁽⁷⁾ Wipe sampling methods for analytes such as metals have been promulgated in the form of voluntary consensus standards,^(8,9) and these techniques are widely used for occupational and environmental hygiene applications. As an alternative to collecting wipe samples, vacuum sampling has been proposed in cases where surface wipe sampling is deemed impractical.⁽¹⁰⁾

For instance, wipe sampling may not be recommended for rough and/or porous surfaces or fragile substrates, so a viable alternative for consideration is sampling by means of suction techniques.⁽¹¹⁾

A variety of vacuum sampling techniques have been used in the industrial hygiene field,⁽¹⁰⁾ but only a few have been standardized.⁽¹²⁾ Of the vacuum sampling procedures that have appeared as American Society for Testing and Materials (ASTM) International voluntary consensus standards,^(13–17) performance data are entirely lacking for the current micro-vacuum sampling methods.^(13–15) In an effort to fill this knowledge gap, the principal aims of this work were to evaluate and characterize the performance of a consensus standard micro-vacuum sampling method, ASTM D7144.⁽¹³⁾

Previous studies have entailed comparisons of the micro-vacuum technique and other surface sampling techniques for lead,^(18–20) although none have specifically addressed the collection efficiency of the micro-vacuum method. It is recognized that vacuum collection will ordinarily result in sampling recoveries well below 100%;⁽¹⁸⁾ this is especially true for surfaces that are not smooth. Yet a “design-based” approach, whereby the equipment for vacuum sampling is specified and the sampling technique is described explicitly, has been supported through the publication of the ASTM International standard procedure.⁽¹³⁾ The instrumentation specified for the standardized micro-vacuum sampling technique is fabricated from equipment that is typically used by industrial hygienists for workplace monitoring purposes, i.e., (a) battery-powered personal sampling pumps, and (b) sampling cassettes ordinarily used for collection of air samples. Widespread use of the standardized procedure will make it possible to compare and contrast vacuum sampling results that are obtained from different types of surfaces. Also, standardization will allow for samples obtained at different sites and taken by different investigators to be collected similarly, thereby fostering harmonization of the vacuum sampling protocol and enabling valid data comparisons. Nevertheless, there previously has been a dearth of performance data for the micro-vacuum sampling technique; hence the need for the present study.

EXPERIMENTAL

Three National Institute of Standards and Technology (NIST) Standard Reference Materials (SRMs) were chosen for investigation. The SRMs selected were meant to represent surface dust materials that may be encountered in typical occupational and/or indoor settings. Also, a number of representative surface substrate types were selected for the study. These ranged from hard and/or smooth surfaces such as tile and steel to soft and/or rough materials like carpet and concrete block. Substrate surfaces were first spiked with weighed masses of each SRM at various loading levels. For each test substrate, SRM and loading level, the standardized micro-vacuum sampling procedure⁽¹³⁾ was then used to collect SRM from the surface. Gravimetric analysis was subsequently

employed to determine the amount of SRM collected in each sample, thereby allowing for estimates of recovery to be computed. Details of the experimental protocol, as well as resulting data and ensuing discussion thereof, are described in the following paragraphs.

Materials and Equipment

The NIST SRMs used were: (1) No. 1579, Powdered Lead-Based Paint; (2) No. 1648, Urban Particulate Matter; and (3) No. 2583, Trace Elements in Indoor Dust.

Sample substrates of wood, linoleum, tile, industrial carpet, plush carpet, concrete block, glass and steel were obtained from a local hardware store (Lowe's). Wood substrate was Hardwood Import 4 ft × 8 ft sheet (Luan Board; Item #12549). Linoleum was Armstrong Royelle 12 in. Dark Oak Sheet Vinyl (Item #7477). Tile substrate was Florim 8 in. × 9 in. Grey Carrara Ceramic Tile (Item #37099). Industrial carpet was Stratos Grey Indoor/Outdoor Carpet (Item #97913). Plush carpet was Beaulieu Home Fashions Abalony 23" × 39" Rug–100% Olefin Pile (Item # 1303). Concrete block was Oldcastle Tumbled Countryside 6 in. × 6 in. Tan/Charcoal Block (Item #182093). Glass substrate was Gardner Glass Products 6–12 in. × 12 in. mirror tiles with plain edge (Item #197427). Steel substrate was Steel Works Welded Steel Sheet (22 Gauge), 12 in. × 24 in. (Item #1806).

