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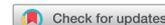
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Lessons learned from surface wipe sampling for lead in three workplaces

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ABSTRACT

Surface wipe sampling in the occupational environment is a technique widely used by industrial hygienists. Although several organizations have promulgated standards for sampling lead and other metals, uncertainty still exists when trying to determine an appropriate wipe sampling strategy and how to interpret sampling results. Investigators from the National Institute for Occupational Safety and Health (NIOSH) Health Hazard Evaluation Program have used surface wipe sampling as part of their exposure assessment sampling strategies in a wide range of workplaces. This article discusses wipe sampling for measuring lead on surfaces in three facilities: (1) a battery recycling facility; (2) a firing range and gun store; and (3) an electronic scrap recycling facility. We summarize our findings from the facilities and what we learned by integrating wipe sampling into our sampling plan. Wiping sampling demonstrated lead in non-production surfaces in all three workplaces and that the potential that employees were taking lead home to their families existed. We also found that the presence of metals such as tin can interfere with the colorimetric results. We also discuss the advantages and disadvantages of colorimetric analysis of surface wipe samples and the challenges we faced when interpreting wipe sampling results.

KEYWORDS

Battery recycling; colorimetric; electronic scrap recycling; firing range; lead; metals; surface sampling; wipes

Introduction

Surface wipe sampling for lead has proven beneficial for investigators from the NIOSH Health Hazard Evaluation Program in workplace evaluations. Employers and employees have requested help regarding surface sampling for lead and the role surface sampling results play in reducing lead exposures in the workplace. This article describes our use of surface sampling for lead during three health hazard evaluations and the lessons we learned in doing so.

Surface wipe samples collected in production areas can be used to identify potential sources of metals, to prioritize cleaning efforts, to identify the need to implement or improve engineering or administrative controls, and to recommend appropriate personal protective equipment (PPE).^[1–4] Surface wipe sampling in non-production areas can be used to investigate the unintentional migration of metals out of production areas or to worker's homes, to further evaluate exposure pathways, and to evaluate the effectiveness of controls or housekeeping. Although not discussed in this manuscript, other benefits

of surface wipe sampling may include checking if workers' skin and/or clothing is contaminated and deciding if areas or equipment are sufficiently decontaminated to allow re-entry, re-use, or release to the general public.^[5,6]

Analyzing surface wipe samples for metals (e.g., lead, silver, cadmium, barium, mercury, chromium) can be done qualitatively and quantitatively.^[7,8] Colorimetric (qualitative) methods provide immediate feedback regarding the presence or absence of lead or other metals on surfaces.^[9–11] Quantitative wipe sample methods, typically using cellulose or cotton gauze material, require laboratory analysis for metals via inductively coupled plasma atomic emission spectroscopy (ICP-AES) (e.g., NIOSH Method 7300), flame atomic absorption spectroscopy (e.g., NIOSH Method 7082), or graphite furnace atomic absorption spectroscopy (e.g., NIOSH Method 7105).^[9,12,13] Quantitative analysis of surface wipe samples has been used successfully to evaluate worker hygiene practices and facilities' housekeeping and PPE programs to identify opportunities for reducing overall metal exposures.^[14,15]

There are many challenges associated with surface wipe sampling. Variables that can affect surface sampling results include the type of surface being sampled (i.e., roughness, porosity); the wipe sampling time and wiping pressure exerted by the investigator; the amount of contamination on the surface being sampled; possible analytical interferences from other materials on the surface (e.g., oils, dirt); and the efficacy of the wiping material and wetting agent (if used) at removing the contaminant(s) of interest from the surface. Ashley et al.^[16] suggest that the variations in wipe sampling practices contribute the greatest uncertainty to the overall sample result. Wipe sampling material should conform to ASTM E1792-03(2016) to reduce variability.² Once surface sampling data are obtained, interpretation of the results can also be challenging. Neither NIOSH nor the Occupational Safety and Health Administration (OSHA) have established numerical criteria for surface contamination in the workplace. However, in their substance-specific lead standard, 29 CFR 1910.1025(h)(1), OSHA requires that all surfaces be maintained as free as practicable of accumulations of lead.^[17] Although the standard does not define “as free as practicable” a standard interpretation letter encourages employers to be vigilant in the effort to ensure that surfaces are kept free of accumulations of lead-containing dust so that they do not become sources of employee lead exposure.

