Applied Occupational and Environmental Hygiene

ISSN: 1047-322X (Print) 1521-0898 (Online) Journal homepage: https://www.tandfonline.com/loi/uaoh20

Optimized Portable Cordless Vacuum Method for Sampling Dry, Hard Surfaces for Dusts

Soo Young Kim , Shane Que Hee & John Froines

To cite this article: Soo Young Kim , Shane Que Hee & John Froines (2000) Optimized Portable Cordless Vacuum Method for Sampling Dry, Hard Surfaces for Dusts, Applied Occupational and Environmental Hygiene, 15:6, 503-511, DOI: 10.1080/104732200301296

To link to this article: https://doi.org/10.1080/104732200301296

Published online: 30 Nov 2010.

Applied Occupational and Environmental Hygiene
Volume 15(6): 503–511, 2000

1047-322X/00 $12.00 + .00

Optimized Portable Cordless Vacuum Method for Sampling Dry, Hard Surfaces for Dusts

Soo Young Kim, Shane Que Hee, and John Froines
Department of Environmental Health Sciences and UCLA Center for Occupational and Environmental Health, University of California at Los Angeles, Los Angeles, California

Surface sampling in industrial/environmental hygiene is a growing field that needs validated standardized methods. There are few standard methods, one being the American Society for Testing and Materials (ASTM) method involving a portable, cordless air sampling pump. In the present work, the ASTM technique was modified to increase efficiency and versatility. A soil sample was first dried and sieved. Known weights of different sieved sizes (125 μm–180 μm, 90 μm–125 μm, and 63 μm–90μm) were then sampled at an average flow rate of 4.0 ± 0.2 L/min from a template of inner dimensions 10 cm by 10 cm on two different surfaces (rough and smooth). Five consecutive sampling passes were performed. For the smooth surface, the first pass efficiency for the largest particles were 45% ± 45% (CV = 100%), and 75% ± 20% (CV = 27%) for the smallest particles. After three passes, the efficiency independent of particle size exceeded 83 percent with a CV better than 11 percent. After five passes, the efficiency exceeded at least 85 percent with about the same precision as for three passes. The rough surface allowed higher efficiencies for the first two sampling passes. Three to five passes are recommended to achieve acceptable efficiencies for the surface loose dust/soil range 100 μg/cm^2 to 1,500 μg/cm^2.

Keywords Lead, Surface Sampling, Dust, Dust Organics, Dust Metals, Surface Soil

Interest in surface dust sampling has been stimulated by research in evaluating metal,(1–25) organic chemical,(26–39) organic dust (biological),(40–52) and radioactive(9,35,53–56) exposures, but especially to children.(1–3,5–7,9–20,23–27,31,34,39,42–49) Among the metals, lead has been of prime interest, especially lead paint exposures to children,(1–3,5–7,9–20,23–25) lead abatement cleanups,(11,14,17) and potential nonferrous foundry exposures to workers from dusts on surfaces.(4) Among the organics, exposure to skin and surface pesticide residues after spraying is well studied.(27–30,32,33,35,37–39) For the biological vectors, studies on exposures to surface allergens(42–49) and microorganisms(40,41,50–52) are currently popular. Some studies on nonspecific dusts have also appeared,(5,57–61) mostly relating to sampling(5,57–59,61) or risk assessment.(5,18,39,56,60,61) All of the hazardous agents may be resuspended into the air by people, vehicles, pets, cleaning, equipment, abatement activities, ventilation, and wind to create inhalation threats.(11,14,17,41–56)

Out of all of these studies, very few investigators have provided efficiency data for sampling surface dusts. The Occupational Safety and Health Administration (OSHA) wipe technique efficiency for foundry dusts on work surfaces was reported in 1984 to vary between 43 to 90 percent, depending on pressure exerted, whether wet or dry (wet wiping was more efficient), and number of wipes (two wipes were more efficient than one).

A cordless vacuum method was reported by the present author in 1985(5) for sampling bioavailable contaminated dust from dry, hard surfaces using personal sampling pumps commonly used in industrial hygiene for air sampling. In addition, hand-wiping and hand-rinsing techniques were evaluated. The efficiency of the cordless method for five passes for known amounts of deposited surface dust of about 50 mg varied between 29 percent to 81 percent (arithmetic mean ± standard deviation 57 ± 14%, coefficient of variation CV = 25%, number n = 12) at a flow rate of 2.5 L/min using a stainless steel sampling probe for several different surfaces.(5) In contrast, for one sampling pass, the respective efficiencies were 21 percent to 59 percent (43 ± 14, CV = 33%, n = 12). The corrresponding one-pass recoveries in terms of mass recovered after five passes were 44 percent to 93 percent (74 ± 14, CV = 19%, n = 12). A similar Tygon sampling probe at 2.0 L/min showed(5) a one-pass recovery between 42 percent to 89 percent (63 ± 11, CV = 17%, n = 7). The surface sampling efficiency for the Tygon probe was 70.0 ± 7.1 percent for particles < 177 μm of an actual leaded house dust comprising about 81–82 percent of the leaded fraction and of dust weight. The collection efficiency decreased above this diameter; the overall efficiency for the whole dust was about 62 percent, this not being statistically different from the absolute efficiency for the stainless steel sampler of 57 ± 14 percent. For a 20 L/min vacuum, the first pass recovery was 76 ± 12 percent, CV = 16%, n = 7 relative to the 63 ± 11, CV = 17%, n = 7 for the 2 L/min technique, not statistically different at $p \leq 0.05$ relative to imprecision (F-test) or recovery (*Student t* test). Thus, surface vacuum techniques, although they were not very efficient, were at least relatively precise (< 20% CV).