Paint used for coating concrete block surfaces was American Tradition Skid-Not Interior/Exterior Skid Resistant Coating.

Sample substrates of vinyl, car seat material, and denim were purchased at a local fabric store (JoAnn Fabrics). Vinyl material was marine vinyl (burgundy) with polyvinylchloride (PVC) skin and polyester backing (Item #1100-55). Car seat material was Waverly 75% polyester/25% nylon (Item #05060). Denim fabric was Bottom Weights Blu Star Denim (Item #808-5060).

Handling of all materials and equipment during sampler assembly, sample collection, weighing, etc., was done while wearing nitrile gloves (Kimberly-Clark, Roswell, Ga.). Plastic sampling cassettes preloaded with preweighed Accucaps (37 mm diameter, 0.8- μ m PVC were obtained from SKC (Eighty Four, Pa.). Accucap inserts were weighed prior to use. Collection nozzles were fabricated from Tygon tubing (0.60 ± 0.005 cm i.d., Fisher Scientific, Pittsburgh, Pa.); the sampling (inlet) end of each nozzle (length 5.0–5.5 cm) was cut at an angle of $\approx 45^\circ$. All components to be weighed were allowed to equilibrate overnight at room (laboratory) temperature (23 ± 1°C). Each collection nozzle was weighed to the nearest 0.0001 g, prior to being attached to the inlet port of a sampling cassette. An example of an assembled micro-vacuum sampler, as described in ASTM Practice D7144,⁽¹³⁾ is shown in Figure 1.

Procedure

Delineated sampling areas (10 cm × 10 cm) on surfaces of the various substrate materials were demarcated using



(a)



(b)

FIGURE 1. (a) Example of a micro-vacuum sampler used with ASTM Practice D7144; (b) Micro-vacuum sampling performed on a section of carpet in accordance with ASTM Practice D7144

adhesive tape. SRM masses were weighed to the nearest 0.0001 g on an analytical balance (Model AT261, Mettler-Toledo, Columbus, Ohio) using glycine weighing paper. Clean, previously unused substrate surfaces were spiked manually as uniformly as possible by pouring the SRM onto the surfaces from the weighing paper and then spreading the material

across the substrate with the weighing paper. Surfaces were spiked within the outlined 100-cm² sampling areas with SRM masses of ≈ 5 mg, ≈ 10 mg, or ≈ 25 mg. Micro-vacuum samplers were attached to an AirCheck 2000 Model 210-2002 personal sampling pump (SKC) by means of flexible tubing (0.60 ± 0.005 cm i.d.). The sampling pump was calibrated

daily at a flow rate of 2.5 ± 0.1 L/min using a DryCal DC-Lite Primary Flow Meter (BIOS International, Butler, N.J.). Calibration was checked after sampling to the nearest ± 0.1 L/min.

Micro-vacuum sampling was carried out by a single investigator in accordance with ASTM Practice D7144.⁽¹³⁾ After the sampling pump was turned on, sample collection was initiated and timed with a stopwatch. While sampling, the collection nozzle was made to lightly touch the surface of the substrate. The nozzle was moved across the surface of the demarcated sampling area at a rate of no faster than 10 cm/sec, and sampling was performed for a total of 1 minute for each sample. The micro-vacuum sampling procedure for a 100-cm² sampling area is illustrated in Figure 1b. After 1 minute of sample collection, the sampling pump was turned off, and the sampler was carefully disassembled with the aid of a filter handling kit (SKC). Each collection nozzle and Accucap were subsequently weighed to the nearest 0.0001 g, in accordance with NIOSH Method 0500.⁽²¹⁾

For each sample, recovery was calculated by simply dividing the mass of material collected within the Accucap by the mass of SRM originally spiked onto the substrate surface. Percentage recovery for each sample was obtained by multiplying the above quotient by 100%.