This article: (1) describes surface sampling for lead in three workplaces; (2) discusses what additionally we learned about each facility by including wipe sampling in our sampling plan; (3) reviews the advantages and disadvantages of colorimetric (qualitative) and quantitative (laboratory analysis) surface wipe sampling methods; and (4) summarizes the challenges we faced in interpreting surface sampling results.

In this article, we present data only from surface wipe samples. Additional data beyond the scope of this manuscript can be found in the health hazard evaluation reports for each facility or in the NIOSH Health Hazard Evaluation Program Lead Measurement Database.^[21–23,25] If a comprehensive workplace exposure assessment is planned, surface sampling should be used alongside air, blood, or other sampling techniques for a more holistic determination of exposure risks.^[19] Blood lead levels are representative of individual dose regardless of the route of exposure. The blood lead level information we collected or reviewed at all three facilities aided us in making tailored recommendations to protect individual employees. Personal and area air samples helped to identify areas of highest airborne lead concentrations and the need to implement or to improve engineering and administrative controls, or to recommend appropriate types of PPE.

Methods

Surface sampling method

Experts recommend standardizing surface sampling techniques to optimize comparing results from different sampling events (see Table 1).^[1,9,18–20] One standardizing technique is using individually packaged, pre-moistened wipes that are free from contaminants.^[12] Other standardizing techniques include using a disposable template to define a specified surface sampling area and wearing a new pair of nitrile gloves to reduce cross contamination between sampling locations (e.g., NIOSH Method 9102). Having the same investigators perform the surface sampling across multiple sites may also help in standardizing how the surface sample is collected.

Table 1. Wipe sampling strategies for different methods for assessing lead on surfaces in occupational settings.

Method	Method description	Sampling strategy	
		Surface area	Wiping protocol
ASTM D6966-08	Standard practice for collection of settled dust samples using wipe sampling methods for subsequent determination of metals	Known area using a template	Two horizontal passes (at right angles to each other), using an “S” or “Z” wiping pattern over the surface, followed by one pass for just the edges and corners
NIOSH 9100	Lead in surface wipe samples	Known area using a template	Three or four “S” strokes to cover area (horizontal, vertical, and horizontal), using clean side of the wipe.
NIOSH 9102	Elements on wipes	Not mentioned	Three “S” strokes to cover area horizontal, vertical, and horizontal), using clean side of the wipe
NIOSH 9105	Lead in dust wipes by chemical spot test (colorimetric screening method)	Known area	Two passes using repeated horizontal and vertical strokes and using the same side of wipe.
OSHA ID-125G	Metal and metalloid particulates in workplace atmospheres (ICP analysis)	10 cm × 10 cm	Starting at the outside edge of the template, progress towards the center by making three concentric squares of decreasing size using clean side of wipe

For the three facilities discussed in this article, we used SKC Inc. Full Disclosure® colorimetric wipe sampling kits to evaluate the presence of lead on production and non-production surfaces (Method 9105).^[9] The method uses dilute (5%) acetic acid to solubilize lead compounds into lead ions. A sodium rhodizonate solution reacts with lead ions to produce a colorimetric change from yellow (the color of the rhodizonate solution) to pink or pinkish-purple in the presence of lead ions. The method has an estimated colorimetric limit of identification of 18 μg of lead per wipe ($\mu\text{g}/\text{wipe}$).^[10] We followed the surface sampling method outlined by NIOSH Method 9100 to collect the surface wipe samples. We used a 10 cm by 10 cm disposable template to demarcate the sample collection area, where possible. For small or irregularly shaped surfaces (i.e., doorknobs) we estimated 100 cm^2 of sample area or took a sample of the entire area or object. We donned a new pair of nitrile gloves to collect each sample. We performed three passes of “S” wiping strokes in horizontal, vertical, and then horizontal again using the same side of the wipe in every pass as recommended by the Full Disclosure manufacturer. Sampling on only one side may improve the limit of identification because the lead is concentrated on the same side of the wipe where the reagents are applied. We applied the chemicals after sampling as described in the Full Disclosure kit instructions and waited for a color change to occur.