The sampling techniques with several different handwipes varied in efficiency and precision also.[5] Efficiencies for five handwipings to recover 50 mg varied between 16 percent to 132 percent (79 ± 35%, CV = 44%, n = 11) for adults and children, with the range for one wiping being from 1.3 to 87 percent (mean 41 ± 26, CV = 61%, n = 11). The handwiping technique was not as precise as the surface vacuum technique, but was as efficient at $p \leq 0.05$. Hand rinsings also varied between 10 percent to 74 percent for five rinsings relative to 10 percent to 45 percent for one rinsing. A combination wipe/rinse method gave an efficiency of about 84 percent. These results explained why epidemiological studies up to that time did not show correlations between hand lead and blood lead for imprecise, inefficient handwiping/handrinsing techniques, but did between surface dust lead and blood lead for precise but moderately inefficient vacuum techniques. The sensitivity and precision of sampling and analytical techniques for lead were less important for when lead dust or soil levels were high and a large sample was taken for analysis (for example, > 100 mg), as for epidemiological studies on populations living around lead smelters,[1–3] on smelter or brass foundry workers, or on children that ate pica. Even if lead concentration was high, a low dust loading on hands usually caused sensitivity and precision problems.

The Environmental Protection Agency (EPA) in 1986 published a model that involved a reference child being exposed by mouthing activity to average daily doses of dust of 50 mg of average lead concentration 0.3 mg/g within households, 40 mg from street dust of average lead concentration 0.090 mg/g, and 10 mg of average lead concentration 0.150 mg/g at schools.[65]

If the hand lead sampling technique was also imprecise and dust loading on hands was low, statistical comparisons of exposed and "unexposed" populations often led to statistically nonsignificant results in studies before 1985.[65] The availability of the dust deposit for human exposure was also postulated as an important variable,[5] surface carpet dust being more important in exposing children than deep carpet dust, so that recovery of all dust from carpets was not so important to ascertain average lead exposure concentration and for the available dust exposure to children. The method was potentially usable for other dusts containing nonvolatile pollutants.

The method was the basis for ASTM Method PS 46-96 of 1996 designed for use in lead abatement activities.[16] In a 1985 report,[66] the estimated contribution of surface dust lead using the 1985 surface sampling technique[5] to ln blood lead of 57 children of age 18 months in the Cincinnati Prospective Lead Project by structural equations analysis had a regression weight of 0.15, about the same contribution as hand lead, and with 3.33 times more contribution of surface dust lead to hand lead than to blood lead. The regression weights varied with child age, a surrogate for time of exposure and crawling.

The other studies that reported efficiencies of sampling surface dusts were: 41 percent–48 percent for sampling bacteria on human skin in 1990[40]; 84–90 percent for the herbicide glyphosate on monkey skin in 1991[30]; 50–55 percent for wet wipe sampling of surface dusts of 71 metals in 1992[6]; 24 percent for a wipe method on carpet, and > 100 percent on linoleum and wood for lead dust in 1997[18]; 95 percent for a high vacuum method for carpet and 54 percent–61 percent for linoleum and wood in 1997[18]; and for the ASTM PS 46-96 method of unspecified number of sampling passes, 31 percent for carpet and 47–67 percent for linoleum and wood in 1997.[18]

The collection efficiencies of the vacuum sampling technique for dusts depend on several factors: particle size, dust loading, surface type, capture velocities, and ergonomic characteristics of the optimized sampling technique. The present study examines these variables in more depth to increase the cumulative absolute efficiency of the cordless vacuum method for hard surfaces for loose dusts.

MATERIALS AND METHODS

The protocols and apparatus of the ASTM method[16] were used as reference. This included calibration of air sampling pumps, testing for leaks, and the sampling templates used. The apparatus is the Tygon tube sampler variant[5] discussed above. All glassware was cleaned and made metal-free by scrubbing manually with brush and detergent, rinsing in distilled water, soaking overnight in 10 percent (v/v) nitric acid, rinsing copiously with distilled water, drying in a dustless oven, and then storing in transparent plastic bags contained in drawers.

Selection and Preparation of Soil for Sample Collection

A large proportion of household dust is soil brought in on shoes or feet or from windborne material.[13,15] Therefore, dust collection methods should be able to cope with soil particles that are part of house dusts. In the workplace, deposited lead metal fume dust is often associated with soil particles from coring materials and sands, in addition to when soil floors are present in unpaved workshops. In the Los Angeles area, the semidesert climatic conditions cause facile home infiltration of desert soils, especially during when hot dusty desert winds blow from the east, termed the "Santa Ana" condition. In areas with more rain, as investigated before by the present investigator in the Cincinnati area[5] and by the many other investigators on the east coast of the United States, the extensive long-distance wind transport of soil is negligible unless dust bowl conditions develop. Another major source of dust in urban Los Angeles homes is the fallout from automobile exhaust and its multiple suspensions and dispersions by traffic, but a reference sample of that dust was not available for this study.

A 1-kg sample of surface soil was taken from the U.S. desert section of the UCLA Botanical Gardens in a clean, wide-mouth Pyrex jar equipped with a Teflon-lined screw cap. The soil was collected with a trowel from several inches below the surface pebbles. The sample in the laboratory was broken up, and then dried in a dustless oven at 130°C to constant weight in an acid-clean pyrex tray. The dust was then sieved completely (minisieve, Fisher Scientific, Tustin, CA) through a 710 μm sieve (25 mesh), and then subsieved into < 63 μm (230 mesh), 63–90 μm (230–170 mesh), 90–125 μm (170–120 mesh), and 125–180 μm (120–80 mesh). The particle size < 149 μm (< 100 mesh) simulates clean room dust.[62] Each sieved fraction was stored individually in a closed, clean, wide-mouth bottle with a Teflon-lined screw cap.