Electron Microscopy

For microscopic examination of particle morphologies, scanning electron micrographs (SEMs) were obtained using a Hitachi S-3000N (Hitachi America, Brisbane, Calif.) scanning electron microscope. For SEM experiments, SRMs were collected onto 25 mm diameter, 1.0- μ m pore size polycarbonate filters (Nuclepore, Pleasanton, Calif.) by micro-vacuum sampling at 2.5 ± 0.1 L/min for a few seconds. SEM images were obtained at an accelerating voltage of 15 kV and a magnification of 300 \times using a secondary electron detector.

RESULTS AND DISCUSSION

Tables I–III show the mean recoveries that were obtained, using micro-vacuum sampling,⁽¹³⁾ from 12 different substrate surfaces for SRMs 1579, 1648, and 2583, respectively. SRM recoveries were computed after gravimetric analysis⁽²¹⁾ of the particulate material that was collected in preweighed Accucaps that were housed within the samplers. The data of Tables I–III include only the results from material captured within the Accucaps and do not include material trapped within the collection nozzles.

Table IV summarizes results obtained from “field blank” measurements, where the micro-vacuum sampling procedure was performed on “clean” substrates that were *not* fortified with SRM prior to sampling. Gravimetric results for these samples are given for both Accucaps and for collection nozzles. It can be seen (Table IV) that significant amounts of substrate material are collected from unpainted concrete block. Lesser amounts of loose material are taken up from soft substrates such as carpet and car seat material, whereas insignificant background masses were measured for hard, smooth substrate materials like steel and tile. Pick-up of loose substrate from some surfaces is highly variable, thereby preventing reliable blank correction.

Two substrates of particular concern are unpainted concrete block and plush carpet (Table IV). It could be observed visually that small pieces of concrete block material were taken up from the substrate, both within the collection nozzle as well as inside the Accucaps. Also, captured fibers from plush carpet could be observed inside the nozzles and Accucaps within micro-vacuum sampling devices. Collection of substrate material from the surface itself will contribute a positive bias to gravimetric measurement. Also, because co-capture of substrate material is sporadic, it will contribute significantly to sampling variability. For unpainted concrete block, the variability induced by collection of substrate

TABLE I. Mean Percentage Recoveries ($\pm 95\%$ CL) of SRM #1579, Powdered Lead-Based Paint

Substrate Material	Mean % Rec. ≈ 5 mg (n = 3)	Mean % Rec. ≈ 10 mg (n = 3)	Mean % Rec. ≈ 25 mg (n = 3)	Mean % Rec. All Samples (n = 9)
Glass	54.6 (± 10.0)	58.7 (± 9.8)	64.3 (± 4.5)	59.2 (± 11.0)
Tile	40.6 (± 24.9)	51.6 (± 20.0)	43.8 (± 18.6)	45.3 (± 27.4)
Steel	45.6 (± 2.7)	51.5 (± 3.3)	55.6 (± 8.0)	50.9 (± 9.8)
Linoleum	34.7 (± 18.8)	43.5 (± 17.4)	44.6 (± 31.0)	41.0 (± 20.6)
Vinyl	33.5 (± 14.1)	37.1 (± 22.0)	45.7 (± 17.1)	38.8 (± 17.6)
Wood	40.5 (± 8.8)	33.6 (± 22.7)	26.8 (± 10.8)	33.6 (± 18.8)
Denim	48.3 (± 9.4)	44.9 (± 9.8)	42.9 (± 29.2)	45.4 (± 16.9)
Car seat material	36.0 (± 12.0)	32.2 (± 25.3)	24.6 (± 10.4)	31.0 (± 17.8)
Industrial carpet	18.9 (± 3.9)	17.8 (± 6.3)	28.1 (± 3.5)	21.6 (± 10.4)
Plush carpet	48.0 (± 5.3)	22.1 (± 32.1)	38.2 (± 24.1)	36.1 (± 30.0)
Concrete block	69.8 (± 35.9)	82.5 (± 20.2)	40.8 (± 34.3)	64.4 (± 21.0)
Concrete block, painted	32.9 (± 22.1)	30.8 (± 13.9)	35.7 (± 3.3)	33.2 (± 13.7)

Notes: From test substrates using micro-vacuum sampling,⁽¹³⁾ as determined by gravimetric analysis of material collected within Accucaps; CL = confidence limit.