After determining the presence or absence of lead with the colorimetric kit, we placed the wipes into labeled 50 mL polyethylene containers for shipment to the laboratory for analyses. Wipe samples were quantitatively analyzed using NIOSH Method 9102 in conjunction with NIOSH Method 7303.^[22] The wipes from the battery recycling facility and the firing range and gun store were only analyzed for lead. The wipes from the electronic scrap recycling facility were analyzed for lead, cadmium, chromium, and nickel; but only lead results are included in this article.

Facility 1: Battery recycling (secondary lead smelter)

NIOSH investigators performed a health hazard evaluation at a lead-acid automotive battery recycling and secondary lead smelter because employees were concerned about workplace lead exposures and take-home lead.^[23] The presence of lead in workers’ vehicles and homes had already been identified by other government agencies, and decontamination activities at these locations were ongoing. Additionally, children and relatives of some company employees had been found to have elevated blood lead levels thought to be a result of take-home lead from the

facility.^[24] At the time of our evaluation, the company employed 106 workers.

We used surface wipe sampling for lead to identify areas of the facility that could contribute to take-home exposure, to evaluate housekeeping practices, and to educate and train facility employees and managers on the importance of exposure controls. We collected samples in non-production areas such as the “dirty” locker room where employees doffed soiled work uniforms and stored PPE, a shower room where employees were required to shower with soap and warm water, and the “clean” locker room where employees put on street clothes before leaving the facility at the end of the shift. We also sampled lunch room tables and office surfaces.

For the qualitative results from the wipe sampling activities at Facility 1, we classified the color change of the wipe samples as (–) indicating no observable color change; (+) indicating a slight color change; and (++) indicating more of a color change.

Facility 2: Firing range and gun store

NIOSH investigators performed a health hazard evaluation at a firing range and gun store.^[25] Employees reported being diagnosed with lead poisoning and being medically removed from the workplace by an occupational physician. The store, with five full-time and one part time employee, had two separate firing ranges (each with six firing lanes) and an adjoining gun store. Employees spent most of their work day in the gun store or in an adjoining office, but periodically entered the ranges to assist shooters or to supervise league shooting. On a daily basis, employees vacuumed the carpeted areas in the gun store and firing ranges, collected spent bullet casings in the ranges, and wiped the sales counter in the store. Once per week employees deep-cleaned the firing range, a process that included removing and replacing air filters from the building’s exhaust ventilation units; scraping, sweeping, and cleaning dust and oil from the bullet trap; applying fresh oil to the bullet trap; and vacuuming the floors inside the range. Each range had a single-pass ventilation system that was separate from the ventilation system for the gun store. However, openings in a wall above the suspended ceiling allowed potentially lead-contaminated air from the ranges to migrate into the gun store and office.

We collected surface wipe samples to characterize the levels of lead throughout the facility, to evaluate the role of ventilation design in distributing lead, and to determine effectiveness of housekeeping and administrative controls. We collected additional colorimetric wipe samples to demonstrate to employees the ways in which they

could have dermal contamination and how this might lead to accidentally taking lead home on clothing or skin.