Sampling Apparatus

A 10-cm-square template was used to define the sampling area (wipe sample test kit, SKC West, Fullerton, CA). A three-piece polystyrene matched weight filter cassette with 0.8 μm 37-mm diameter mixed cellulose ester filters (SKC West) was weighed before and after sampling. The sampling probe was of 5-cm-long Tygon tubing with an inner diameter of 6.0 ± 0.5 mm. One end of the probe was cut at a 45 degree angle.[5] The other end was connected to the sampling cassette. The cassette exit was connected by 6.35 mm i.d. Tygon tubing to a portable battery-operated vacuum pump (SKC Aircheck Sampler Model 224-PCXR4). Calibration with a M-5 MiniBuck calibrator (Buck Scientific, East Norwalk, CT) occurred with the sampling assembly in-line.

The inner surface margin of the sampling template was taped down with masking tape with about a tape margin of 1–2 mm covering the inner surface to be sampled. Two types of surfaces were used, rough and smooth, both made of polyethylene (dissecting board, Fisher Scientific). A hand-held inclinometer (Lev-O-Gage, Edmund Scientific, Barrington, NJ) was utilized to measure the angles of the probe at optimal sampling conditions. A calibrated model 1440-4 model 5415 II hot-wire anemometer (Kurz, Monterey, CA) measured face velocity. Surface hardness was assessed with a portable tensiometer (type D Durometer Model 307L, Davis Instruments, Baltimore, MD).

Methods

Each dust of different size and of known weight was poured slowly through the appropriate sieve which was moved six inches above and all over the template sampling surface. The pump flow rate (4.0 ± 0.2 L/min) was checked before and after each experiment. The pump was stabilized for five minutes before calibrating and sampling.

The dust was collected by slowly sliding the probe along the inner taped border of the template, and then in a concentric rectangular pattern inwards to the center. Every 30 seconds or about 50 percent of a single complete sampling pass and at the end, the probe was inverted and tapped to loosen any dust sticking to the inner tubing to facilitate dust collection on the filter. The probe was held in a manner to provide the most efficient sampling. This included tilting, bending, and combinations. The index finger placed on the probe was used to manipulate probe position, direction, and downward pressure.

Five separate sampling passes were done for each experiment. The total weight of the dust sampled cumulatively after each of one through five passes was measured by subtracting the original weight of the cassette from the total weight. The sampling efficiency was then calculated from the weight sampled divided by that applied. The particle size ranges 63–90 μm, 90–125 μm, 125–180 μm, and mixed size dust (63–180 μm of equal proportion by weight of the three size fractions) were evaluated. Different dust weights were applied ranging from ~ 10 mg to ~ 160 mg. Experiments were done in triplicate. The loading capability of the filter to cause decrease in flow rate was also determined. Probe weight changes were noted for each experiment, as well as the weight of the probe-filter cassette assembly.

Optimal sampling angles of the probe indicated by the inclinometer were observed. Times for sampling, and the times to achieve consistent results and constant CV were also determined.

The dependence of probe face velocity on area was assessed by covering the open end of the probe with transparent tape to allow the area not blocked to be determined by outline onto graph paper. A supporting spatula ensured the tape did not bend during the experiment.

Surface hardness measurements were done with the sampling surfaces on a flat surface with measurements done 1 cm away from the template edge and at least 6 mm apart. At least five measurements were done.

RESULTS

Cumulative Efficiency of Surface Sampling for Various Soil Size Ranges and Surface Type

The influence of particle size and type of surface on mean collection efficiencies of applied weights of 125–160 mg is given in Table I. At least three sampling passes were required for a sampling efficiency exceeding 80 percent for both surfaces independent of particle size and surface type. The rough surface promoted more efficient and precise sampling than the smooth one for the first two sampling sweeps. The two smaller particle sizes were sampled more efficiently and precisely than the larger size during the first two sweeps for both surfaces. However, both variables did not affect sampling efficiencies after the second sweep, where sampling was both accurate and precise. The actual efficiency for sampling a 1:1:1 mixture of the three size fractions for about the same surface loading and sampling flow rate was not significantly different at $p \leq 0.05$ from the overall calculated average for five sampling passes.

The particles adsorbed by a new Tygon probe never exceeded 0.7 mg. This sets a conservative method collected mass detection limit of about three mg using a S/N Student t criterion of 4.6 at 4 degrees of freedom (ν) at $p \leq 0.01$ (2.58 at $\nu = \infty$), and a practical similar lower quantitation limit of about 12 mg using

TABLE I
Sampling mean cumulative efficiency dependence on particle size range and surface for triplicate experiments using applied soil masses and a flow rate of 4.0 L/min

Surface	Applied mass (SD) (mg)	Diameter range (μm)	Cumulative efficiency (SD) in % for sampling pass 1	2	3	4	5
Rough	151.1 (6.1)	63–90	88.1 (8.1)	91.9 (4.8)	93.2 (3.7)	93.3 (3.7)	93.8 (3.2)
	144 (13)	90–125	89.8 (8.7)	94.7 (3.2)	96.2 (2.1)	96.2 (2.1)	96.4 (1.8)
	149 (17)	125–180	68 (35)	81 (28)	89 (16)	94.7 (6.3)	95.4 (5.0)
Mean (SD)	148.0 (3.6)	63–180	82 (12)	89.2 (7.2)	92.8 (3.6)	94.7 (1.5)	95.2 (1.3)
CV	2.4		14	8.1	3.9	1.6	1.4
	123 (19)	63–180[A] (1:1:1)					97.33 (0.65)
Smooth	134 (13)	63– 90	75 (20)	82.4 (8.7)	83.4 (8.0)	84.2 (7.6)	84.7 (7.3)
	136.8 (9.8)	90–125	72 (22)	86.3 (9.7)	87.3 (9.3)	87.9 (9.2)	88.4 (8.4)
	128.7 (7.3)	125–180	45 (45)	68 (25)	85.8 (9.4)	88.7 (8.3)	90.6 (9.6)
Mean (SD)	133.2 (4.1)	63–180[A]	64 (17)	78.9 (9.6)	85.5 (2.0)	86.9 (2.4)	87.9 (3.0)
CV	3.1		27	12	2.3	2.8	3.4

SD, standard deviation; CV, coefficient of variation.
[A]The range.