TABLE II. Mean Percentage Recoveries ($\pm 95\%$ CL) of SRM 1648, Urban Particulate Matter

Substrate Material	Mean % Rec. ≈ 5 mg (n = 3)	Mean % Rec. ≈ 10 mg (n = 3)	Mean % Rec. ≈ 25 mg (n = 3)	Mean % Rec. All Samples (n = 9)
Glass	39.1 (± 12.2)	42.8 (± 5.7)	47.6 (± 3.3)	43.2 (± 10.0)
Tile	32.1 (± 19.8)	48.1 (± 36.5)	46.4 (± 5.7)	42.2 (± 35.3)
Steel	36.5 (± 7.3)	36.7 (± 4.1)	42.4 (± 13.3)	38.5 (± 9.4)
Linoleum	24.2 (± 11.0)	26.8 (± 5.9)	31.9 (± 5.7)	27.7 (± 9.6)
Vinyl	39.3 (± 11.6)	31.2 (± 14.1)	37.0 (± 12.7)	35.8 (± 13.1)
Wood	30.3 (± 8.6)	34.4 (± 12.3)	35.6 (± 9.0)	33.4 (± 10.0)
Denim	41.5 (± 2.7)	31.7 (± 12.3)	37.7 (± 5.5)	36.9 (± 13.3)
Car seat material	46.6 (± 6.3)	43.6 (± 9.2)	55.5 (± 3.3)	48.6 (± 12.2)
Industrial carpet	28.7 (± 16.3)	27.3 (± 8.2)	38.6 (± 3.9)	31.5 (± 14.1)
Plush carpet	38.2 (± 24.1)	29.0 (± 38.2)	35.2 (± 8.4)	34.2 (± 24.3)
Concrete block	73.5 (± 58.4)	62.8 (± 35.5)	71.3 (± 5.3)	69.2 (± 37.0)
Concrete block, painted	36.4 (± 11.8)	42.0 (± 10.8)	57.2 (± 10.6)	45.2 (± 20.6)

material can make recovery data meaningless. In several cases, as indicated by wide 95% confidence limits (Table I), it is impossible to distinguish between collected SRM particles and the substrate itself. It should be mentioned that co-collection of loose substrate material from some surfaces is an inherent problem for any surface sampling technique and is not unique to the micro-vacuum sampling method.

Because of the possibility of loose material being collected from concrete block substrates, a separate set of experiments on painted concrete block surfaces was carried out. The paint coating served to immobilize loose particulate material that could otherwise be collected during micro-vacuum sampling. However, no similar strategy can be employed to prevent the collection of loose fibers from fabric materials and carpet. For SRMs collected using micro-vacuum sampling, mean recoveries ranged from a low of $\approx 20\%$ for SRM 1579 from industrial carpet (Table I) to an apparent high of $\approx 85\%$ for

SRM 2583 from concrete block (Table III). However, the results for concrete block were highly biased and variable because of loose substrate material being collected along with the SRM, as discussed in the preceding paragraphs. Also, SRM recoveries from plush carpet were biased and variable due to co-collection of carpet fibers that were removed from the substrate. Not surprisingly, recoveries were generally highest from smooth, hard materials such as glass, and lowest from soft, porous substrates like carpet. For most SRM/substrate combinations, recoveries ranged from $\approx 25\%$ to $\approx 50\%$ (Tables I–III); a wide range of variabilities (as indicated by 95% confidence limits) were observed. Fine particulate matter can become entrained within materials like carpet that are highly porous and can be difficult to remove using suction. Particles are more effectively collected from smooth, hard surfaces, and this is reflected in the generally higher SRM recoveries observed for such substrates.