Facility 3: Electronic scrap recycling

NIOSH investigators performed a health hazard evaluation at an electronic scrap recycling facility because of employee health concerns about lead and cadmium exposures.^[22] At the time of our evaluation the recycling plant had 80 employees. The facility processed a wide variety of electronic components including computers, monitors, hard drives, televisions, printers, light bulbs, and other electronic scrap. Recycling employees shipped, sorted, tested, and refurbished electronic scrap for reuse or resale. Electronic scrap that could not be reused or resold was dismantled and shredded. We collected samples in production areas to confirm the presence of specific metals in the waste stream and in non-production areas such as break rooms, locker rooms, and offices to characterize lead migration to determine effectiveness of controls.

Results

Facility 1: Battery recycling (secondary lead smelter)

Lead was present on all non-production area surfaces that we tested, although at levels below those measured in the production areas (Tables 2 and 3). The lowest surface lead levels were in the employee lunchroom and shuttle bus that transported employees from the facility to their personal vehicles; both locations were cleaned at least daily. We found lead on the interior surfaces of the filtering facepiece respirators, supporting our observations of respirators being improperly stored and cleaned. Surface lead levels decreased from the “dirty side” locker room/uniform doffing area (geometric mean (GM): 317 micrograms per 100 cm² (317 μg/100 cm²)), to the shower area (GM: 200 μg/100 cm²), and finally to the “clean side” locker room (GM: 16 μg/100 cm²). We found lead levels on the soles of sandals (GM: 455 μg/100 cm²) that employees wore through the shower area and into the clean locker room.

Table 2. Surface wipe sample results on work surfaces for lead at facility 1 (site visit 1).

Location	Lead detected with laboratory analysis (μg/100 cm ²)	Lead detected with Full Disclosure® [Visual classification]
Production and changing/shower/locker room surfaces		
Sole of employee's boot after washing	23,000	Yes [+++]
Sole of employee 2's sandal after he exited the shower	540	Yes [+++]
Floor of dirty changing area in front of bench	480	Yes [+++]
Sole of sandal at exit of the dirty locker room	470	Yes [+++]
Bubbler of water fountain to left of hand punch machine	430	Yes [++]
Hand punch machine used at beginning and end of shift	420	Yes [+++]
Sole of employee 1's sandal after he exited the shower	370	Yes [+++]
Hand punch machine used before lunch	330	Yes [+++]
Tile floor of area after the shower room before gate	280	Yes [+++]
Tile floor of area after the shower room after gate	240	Yes [+++]
Floor mat next to entry door in clean locker room	180	Yes [+++]
Laundry room floor in front of washing machine	86	Yes [++]
Laundered uniform pants on table lunch	85	Yes [++]
Floor of dirty changing area where towels are picked up	63	Yes [++]
Laundry room shelf where laundered clothes are folded	17	No [-]
Floor of randomly-selected locker #9	5.5	No [-]
Non-Production surfaces		
Air exhaust from dryer	25,000	Yes [+++]
Floor next to shoe vacuum near conference room	5,200	Yes [+++]
Inside full facepiece respirator 3 at the end of shift	330	Yes [+++]
Hallway floor between offices	150	Yes [+++]
Inside full facepiece respirator 2 at the end of shift	130	Yes [++]
Inside full facepiece respirator 1 at the end of shift	110	Yes [++]
Floor adjacent to the mat at the entrance	100	Yes [++]
Laboratory floor	92	Yes [++]
Lobby floor after the front entrance door	56	Yes [++]
Lobby floor in front of administrative window	55	Yes [++]
Floor under desk in administrator's office	54	Yes [++]
Floor of the far aisle	48	Yes [++]
Floor after mat at entrance in the employee lunch room	46	Yes [++]
Lunch room table	19	No [-]
Handle of microwave in the employee lunch room	12	No [-]
Floor in front of women's shower	9	No [-]
Conference room table	4.2	No [-]
Surface of center table in employee lunch room	1.6	No [-]
Limit of detection (μg)	0.4	~18

Table 3. Surface wipe sample results on work surfaces for lead at facility 1 (site visit 2).