TABLE II
Influence of rough surface loading for specific particle size ranges on the five-pass sampling efficiency at 4.0 L/min flow rate

Particle size range (μm)	Loading (mg)	Efficiency (%)	Mean (%)	SD (%)	CV (%)
63–90	9.3	85.0			
	23.8	88.8			
	27.1	87.4			
	146.6	97.4			
	148.7	91.7			
	158.0	92.2			
	9.3–158	85–97.4	90.4	4.4	4.8
90–125	10.3	92.0			
	26.4	102.7			
	29.9	93.7			
	130	96.2			
	148.4	98.2			
	155.5	94.7			
	10.3–155.5	92.0–102.7	96.3	3.8	4.0
125–180	10.3	94.0			
	22.3	94.5			
	27.6	91.4			
	136.2	89.7			
	142.7	89.7			
	168.8	98.5			
	10.3–168.8	89.7–98.5	93.0	3.4	3.7
Grand ranges	9.3–168.8	85–103	90.4–96.3	3.4–4.4	3.7–4.8
Overall grand means			93.2	4.4	4.7

SD, standard deviation; CV, coefficient of variation.
The overall mean, its standard deviation, and its CV are for n = 18.

an equivalent S/N criterion of 10 at $\nu = \infty$ as recommended by the U.S. Environmental Protection Agency (EPA).[63] Probe masses ≤ 0.1 mg were found in 27 out of 39 sampling runs when the probe was presaturated with dust. The method detection limit is then about 0.4 mg and the practical lower quantitation limit is about 2 mg.

Influence of Surface Loading on Sampling Efficiency

Table II shows the effects of surface loading and particle size on the five-pass sampling efficiency at the same flow rate for the rough surface. As expected from Table I, there is no dependence on particle size for the five-sweep technique, the mean efficiencies for each size fraction not being statistically different at $p \leq 0.05$. In addition, there is no significant difference at $p \leq 0.05$ either, for surface loading in the range 9.3–169 mg. The overall mean efficiency of 93.2 percent has an associated range of 85–103 percent and a CV of 4.7 percent. The efficiency near 10 mg loading (90.3 ± 4.7) percent is still independent of particle size investigated. In comparison, the sampling efficiency above 100 mg loading independent of particle size was (94.3 ± 3.5) percent, not statistically different at $p \leq 0.05$.

Other Characterizations

Table III gives the observed data for sampling time, pump-related variables (flow rate and face velocity), probe angle during sampling, and hardness characterization of the two surfaces. The average time for sampling decreased from > 60 s initially to 48 s after about 20 sampling trials. The interrun CV also decreased to 10 percent. The decrease in pump flow rate from initial to final calibration for each set of five passes was not significantly different at $p \leq 0.05$, even for high loadings.

The dependence of face velocity on open probe area shows that the face velocity increases linearly from 40 mm^2 to 8 mm^2 (Velocity = −7.06 area + 510 for r = −0.999 for velocity in ft/min units and area in mm^2), but increases exponentially below 8 mm^2 due to turbulent flow. Difficulties in measurement were apparent below and at 1 mm^2 because of anemometer probe size relative to size of the sampling aperture. The face velocity at 1 mm^2 was 1083 ft/min (330 m/min), a high enough capture velocity to lift loose surface dust or soil particles. It is about double the velocity predicted from the linear regression equation.

The angle at which the probe had to be held relative to the surface to be sampled depended on particle diameter deposited. The large particle size required angles of 30–35 degrees, with bending of the probe from its inclination to increase capture velocity inside the probe to remove any stuck particles. The smallest particles needed steeper angles (30–45 degrees) for successful sampling, resulting in more probe tilting. The intermediate particle size required both bending and tilting. Probe inversion with tapping was also necessary from time to time to promote collection on the filter.

TABLE III

Variables (pass time, face velocity, flow rate stability, particle size dependence on probe angle for efficient sampling, and surface hardness) measured to further characterize the optimized cordless sampling method at flow rate 4.0 L/min

Variable	Observations	
Sampling time for one pass	47, 52, 48, 46 s with mean ± SD of 48.3 ± 2.6 s	
Face velocity at probe entrance	Area (mm^2)	Face velocity (ft/min) (SD for n = 3)
	35	262(10)
	20	369(10)
	15	405(10)
	8	452(10)
	4	571(20)
	3	869(20)
	1	1083(30)
Decrease in flow rate from beginning to end of sampling	Load sampled (mg)[A]	Relative flow decrease (%)
	101.2	−3.7
	129.1	−0.67
	138.3	−0.48
Probe angle and particle size	Particle size range (μm)	Probe angle (degrees from horizontal)
	63–90	30–45
	90–125	35–40
	125–180	30–35
Surface hardness	Surface type	Hardness (load pound)
	Smooth	7.08(0.46)
	Rough	6.64(0.19)

The bracketed numbers are standard deviations (SD).
[A] 125–180 μm diameter.

There was no statistical difference at $p \leq 0.05$ in surface hardness for the two polyethylene surfaces.

DISCUSSION

Several modifications of the ASTM method[16] based on the cordless vacuum technique[5] resulted in enhanced reproducible sampling efficiencies exceeding the NIOSH minimum of 75 percent and imprecision less than 10 percent, and a greater understanding of the limitations of the method to sample loose surface dusts/soils at coverages between 0.1 mg/cm^2 to 1.5 mg/cm^2.

The method innovations included: tapping and inversion of the probe, taping the inner margin of the sampling template, saturation of the inner surface of the probe, sampling from the inner walls of the template to the center, increasing the flow rate to about 4.0 L/min, and weighing the entire sampling train.