TABLE III. Mean Percentage Recoveries ($\pm 95\%$ CL) for SRM 2583, Trace Elements in Indoor Dust

Substrate Material	Mean % Rec. ≈ 5 mg (n = 3)	Mean % Rec. ≈ 10 mg (n = 3)	Mean % Rec. ≈ 25 mg (n = 3)	Mean % Rec. All Samples (n = 9)
Glass	43.4 (± 10.4)	58.7 (± 9.8)	56.3 (± 8.8)	52.8 (± 13.5)
Tile	44.5 (± 20.4)	43.7 (± 9.2)	58.5 (± 14.5)	48.9 (± 17.8)
Steel	25.3 (± 14.7)	43.0 (± 3.3)	46.6 (± 7.4)	38.3 (± 21.2)
Linoleum	25.0 (± 8.2)	32.3 (± 2.4)	32.4 (± 24.5)	29.9 (± 14.9)
Vinyl	36.1 (± 20.2)	44.9 (± 12.7)	37.8 (± 3.9)	39.6 (± 17.6)
Wood	37.3 (± 22.9)	52.4 (± 15.3)	58.4 (± 5.9)	49.4 (± 23.3)
Denim	51.2 (± 32.9)	44.9 (± 9.8)	62.0 (± 3.7)	52.7 (± 21.2)
Car seat material	46.3 (± 6.9)	44.3 (± 11.8)	55.5 (± 3.3)	48.7 (± 12.3)
Industrial carpet	22.8 (± 4.1)	26.8 (± 6.1)	30.3 (± 8.0)	26.7 (± 8.4)
Plush carpet	37.6 (± 10.0)	35.2 (± 3.9)	49.6 (± 14.5)	40.8 (± 15.9)
Concrete block	70.7 (± 99.8)	107.4 (± 77.0)	81.3 (± 29.2)	86.5 (± 72.1)
Concrete block, painted	38.9 (± 11.2)	41.1 (± 25.3)	48.1 (± 40.4)	42.7 (± 25.9)

TABLE IV. Gravimetric Results from Clean Substrates (n = 12)

Substrate Material	Mean Mass, mg (SD) Accucaps	Mean Mass, mg (SD) Collection Nozzles
Glass	0.0 (0.0)	0.0 (0.1)
Tile	0.0 (0.1)	-0.2 (0.1)
Steel	0.0 (0.0)	0.0 (0.1)
Linoleum	0.0 (0.0)	-0.2 (0.1)
Vinyl	0.5 (1.7)	-0.3 (0.1)
Wood	0.6 (0.6)	1.0 (0.7)
Denim	0.3 (0.3)	0.5 (0.2)
Car seat material	0.4 (0.2)	0.8 (0.2)
Industrial carpet	0.4 (0.2)	0.3 (0.2)
Plush carpet	0.5 (0.2)	1.3 (0.5)
Concrete block	20.8 (13.5)	3.9 (2.0)
Concrete block, painted	0.2 (0.3)	0.8 (1.2)

For the SRMs, with a few exceptions, there was no general overall trend in percent recovery changing as a function of original SRM loading on the substrate (Tables I-III). Although mean recoveries appear to differ for many of the entries in the tables, few of these differences are statistically significant ($P = 0.05$). With a couple of exceptions, no statistically significant differences in overall recovery were observed between the three SRMs (see last columns of Tables I-III). SRM 1579 recoveries from glass, tile and steel were statistically significantly greater than from industrial carpet (Table I). Also, recoveries of SRM 2583 from glass and car seat material were statistically significantly greater than from industrial carpet (Table III). But otherwise, apparent differences in mean values observed (Tables I-III) were not statistically significant, owing to sampling variability (as indicated by 95% confidence limits).