Location	Lead detected with laboratory analysis ($\mu\text{g}/100\text{ cm}^2$)	Lead detected with Full Disclosure [®] (Visual classification)
Production and changing/shower/locker room surfaces		
Changing area before dirty locker room	600	Yes [+++]
Dirty locker room in front of towel pick-up window	560	Yes [+++]
Floor after shower clean clothing pick-up room	240	Yes [++]
On sticky mat in clean locker room	130	Yes [++]
Shower room in front of shower	100	Yes [++]
Floor of clean locker room in front of #88	35	No [-]
In front of sticky mat in clean locker room	31	Yes [++]
Inside locker #49	2.8	No [-]
Inside locker #9 (not in use)	2.6	No [-]
Non-Production surfaces		
Storage room, former shoe vacuum location	730	Yes [+++]
Hall in front of office	130	Yes [++]
Lobby in front of admin window	71	Yes [++]
Lobby in front of main entrance door	65	Yes [++]
Employee lunch room in front of sticky mat	21	Yes [++]
In front of women's shower	19	No [-]
Shuttle bus paper on middle of floor, aisle	16	No [-]
Shuttle bus on floor seat 4, right side	12	No [-]
Shuttle bus on floor seat 2, left side	11	No [-]
Admin building lunch table	9.8	No [-]
Shuttle bus on seat 4, right side	4.6	No [-]
Shuttle bus on seat 1 back, left side	4.3	No [-]
Shuttle bus on seat 2, left side	2.9	No [-]
Lunch room table top	0.93	No [-]
Limit of detection (μg)	0.4	~18

Table 4 shows results of descriptive statistics for the 57 wipe samples classified as (-), (+), or (++). Eighteen of the 19 (95%) colorimetric surface wipes that were classified as (-) returned quantitative results at or below 18 μg per wipe. The GM lead loading for the 19 samples classified as (-) was 7 $\mu\text{g}/100\text{ cm}^2$ (range: 0.9–35 $\mu\text{g}/100\text{ cm}^2$; geometric standard deviation: 2.6). The 21 surface wipes that were classified as (+) returned a GM lead loading of 81 $\mu\text{g}/100\text{ cm}^2$ (range: 21–430 μg ; geometric standard deviation: 1.9). The 17 surface wipes that were classified as (++) returned a GM lead loading of 709 $\mu\text{g}/100\text{ cm}^2$ (range: 150–25,000 $\mu\text{g}/100\text{ cm}^2$; geometric standard deviation: 4.6). To determine if there is a relationship between the qualitative colorimetric determination and the quantitative lead level, we transformed each sample's lead level result by taking the natural log and performed an ANOVA test. We found there to be a significant difference between the average log (lead level) for the three colorimetric groups ($F(2,54) = 83.5638$, $p\text{-value} < 0.0001$). Using Fisher's least significant differences for all pairwise comparisons, we found that the mean log (lead level) for each colorimetric group is

Table 4. Descriptive statistics for surface wipe samples collected at facility 1.

Visual Classification	n	GM [$\mu\text{g}/100\text{ cm}^2$] (Geometric SD)	Median [$\mu\text{g}/100\text{ cm}^2$] (Interquartile Range)	Range [$\mu\text{g}/100\text{ cm}^2$]
-	19	7 (2.6)	9 (13.1)	0.9–35
+	21	81 (1.9)	85 (65.5)	21–430
++	17	709 (4.6)	470 (360)	150–25,000

different, with (++) having the largest log (lead level) on average and (-) having the lowest log (lead level) on average.

Facility 2: Firing range and gun store

We detected lead on surfaces throughout the facility and on employees' shoes as they prepared to leave work (Table 5). We found lead on the handle of a coffee pot, on the sink in the employee break room, all three air supply diffusers in the showroom, and on the return air intake for the showroom. Wipe samples on all air supply diffusers and return air grilles confirmed distribution of contaminated air from the ranges into the rest of the building.