Vigorous tapping of the probe in the inverted position at the halfway mark of each sampling pass helped to give efficiencies above 90 percent for rough surfaces and above 80 percent for smooth surfaces, and also allowed more dust to be collected on the filter for later analytical chemical analysis. Probe local bending increased the local capture velocity inside the probe to assist transfer to the filter, and to loosen wall material. Tilting varied the face velocity at the sampling surface. The method is ineffective without movement on very smooth surfaces. This accounts for why rough surfaces are sampled more efficiently than smooth, flat surfaces. Rough surfaces allow makeup air to move surface particles whereas probe movement is necessary for very smooth surfaces.

Another modification was taping the inside edge of the template to the surface with no more than 1–2 mm of sampling surface margin covered with tape. A 2-mm margin produces 4 percent error, and a 1-mm margin causes 2 percent error. Taping minimized sample loss from soil/dust being pushed underneath the template inner edge, and prevented movement of the template during sampling to ensure the sampled area remained constant and did not change inadvertently. A sampling motion inwards was inherently better than one from the center to the edge.

Preliminary presaturation of the probe to constant weight by surface sampling of particles assured higher sampling efficiencies at low coverages below 10 mg to a practical lower limit of about 2 mg. In its field use for areas of low dust coverage yielding < 10 mg of total collected dust, it is therefore recommended to presaturate the probe in the general area to be sampled using a sensitive portable electronic or mechanical balance to indicate probe presaturation and to provide the initial probe presampling weight. The alternative is to sample multiple 100 cm^2 areas until sufficient dust/soil is collected to make the mass held by the probe to be small (< 10%) relative to the total mass collected in the cassette and maximizing that collected on the filter for subsequent analysis. Thus, the whole sampling train (probe plus cassette) needs to be weighed rather than just the filter because coverage values at low collection masses are affected, whereas the xenobiotic concentration collected on the filter is not, if this is already above the least quantifiable limit.

The technique must also be "in the fingers" and "in the wrist" as shown by an acceptable CV in performance-based tests with known amounts of applied dusts and soils in laboratory practice runs, before field sampling can be done. An initially untrained operator required about 20 cassettes with a five-pass technique/cassette to lower the interrun CV to below 10 percent, and to optimize sampling times.

The increased flow rate allowed higher capture velocities to be generated on the surface, resulting also in higher collection efficiencies for the key size fraction. The effects of particle size, surface coverage, operator training, flow rate, and operator technique become less important if three to five sweeps are performed rather than just one or two. Natural dusts will have a spectrum of dust sizes. The sampling of mixtures of particle sizes appears as efficient or more so, than predicted by the size fraction studies of Tables I and II.

From previous work,[5] the technique at 2 L/min is inefficient at removal of all dust from deep pile carpet, greasy surfaces, and for the larger particle sizes > 177 μm of loose dust on smooth surfaces. However, the most powerful vacuum cleaners and shampooing do not remove all the dust from plush carpets,[13,15] and even exhaustive scrubbing is often necessary to remove greasy deposits. Deep carpet dust is unavailable for exposure unless dispersed into the air by some agency, for example, carpet shaking, frequent walking, or children playing boisterously on the carpet. Dust on the surface of greasy deposits is also not readily bioavailable. It is also expected that a technique that employs a 16 L/min sampler as utilized for the Baltimore repair and maintenance study[12,19,23] should be more efficient at sampling larger particles than one that utilizes 2 to 4 L/min, though this depends on the aerodynamics at the sampled surface and exactly how the technique is put into practice. Such details are hardly ever provided in published papers, thus making comparisons difficult.

The cordless vacuum sampling technique[5] was originally developed to gauge the availability of surface dusts to the hands of children relative to their hand-to-mouth or toy-to-mouth behavior. The reasoning was as follows: children at play are often on all fours on a surface, whether hard or otherwise. The dust (mostly < 149 μm[62] on the surface, comprising about 76% of the surface dust[5]) is partially retained on the hand. The highest hand dust retention occurred[5] for deposited loose dust sizes 149–246 μm with about fourfold lower adherence for 44–149 μm and 246–392 μm dusts, and 1.6 times lower adherence for the < 44 μm fraction. The efficiency was independent of particle size below 180 μm, which comprised about 81 percent of the weight of reference house dust and about 82 percent of the lead. This fraction included the most available, hand-retained fraction of dust.[5]

The modified technique should be more efficient for larger particle sizes also, but these are a minor fraction of house dust and of complex retention characteristics.[5] The increase in flow rate to 4 L/min and the other modifications have resulted in a modified technique that is more efficient (the average efficiency for the size fraction 63 μm to 177 μm was increased from

70 ± 13% to 93.2 ± 4.4%). The modifications still retain the cordless pump advantage, but take advantage of technological advantages not available when the technique was first developed in the early 1980s. How the more efficient technique will relate to blood lead remains to be tested.

The apparent inconsistencies[12] of the 1985 method[5] may be related to availability of the dust being sampled rather than total dust, to defective or different comparison statistical designs, to the number of dust samples taken (for example, 36/house for 205 children in reference 12), inadequate or noncomparable training in use of sampling techniques (all training must be performance-based, in our opinion, as emphasized above), and to the wide variabilities of field dust coverage, xenobiotic concentration, and particle sizes, as also demonstrated by use of lognormal statistics in reference 12 to describe surface sampling parameters so that a random number selection design for side-by-side sampling area and method may not be adequate. This last factor is best controlled in laboratory studies. Nevertheless, the data on laboratory recovery of applied leaded dust on linoleum and wood surfaces for the 16 L/min versus the 2 L/min methods in reference 19 show no statistical differences in the means at $p \leq 0.05$ with significant differences, as expected, for carpet. These results were the same as for the studies with the 20 L/min and 2.0 L/min samplers reported in reference 5 using applied weights of dusts and soils. In field studies, the only way to account for side-by-side surface deposit variability and surface variation is what was done in reference 5, that is, resample the same surface already sampled by the rival technique. This was not done in reference 12 or 19.