Table V summarizes results for percentages of SRMs from all substrate surfaces that were captured within the collection

nozzles. The data shown combine all three SRM loading levels, because no statistically significant differences were seen with different loading. Percentage of SRM captured inside of collection nozzles ranged from $\approx 13\%$ for SRMs 1579 and 2583 on industrial carpet to $\approx 45\%$ for SRM 1648 on glass, tile and steel. In some cases, owing to co-collection of loose substrate material, the sum of apparent recovery from the Accucaps (Tables I-III) and the collection nozzles (Table V) can reach or exceed 100% (e.g., for concrete block). Particulate material that was retained on the inside walls of the collection nozzles was observed visually. It can be seen from these results (Table V) that a highly significant fraction of the SRM that is removed from the substrate surface is caught within the collection nozzles and does not reach the Accucaps. While most of the SRM that is removed from the substrate is captured within the Accucaps (Tables I-III), about 25-45% of collected particulate matter is retained within the collection nozzles (Table V), depending on the substrate/SRM combination in question.

It is of interest to consider the particle morphologies of the SRMs used in this study. Figure 2 shows scanning electron micrographs (SEMs) of SRMs 1579, 1648, and 2583, respectively. These SEMs are from SRMs that were collected onto polycarbonate filters by using the micro-vacuum sampling technique. Collected SRM 1579 illustrates a wide range of particle sizes: $\approx 1 \mu\text{m}$ to $>100 \mu\text{m}$ (Figure 2a). Individual particles and aggregates of various sizes are observed. In contrast, collected SRM 1648 consists largely of finely divided particles of sizes ranging from $\approx 1 \mu\text{m}$ to $\approx 25 \mu\text{m}$ (Figure 2b). For SRM 1648, aggregation of particles is much less extensive than for SRM 1579. Collected SRM 2583 demonstrates a wide range of particle sizes, i.e., $\approx 2 \mu\text{m}$ to $\approx 75 \mu\text{m}$ (Figure 2c); but individual particles, not aggregates, are predominant.

Of the three SRMs investigated, SRM 1648 was more prone to be retained within the collection nozzles means were statistically significantly greater for SRM 1648 from substrates such as glass, wood and industrial carpet (Table V).

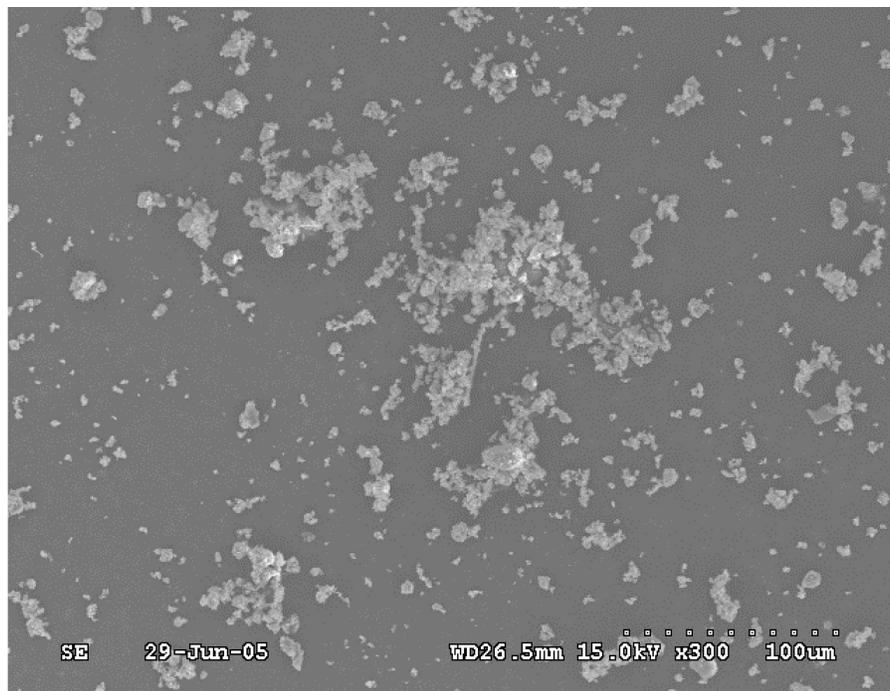
TABLE V. Summary Percentages of SRMs Captured in Collection Nozzles (n = 9)