Facility 3: Electronic scrap recycling

Lead was present on production surfaces and non-production surfaces (Table 6). Most non-production surfaces had lower lead levels (less than 10 $\mu\text{g}/100\text{ cm}^2$) than the production areas; the highest levels we found were from a location close to the PPE room. The PPE room had employee lockers where both clean and dirty PPE were stored. The electronic scrap recycling facility had many metals including cadmium, chromium, nickel, and tin as well as lead (results for metals other than lead are not presented in this article).^[22] Interestingly, none of the colorimetric wipes exhibited a conclusive color change even in the presence of lead above 18 $\mu\text{g}/\text{wipe}$, a finding thought to be the result of the presence of interfering metals such as tin.

Table 5. Surface wipe sample results on work surfaces for lead at facility 2.

Location	Lead detected with laboratory analysis ($\mu\text{g}/100\text{ cm}^2$)	Lead detected with Full Disclosure (yes/no)
Prior to employee arrival		
Air intake by purchasing counter*	1,900	Yes
Cashier keyboard*	130	Yes
Counter above where targets are stored	32	Yes
Long gun purchase counter	5.1	No
Purchasing counter	4.2	No
Rental counter	4.2	No
Clean towel after arrival from laundry	1.8	No
After employee arrival		
Office, air intake grill*	6,600	Yes
Carpet outside of range B	400	Yes
Classroom, counter next to water fountain	310	Yes
Women's customer restroom sink*	130	Yes
Door handle to range A*	92	Yes
Handle of doorknob to women's restroom*	79	Yes
Carpet in front of the entrance	74	Yes
Break room table	72	Yes
Ceiling tile near range*	46	Yes
Break room table, after cleaning with D-Lead	27	Yes
Door handle to range A after Hygenall®*†	14	No
Office, owner's computer keyboard*	14	Yes
Limit of detection (μg)	0.4	~18

*Estimated area 100 cm²

†Hygenall wipes were used to decontaminate the surface. Hygenall wipes are specifically designed to remove lead from surfaces and skin.

Table 6. Lead surface wipe sample results on production and non-production surfaces at facility 3.

Location	Lead detected with laboratory analysis ($\mu\text{g}/100\text{ cm}^2$)	Lead detected with Full Disclosure® (yes/no)*
Production surfaces		
Shredding room scaffolding	6400	No
Forklift foreface	1400	No
Table near bailer in tear down area	150	No
Computer station glass break	130	No
Non-production surfaces		
Locker PPE room	18	No
Bench locker room	9.0	No
Lunch table near PPE room	5.3	No
Microwave	4.0	No
Lunch table near window	3.4	No
Desk office 2	3.2	No
Lobby coffee table	2.6	No
Table in conference room	2.5	No
Desk office 1	1.8	No
Receptionist's desk	0.58	No
Limit of detection	0.3	~18

* Negative results are believed to result from the presence of interfering elements

Discussion

Advantages of including surface wipe sampling in a sampling plan

Because we detected lead on non-production surfaces (i.e., water fountains, coffee pots, inside of respirators, etc.) and in employee's personal lockers, we were able to demonstrate that oral and dermal exposure routes existed. We determined that all three facilities could improve their lead control programs (i.e., reducing lead releases during production) and their housekeeping programs (i.e., using cleaning products in non-production areas proven to remove lead). We were also able to tailor recommendations to reduce the potential for taking home lead, such as redesigning the pathway from the dirty to clean locker room at facility 1 or providing uniforms and/or washing them at facilities 2 and 3.

Advantages and disadvantages of colorimetric (qualitative) surface wipe sampling for lead

The advantages and disadvantages of qualitative and quantitative surface wipe sampling methods are summarized in Table 7. One advantage of colorimetric sampling for lead is that it provides immediate results. Therefore, it can be used to evaluate lead control practices and programs, for example by demonstrating whether surfaces have been properly cleaned. However, one disadvantage is that a color change is subject to an individual's ability to detect differences in color. In contrast, quantitative results provide an objective assessment of lead levels and can be particularly useful when several metals are present or when a lower limit of detection (0.4 $\mu\text{g}/\text{wipe}$) than that provided by the colorimetric method (18 $\mu\text{g}/\text{wipe}$) is required. However, results can take days to obtain from a laboratory.