Another problem for study-to-study comparisons involving blood lead and environmental parameters is that many studies involve low blood leads (as for reference 12 children where only six or 3% had blood leads ≥20 μg/dL with a population mean of 7.7 ± 5.1 μg/dL) and so make interpretation of any correlations difficult relative to others (as for the Cincinnati Prospective Lead Study[66,67] where at least 27 children in 1985 had blood leads ≥20 μg/dL with an arithmetic mean of 20 ± 10 μg/dL between 15–24 months of age for $n = 57$ for children having blood lead ≥20 μg/dL at least once) or when blood leads are close to background blood leads.

Blood lead values from different age groups often may be compared, and it is known that the contributions of surface and hand lead vary with house activity of the child. With regard to the latter, the steep increase in blood lead for the Cincinnati Prospective Lead Study children occurred between 4 to 15 months of age, followed by a gradual decrease.[67] The regression weight contributions to ln blood lead for surface dust lead stayed fairly constant (0.16–0.23) between 12 to 21 months, and those for hand lead (0.09 to 0.16) between months 9 to 18. However, only hand lead at month 18 was a significant contributor at $p \leq 0.05$. In reference 12, all the correlations of blood lead with environmental sampling alternatives appear based on the whole population of children between 12–30 months of age, an averaging procedure that will miss some age-related correlations. Also, it should be kept in mind that correlations do not necessarily signify cause and effect.

An activity analysis often shows that a child usually mouths only selected parts of the hand or toy. Thus, not all the dust that is on the hand will frequently be actually bioaccessible (ingested) to be bioavailable (absorbed). It is exceedingly difficult to simulate the bioavailability of pollutants coingested with the dust. Sampling methods that remove all dust from a surface[9,12,13,18,19] provide maximum answers of pollution potential and allow the best chance to detect xenobiotic concentrations, but correlations with blood lead may be misleading because the available dust fraction adheres to the hand, and then only part of the adhered dust may be ingested. A surface sampling technique that mimics the characteristics of the available dust, the hand retention characteristics of the dust, and the favored hand mouthing area of the child is clearly still desirable, just as air particulate samplers that mimic inhalability or respirability of particulates are advantageous.[64] Most of the existing alternative sampling techniques including the present modified technique strive for efficiency rather than to mimic the exposure situation of the child simply because adequate analytical sensitivity is still a major problem, though this is now less of a factor with the advent of inductively coupled plasma/mass spectrometry which, however, is expensive.

The application of the present technique to sample surface dusts and soils containing metals, nonvolatile organics like many pesticides, organic (biological) dusts, and radioactive compounds reviewed in the introduction is obvious.

CONCLUSIONS

The cordless vacuum method for sampling surface dusts on hard surfaces has been optimized relative to sampling efficiency, number of sampling passes, manipulation of the sampling probe, flow rate, and surface loading. The technique utilizes pumps that are currently used for air sampling for particulates and for some gases and vapors by industrial and environmental hygienists. At least 20 cassettes with five sampling passes per cassette in the laboratory are necessary to provide acceptable speed, precision, and accuracy for training purposes before field sampling will be adequate.

ACKNOWLEDGMENT

NIOSH/CDCP/Department of Energy Grant No. CCR 912-034 and the UCLA Center for Occupational and Environmental Health provided financial support.

REFERENCES

1. Vostal, J.; Traves, E.; Sayre, J.; Charney, E.: Lead Analysis of House Dust: A Method for the Detection of Another Source of Lead Exposure in Inner City Children. Environ Health Perspect 7:91–97 (1974).