Substrate Material	% Collected SRM 1579	% Collected SRM 1648	% Collected SRM 2583
Glass	27.9 (± 7.4)	44.6 (± 8.8)	25.5 (± 9.4)
Tile	25.9 (± 17.2)	45.8 (± 25.7)	35.4 (± 10.8)
Steel	20.5 (± 5.9)	44.0 (± 7.4)	32.6 (± 9.4)
Linoleum	30.1 (± 9.4)	41.9 (± 9.2)	25.6 (± 8.8)
Vinyl	25.7 (± 11.0)	40.9 (± 13.1)	27.0 (± 3.5)
Wood	20.6 (± 8.4)	43.1 (± 5.1)	26.0 (± 5.9)
Denim	26.4 (± 9.4)	43.8 (± 12.0)	30.1 (± 8.6)
Car seat material	23.8 (± 9.4)	29.0 (± 11.6)	27.6 (± 9.0)
Industrial carpet	13.0 (± 5.1)	24.6 (± 6.3)	13.2 (± 4.3)
Plush carpet	23.4 (± 9.6)	38.8 (± 16.5)	27.6 (± 12.5)
Concrete block	40.7 (± 41.4)	43.8 (± 25.1)	43.1 (± 43.9)
Concrete block, painted	22.1 (± 15.5)	27.3 (± 22.7)	16.1 (± 25.7)

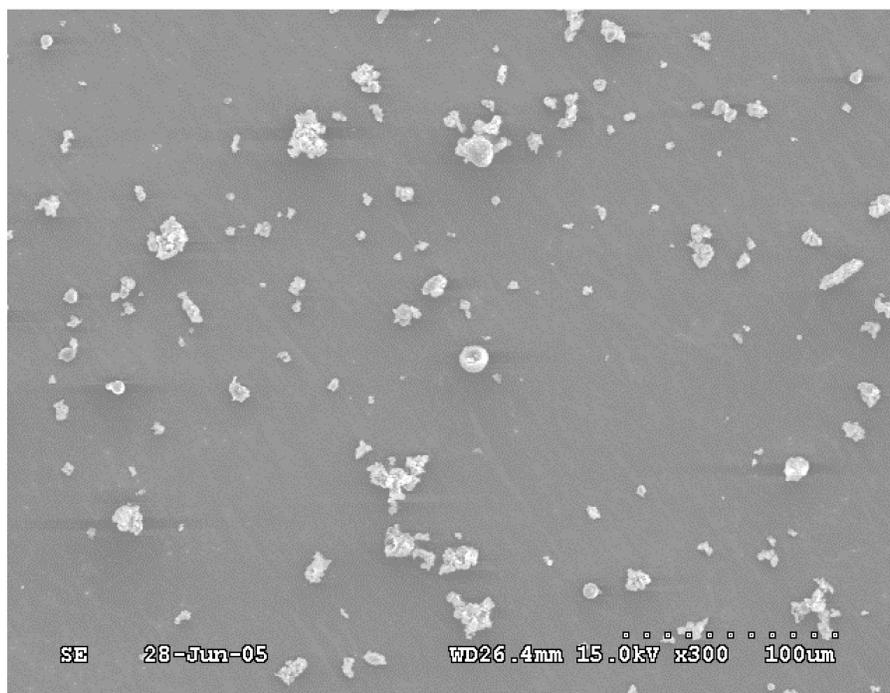
For the various substrates studied, nozzle capture of SRM was generally similar for SRMs 1579 and 2583, although variabilities were appreciable (Table V). This may suggest that smaller particles are preferentially retained on the walls of the

collection nozzles, whereas larger particles are more likely to pass through and be collected within the Accucaps.

To minimize problems due to sample losses within the collection nozzles, alternative sampler designs can be considered.