At facilities 1 and 2, we used the colorimetric method to educate employees on how lead may be tracked through the facility and how it could be taken home to their family members.^[31] At facility 1, due to the large number of wipe samples collected, we classified the visual sample results by the intensity of the color change. This classification helped NIOSH investigators and managers from the facility identify the areas with the highest surface lead burden and prioritize the recommended work practices changes, including improved administrative controls and cleaning practices. A review of the data in Tables 2, 3, and 5 shows the ability of the colorimetric method to predict whether the quantitative results are above or below the test's limit of detection (LOD) of approximately 18 $\mu\text{g}/\text{wipe}$. Using the wipe sample data from facilities 1 and 2, we performed a Pearson's chi-square test for independence to statistically

Table 7. Comparing colorimetric and quantitative wipe surface sampling methods for lead.

Characteristic	Colorimetric results	Quantitative results
Sensitivity	Positive (>18 µg lead) turns from yellow/orange to red/pink	Depends on laboratory (lead limit of detection often <0.5 µg)
Range	Positive/negative (+/-) or color scale (e.g., ++, +, -)	Depends on the metal and laboratory (often from detection limit up to 10,000 µg)
Instrument needs	Colorimetric wipe kit commercially available (Full Disclosure)	Inductively coupled argon plasma, atomic emission spectroscopy (ICP-AES)
Time required for analysis	1–3 min	Approximately 1 week, depending on laboratory
Main advantages	<ul style="list-style-type: none"> • Instantaneous results • Positive results are easy to interpret • Wipes can be used as an education tool in the field • Little training required • No shipping or analysis costs unless laboratory confirmation is desired 	<ul style="list-style-type: none"> • Objective results that are not subjective to the reader • Can provide information for different metals and minerals • Numeric results can be compared to any existent surface sampling guideline (e.g., HUD) • Low cost associated with materials (i.e., wipe and collection bottle)
Main disadvantages	<ul style="list-style-type: none"> • Best for surfaces with high levels of lead • Color scoring is subjective to the reader and lighting when assessing color • Potential for false positives/negatives — Other metals and minerals can interfere with the color reading, especially tin • Sample color may degrade so color assessment should be done immediately after color develops, photos can be taken for documentation 	<ul style="list-style-type: none"> • Specialized and certified laboratory are ideally needed for analysis • Interpretation of results may require of an expert professional • More costs and time involved with shipping and analysis

HUD = Department of Housing and Urban Development

determine if the visual determination of the presence of lead (i.e., yes or no) is related to quantitative analytical results above or below the LOD (i.e., ≥ 18 or <18 µg/wipe). Pearson's chi-squared test for independence shows that the visual and analytical results were statistically related ($\chi^2(1) = 58.469$, p-value <0.0001).

At facility 3 the colorimetric method for lead unexpectedly did not prove useful. We suspect that the presence of interfering metals (especially tin) and other elements on the surfaces evaluated caused the colorimetric wipes to have a yellow or orange color and not red. A red color change should have occurred because subsequent quantitative analysis of the wipes found lead at levels above 18 µg per wipe. The colorimetric method is based on the ability of a weak acid (acetic acid) to dissolve lead oxides from surface contaminants, forming lead ions that react with the rhodizonate solution to create the red color. If the acid is not able to dissolve the lead compound (lead chromates for example) then a colorimetric reaction will not occur (a false negative) independent of the quantity of lead in the sample. The laboratory-based method uses a stronger acid to solubilize the lead which results in a much lower limit of detection and higher recovery rate. According to the operating instructions included in the Full Disclosure kit, silver, cadmium, mercury, barium, tin, and titanium can cause an unexpected color change from the typical pinkish-purple color associated with lead. Silver, titanium, and mercury will cause a red to hot-pink color change, and cadmium and barium would cause a colorimetric reaction similar to that of lead, but only at higher concentrations. Tin is known to cause a strong negative interference, meaning its presence inhibits any color change even while lead is present.