2. Lepow, M.; Bruckman, L.; Gillette, M.; et al.: Investigation into Sources of Lead in the Environment of Urban Children. Environ Res 10:415–426 (1975).
3. Roels, H.; Buchet, J.; Lauwerys, R.; et al.: Exposure to Lead by the Oral and the Pulmonary Routes of Children Living in the Vicinity of a Primary Lead Smelter. Environ Res 22:81–94 (1980).
4. Chavalitnitikul, C.; Levin, L.: A Laboratory Evaluation of Wipe Testing Based on Lead Oxide Surface Contamination. Am Ind Assoc J 45:311–317 (1984).
5. Que Hee, S.; Peace, B.; Clark, C.; et al.: Evolution of Efficient Methods to Sample Lead Sources, such as House Dust and Hand Dust, in the Homes of Children. Environ Res 38:77–95 (1985).
6. Lichtenwalner, C.: Evaluation of Wipe Sampling Procedures and Elemental Surface Contamination. Am Ind Hyg Assoc J 53:657–659 (1992).
7. American Society for Testing and Materials (ASTM): Proposed Standard Practice for the Field Collection of Dust Samples Using Wipe Sampling Methods for Lead Determination by Atomic Spectrometry Techniques. ASTM, Philadelphia (1993).
8. Wester, R.; Maibach, H.; Sedik, L.; et al.: In Vivo and in Vitro Percutaneous Absorption and Skin Decontamination of Arsenic from Water and Soil. Fund Appl Toxicol 20:336–340 (1993).
9. Farfel, M.; Lees, P.; Rohde, C.; et al.: Comparison of a Wipe and a Vacuum Collection Method for the Determination of Lead in Residential Dusts. Environ Res 65:291–301 (1994).
10. Gulson, B.L.; Davis, J.J.; Mizon, K.J.; et al.: Lead Bioavailability in the Environment of Children: Blood Lead Levels in Children Can Be Elevated in a Mining Community. Arch Environ Health 49:326–331 (1994).
11. Aschengrau, A.; Beiser, A.; Bellinger, D.; et al.: The Impact of Soil Lead Abatement on Urban Children's Blood Lead Levels: Phase II Results from the Boston Lead-in-Soil Demonstration Project. Environ Res 67:125–148 (1994).
12. Lanphear, B.; Emond, M.; Jacobs, D.; et al.: A Side-by-Side Comparison of Dust Collection Methods for Sampling Lead-Contaminated House Dust. Environ Res 68:114–123 (1995).
13. Roberts, J.W.; Dickey, P.: Exposure of Children to Pollutants in House Dust and Indoor Air. Rev Environ Contam Toxicol 143:59–78 (1995).
14. Gulson, B.L.; Davis, J.J.; Bawden-Smith, J.: Paint as a Source of a Recontamination of Houses in Urban Environments and Its Role in Maintaining Elevated Blood Leads in Children. Sci Tot Environ 164:221–235 (1995).
15. Adgate, J.L.; Weisel, C.; Wang, Y.; et al.: Lead in House Dust: Relationships Between Exposure Metrics. Environ Res 70:134–147 (1995).
16. ASTM: Provisional Standard Practice for Collection of Surface Dust by Air Sampling Pump Vacuum Technique for Subsequent Lead Determination, Designation: PS 46-96. ASTM, Philadelphia (1996).
17. Langlois, P.; Smith, L.; Fleming, S.; et al.: Blood Lead Levels in Toronto Children and Abatement of Lead-Contaminated Soil and House Dust. Arch Environ Health 51:59–67 (1996).
18. Lemus, R.; Abdelghani, A.A.; Akers, T.G.; Horner, W.E.: Health Risks from Exposure to Metals in Household Dusts. Rev Environ Health 11:179–189 (1996).
19. Emond, M.; Lanphear, B.; Watts, A.; Eberly, S.: Measurement Error and Its Impact on the Estimated Relationship Between Dust Lead and Children's Blood Lead. Environ Res 72:82–92 (1997).
20. Trepka, M.J.; Heinrich, J.; Krause, C.; et al.: The Internal Burden of Lead Among Children in a Smelter Town—A Small Area Analysis. Environ Res 72:118–130 (1997).
21. Hwang, Y.H.; Bornschein, R.L.; Grote, J.; et al.: Environmental Arsenic Exposure of Children Around a Former Copper Smelter Site. Environ Res 72:72–81 (1997).
22. Scott, P.K.; Finley, B.L.; Sung, H.M.; et al.: Identification of an Accurate Soil Suspension/Dispersion Modeling Method for Use in Estimating Health-Based Soil Cleanup Levels of Hexavalent Chromium in Chromite Ore Processing Residues. J Air Waste Manage Assoc 47:753–765 (1997).
23. Lanphear, B.P.; Burgoon, D.A.; Rust, S.W.; et al.: Environmental Exposures to Lead and Urban Children's Blood Lead Levels. Environ Res 76:120–130 (1998).
24. Murgueytio, A.M.; Evans, R.G.; Roberts, D.: Relationship Between Soil and Dust Lead in a Lead Mining Area and Blood Lead Levels. J Expos Anal Environ Epidemiol 8:173–186 (1998).
25. Tong, S.T.; Lam, K.C.: Are Nursery Schools and Kindergartens Safe for Our Kids? The Hong Kong Study. Sci Tot Environ 216:217–225 (1998).
26. Keenan, R.; Cole, S.: A Sampling and Analytical Procedure for Skin-Contamination Evaluation. Am Ind Assoc J 43:473–476 (1982).
27. Wester, R.; Maibach, H.: In Vivo Percutaneous Absorption and Decontamination of Pesticides in Humans. J Toxicol Env Health 16:25–37 (1985).
28. World Health Organization (WHO): World Health Organization Field Surveys of Exposure to Pesticides Standard Protocol. Toxicol Lett 33:223–236 (1986).
29. Abbot, I.; Bonsall, J.; Chester, G.; et al.: Worker Exposure to a Herbicide Applied with Ground Sprayers in the United Kingdom. Am Ind Hyg Assoc J 48:167–175 (1987).
30. Fenske, R.: Correlation of Fluorescent Tracer Measurement of Dermal Exposure and Urinary Metabolite Excretion During Occupational Exposure to Malathion. Am Ind Hyg Assoc J 49:438–444 (1988).
31. Wester, R.; Maibach, H.; Bucks, D.; et al.: Percutaneous Absorption and Skin Decontamination of PCBs: In Vitro Studies with Human Skin and In Vivo Studies in the Rhesus Monkey. J Toxicol Env Health 31:235–246 (1990).
32. Wester, R.; Melendres, J.; Sarason, R.; et al.: Glyphosate Skin Binding, Absorption, Residual Tissue Distribution, and Skin Decontamination. Fund Appl Toxicol 16:725–732 (1991).
33. Wester, R.; Melendres, J.; Maibach, H.: In Vivo Percutaneous Absorption and Skin Decontamination of Alachlor in the Rhesus Monkey. J Toxicol Env Health 36:1–12 (1992).
34. Weber, L.; Zesch, A.; Rozman, K.; Decontamination of Human Skin to 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) in Vitro. Arch Env Health 47:302–308 (1992).
35. Wester, R.; Maibach, H.; Sedik, L.; Melendres, J.: Percutaneous Absorption of [14C]Chlordane from Soil. J Tox Env Health 35:269–277 (1992).
36. Surber, C.; Wilhelm, K.; Bermann, D.; Maibach, H.: In Vivo Skin Penetration of Acitretin in Volunteers Using Three Sampling Techniques. Pharm Res 10:1291–1294 (1993).
37. Fenske, R.: Dermal Exposure Assessment Techniques. Ann Occup Hyg 37:687–706 (1993).