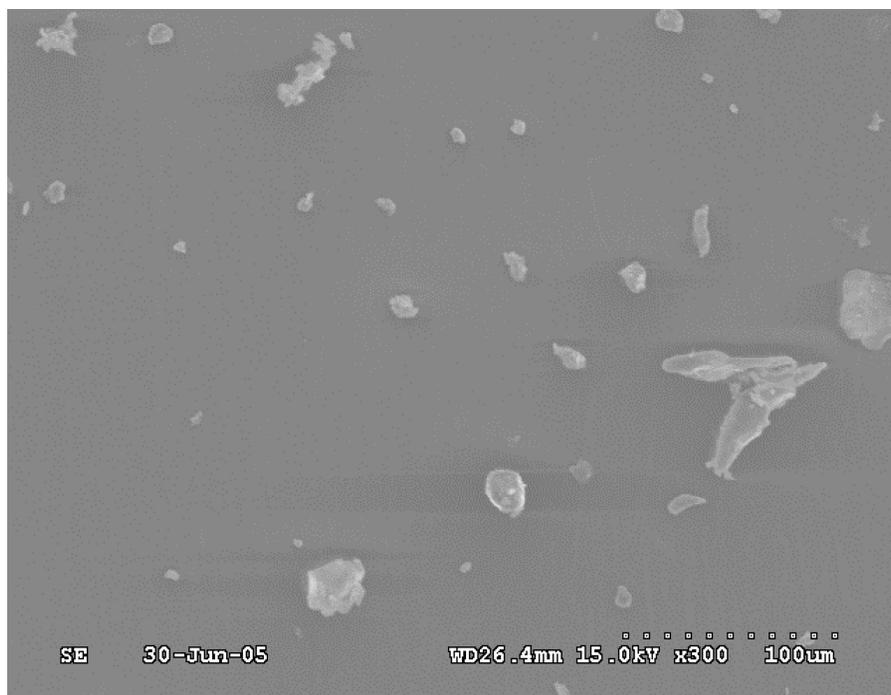


(a)



(b)

FIGURE 2. Scanning electron micrographs of (a) NIST SRM No. 1579, Powdered Lead-Based Paint; (b) NIST SRM No. 1648, Urban Particulate Matter; and (c) NIST SRM No. 2583, Trace Elements in Indoor Dust (*Continued*)



(c)

FIGURE 2. (Continued)

One possibility would be to design a sampler that incorporates the collection nozzle together with the collection device so that the entire apparatus (nozzle plus cassette or insert) could be weighed. This sampler design would thereby include all of the particulate matter that is removed from the surface. Another possibility would be to use conductive collection nozzles, thereby minimizing their static charge and ensuring that the collected particulate matter is captured within the sampling cassette vs. on the inside walls of the collection nozzle.^(22,23) The use of high-volume sampling pumps affording sampling flow rates of >10 L/min could also improve micro-vacuum sampling efficiencies.⁽¹²⁾

Another limitation of the present work is that only one investigator performed sample collection. It would be of interest to conduct a follow-up study where comparisons could be made among results from different individuals carrying out micro-vacuum sampling.

CONCLUSION

This study has provided performance data on a standardized micro-vacuum method for collecting surface dust samples. Micro-vacuum sampling can be used to complement other surface sampling techniques such as wipe sampling^(6,7) and tape stripping removal.^(24,25) One of the strengths of this method is the ability to determine loading (i.e., mass of collected material per unit area of sampled substrate) as well as analyte concentration on a mass of analyte per total sampled mass basis (if, for example, using subsequent elemental analysis by atomic spectrometry). Although recov-

eries were significantly less than 100%, it is emphasized that standardization of the micro-vacuum sampling procedure will enable harmonization of surface dust sample collection. Use of a standardized approach will ensure that data obtained by different investigators and from varying locations, substrates and times, can be compared and contrasted. Nevertheless, alternative sampler designs may be considered in order to improve sampling recoveries. Co-collection of loose substrate material is observed for some surfaces, but this is an inherent problem for any surface sampling technique.

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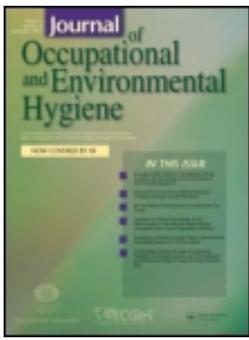
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