Challenges interpreting surface wipe sampling data and possible solutions

In the absence of a quantitative limit for lead levels on workplace surfaces, interpreting positive results can be challenging. The simplest interpretation is to use a pass/fail approach where wipe samples are only collected in areas that should not have lead on them. This method can be an inexpensive and rapid means to evaluate the potential for take-home lead.^[23]

Another use of wipe sampling results is to assess lead migration from production to non-production areas. For example, by looking at decreasing lead levels, we could evaluate employee cleaning practices and determine how lead was getting to non-production areas.

Lastly, although neither OSHA nor NIOSH have developed consensus standards on interpreting surface wipe data, the United States Environmental Protection Agency and the United States Department of Housing and Urban Development have developed risk assessment and clearance criteria for lead on bare and carpeted interior floors in public buildings and child-occupied housing.^[27,28] In addition, many companies develop internal standards for surface limits. For example, Brookhaven National Laboratories has developed housekeeping and equipment release surface exposure limits for cadmium, trivalent chromium, hexavalent chromium, cobalt, lead, manganese, nickel, and silver.^[6] Additional guidelines to develop a sampling plan appropriate for surface sampling of metals in the workplace are outlined in the ASTM Method D7659-10 "Standard Guide for Strategies for Surface Sampling of Metals and Metalloids for Worker Protection."^[19]

One limitation of the exposure evaluations in these three facilities is that we collected surface wipe samples from porous surfaces (e.g., carpets and clothing). For porous and/or irregular surfaces vacuum methods are generally preferred.^[16,29,30] Because we used traditional surface wipes, we do not know how reliable or reproducible the results might be. Other limitations are variations in wipe sampling procedures and investigators. In these three facilities we used the same wipe sampling media and method, but sampling was done by different investigators.

Conclusion

In these facilities surface wipe sampling demonstrated that lead was migrating from production to non-production areas. Either colorimetric or quantitative surface wipe sampling for lead (or both) can be used, especially in conjunction with a sampling strategy that includes biological monitoring and personal and area air samples. On the basis of these evaluations, we conclude that colorimetric sampling is best when lead is the primary metal present, and no potentially interfering metals are suspected or known. Colorimetric sampling is also best for situations where a “yes/no” is all that is needed to make decisions. Regardless of whether qualitative or quantitative surface wipe sampling is done, interpreting sampling results in the absence of consensus standards remains a challenge. We encourage investigators to clearly define their sampling objectives ahead of time and follow standardized methods such as those outlined in Table 1.

Sampling in non-production areas provided information to determine the effectiveness of engineering and administrative controls and employee work practices to prevent lead migration throughout the facility or to workers' homes. It also helped to identify sources for lead ingestion or re-aerosolization. Because a variety of surface sampling strategies can be employed, it is also important to be as consistent as possible with sampling techniques and materials to facilitate comparison of results between locations when such a comparison is necessary.

Key lessons learned from wipe sampling:

- Wipe sampling can demonstrate oral and dermal exposure routes and can be used to assess lead migration from production to non-production areas by looking at decreasing lead levels.
- Colorimetric sampling can be used to evaluate lead control programs and to educate employees on how lead may be tracked through the facility, and possibly taken home to their family members.
- The intensity of the color change on colorimetric wipes can identify areas with the highest surface lead

burden and aide in the prioritization of work practice changes.

- The colorimetric method did not prove useful for mixed-metal environments, especially those with tin.

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Disclaimer

The findings and conclusion in this article are those of the author(s) and do not necessarily represent the official position of NIOSH policy. Mention of trade names and/or commercial products does not constitute endorsements or recommendations for use. The authors have no known conflicts of interest in conducting and reporting this research.

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