38. Fenske, R.; Lu, C.: Determination of Handwash Removal Efficiency: Incomplete Removal of the Pesticide Chlorpyrifos from Skin by Standard Handwash Techniques. Am Ind Hyg Assoc J 55:425–432 (1994).
39. van Hemmen, J.; Brouwer, D.: Assessment of Dermal Exposure to Chemical. Sci Total Env 168:131–141 (1995).
40. Hambraeus, A.; Hoborn, J.; Whyte, W.: Skin Sampling-Validation of a Pad Method and Comparison with Commonly Used Methods. J Hosp Infect 16:9–27 (1990).
41. Rylander, R.: Organic Dusts—From Knowledge to Prevention. Scand J Work, Environ Health 20:116–122 (1994).
42. Zock, J.P.; Brunekreef, B.: House Dust Mite Allergen Levels in Dust from Schools with Smooth and Carpeted Classroom Floors. Clin Exp Allergy 25:549–553 (1995).
43. Nelson, H.S., Fernandez-Caldas, E.: Prevalence of House Dust Mites in the Rocky Mountain States. Ann Allergy, Asthma, Immunol 75:337–339 (1995).
44. Hewitt, C.R.; Brown, A.P.; Hart, B.J.; Pritchard, D.I.: A Major House Dust Mite Allergen Disrupts the Immunoglobulin E Network by Selectively Cleaving CD23: Innate Protection by Antiproteases. J Exp Med 182:1537–1544 (1995).
45. Gordon, S.; Tee, R.D.; Newman Taylor, A.J.: Analysis of the Allergenic Composition of Rat Dust. Clin Exp Allergy 26:533–541 (1996).
46. Chrisiansen, S.C.; Martin, S.B.; Schleicher, N.C.; Koziol, J.A.; Hamilton, R.G.; Zuraw, B.L.: Exposure and Sensitization to Environmental Allergen of Predominantly Hispanic Children with Asthma in San Diego's Inner City. J Allergy Clin Immunol 98:288–294 (1996).
47. Miguel, A.G.; Cass, G.R.; Weiss, J.; Glovsky, M.M.: Latex Allergens in Tire Dust and Airborne Particles. Environ Health Perspect 104:1180–1186 (1996).
48. Van der Heide, S.; Kauffman, H.F.; Dubois, A.E.; de Monchy, J.G.: Allergen Reduction Measures in Houses of Allergic Asthmatic Patients: Effects of Air-Cleaners and Allergen-Impermeable Mattress Covers. Eur Resp J 10:1217–1223 (1997).
49. Patchett, K.; Lewis, S.; Crane, J.; Fitzharris, P.: Cat Allergen (Fel d 1) Levels on School Children's Clothing and in Primary School Classrooms in Wellington, New Zealand. J Allergy Clin Immunol 100:755–759 (1997).
50. Kwaasi, A.A.; Parhar, R.S.; al-Mohanna, F.A.; Harfi, H.A.; Collison, K.S.; al-Sedairy, S.T.: Aeroallergens and Viable Microbes in Sandstorm Dust. Potential Triggers of Allergic and Nonallergic Respiratory Ailments. Allergy 53:255–265 (1998).
51. Pear, J.K.; Dickerson, J.; Li, J.: Effects of Damp and Mold in the Home on Respiratory Health: A Review of the Literature. Allergy 53:120–128 (1998).
52. Raitiala, S.; Reponen, T.; Nevalainen, A.; Husman, T.; Kalliokoski, P.: Control of Exposure to Airborne Viable Microorganisms During Remediation of Moldy Buildings; Report of Three Case Studies. Am Ind Hyg Assoc J 59:455–460 (1998).
53. Sill, C.W.: Rapid Monitoring of Soil, Water, and Air Dusts by Direct Large-Area Alpha Spectrometry. Health Physics 69:21–33 (1995).
54. Yu, R.C.; Sherwood, R.J.: The Relationships Between Urinary Elimination, Airborne Concentration, and Radioactive Hand Contamination for Workers Exposed to Uranium. Am Ind Hyg Assoc J 57:615–620 (1996).
55. Shinn, J.H.; Homan, D.N.; Robison, W.L.: Resuspension Studies in the Marshall Islands. Health Physics 73:248–257 (1997).
56. Wolbarst, A.B.; Mauro, J.; Anigstein, R.; et al.: Model for Estimating Population Impacts Averted Through the Remediation of Contaminated Soil. Health Physics 75:67–76 (1998).
57. Driver, J.; Konz, J.; Whitmyre, G.: Soil Adherence to Human Skin. Bull Environ Contam Toxicol 43:814–820 (1989).
58. Environmental Protection Agency (EPA): Engineering Study to Explore Improvement in Vacuum Dust Collection. Final Report. Office of Pollution Prevention and Toxics, Environmental Protection Agency, Washington, D.C. (1992).
59. EPA: Quality Assurance Project Plan for the Comprehensive Abatement Performance Study. Office of Pollution Prevention and Toxics, Environmental Protection Agency, Washington, D.C. (1992).
60. Finley, B.; Scott, P.; Mayhall, D.: Development of a Standard Soil-to-Skin Adherence Probability Density Function for Use in Monte Carlo Analyses of Dermal Exposure. Risk Anal 14:555–569 (1994).
61. Ness, S.: Surface and Dermal Monitoring for Toxic Exposures. Van Nostrand Reinhold, New York (1994).
62. Whitfield, W.J.: A Study of the Effects of Relative Humidity on Small Particle Adhesion to Surfaces. In: Surface Contamination: Genesis, Detection and Control, Mittal, K.L., Ed. Plenum, New York (1979).
63. EPA: Methods for the Determination of Metals in Environmental Samples, C.K. Smoley, Ed. CRC Press, Boca Raton FL (1992).
64. Werner, M.A.; Spear, T.M.; Vincent, J.H.: Investigation into the Impact of Introducing Workplace Aerosol Standards Based on the Inhalable Fraction. Analyst 121:1207–1214 (1996).
65. EPA: Air Quality Criteria for Lead, EPA 600/8-83-018F. Office of Health and Environmental Assessment, Research Triangle Park, NC (1986).
66. Bornschein, R.L.; Succop, P.; Dietrich, K.N.; et al.: The Influence of Social and Environmental Factors on Dust Lead, Hand Lead, and Blood Lead Levels in Young Children. Environ Res 38:108–118 (1985).
67. Bornschein, R.L.; Hammond, P.B.; Dietrich, K.N.; et al.: The Cincinnati Prospective Study of Low-Level Lead Exposure and Its Effects on Child Development: Protocol and Status Report. Environ Res 38:4–18 (1985).