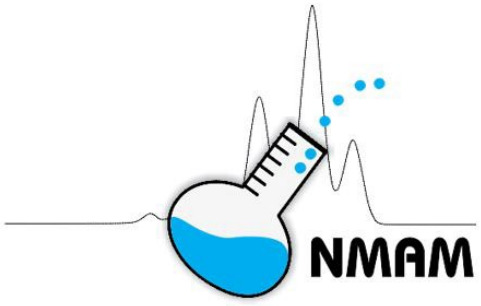

NIOSH Manual of Analytical Methods (NMAM), 5th Edition

Surface Sampling Guidance, Considerations, and Methods in Occupational Hygiene

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1 Introduction

Work surfaces can become contaminated with chemical, biological, or radiological agents in different circumstances: during typical and emergency work activities, after accidental or intentional agent release and dispersal, or during naturally occurring processes. Skin (dermal) contact with contaminated surfaces has been recognized as an occupational exposure route resulting in dermal absorption and/or accidental ingestion [Boeniger 2003; Cherrie et al. 2006; EPA 1995b, 2008; Ness 1994]. Surfaces can be sampled to assess these exposures or the potential for them. In fact, surface sampling followed with analysis is now widely used to evaluate contamination levels in workplaces [ASTM 2011b]. The data collected from surface and dermal sampling can be used when designing and evaluating mitigation and prevention strategies and can complement workplace air monitoring and other types of exposure assessments.

Analytes of interest can often be sampled and analyzed using more than one method [Ashley et al. 2011; Lichtenwalner 1992; McArthur 1992; Ness 1994]. Consistency in sampling and analyzing surface agents in occupational settings can be achieved by standardizing methods. Standardization allows for reliable and high-quality comparisons of analytical results from samples collected across different investigators, locations or surfaces, times, and sampling methods. Because sample collection is usually responsible for the greatest measurement uncertainty in sampling and analysis, developing and using standardized sampling methods should be a priority. Some standardized methods for surface sampling have already been developed, validated, and published. However, for substances that do not have such methods, careful planning, consideration, and documentation of the sampling strategies and methods used is necessary for high data quality and reliability.

This chapter provides information that will (1) aid in the selection of collection methods (e.g., surface sampling medium, wetting agent, and sampling technique), sample locations, and number of samples; and (2) describe available resources for these decisions (e.g., standardized methods, consensus standards, and regulations and their accompanying guidance).

While we focus on surface and dermal sample collection and analyses here, other evaluation techniques, such as using direct reading instruments (e.g., X-ray fluorescence, chemical spot tests), also apply.

2 Rationale for surface sampling

Surface sampling data can provide important information about surface contamination, or lack thereof, in workplaces. Understanding and defining the purpose for collecting surface samples

before making a decision to take the samples or creating a sampling strategy are critical. The purposes and objectives for the surface sampling dictate several aspects of the sampling plan, such as the collection method, location, sample number, and analytical method. Primary objectives should include that the surface sampling data collected be defensible and meet the preestablished goals.

The sampling strategy, which includes number, location, and method, will define how the data can be used. Therefore, these should be decided and thoroughly documented before sampling begins. Make sure the sample collection and analysis methods will meet the data quality objectives and performance requirements for the selected goals. Other concerns are the potential location and temporal variability in surface contamination. The change in contamination levels over time, or temporal variability, is related (1) to when and how the contaminating process happens and (2) to exposure controls such as containment or cleaning. These impact whether the collected samples accurately represent the contamination and partially dictate where samples should be taken (e.g., select locations likely to be highly contaminated). Collecting enough samples and using sampling areas of adequate size are required for defensible and useful data that meet the sampling strategy objectives.

Some purposes for surface sampling in occupational settings are outlined in ASTM D7659-21 *Standard Guide for Strategies for Surface Sampling of Metals and Metalloids for Worker Protection* and summarized here [2021b]:

- *Hazard identification* – To identify and quantify analyte(s) of interest in the workplace. This information is used to evaluate risk, to develop and recommend worker protection requirements, and to assess the probability of adverse health effects.
- *Source and exposure pathway identification* – To determine the process or origin that contribute to the presence of the analyte(s) of interest, the fraction of emission coming from each source, and how workers may be exposed during these processes. Exposure pathway identification may also look at if contaminants migrate into workers' vehicles or homes [NIOSH 1995].
- *Exposure assessment* – To measure or evaluate potential exposure when a health hazard is known or suspected to be present. Assessment may be conducted for similar exposure groups (workers in the same location or in the same role with similar exposure potential). Select, whenever possible, instrumentation and methods that offer the lowest available analytical reporting limits for the analyte that is undergoing assessment. The reporting limit should be below any regulatory limit for a particular agent or level that can lead to adverse health outcomes, if that level is known.

- *Site characterization* – To find the surface contamination levels within a facility at an initial or baseline point, during or after process or engineering controls operations, or as part of facility decommissioning.
- *Selection of exposure controls* – To determine which exposure controls (engineering, administrative, personal protective equipment) should be used and how efficient collection or capture control devices need to be to reduce or eliminate deposition or to remove material that has already been deposited.
- *Evaluation of controls, including housekeeping* – To measure the efficiency of exposure controls, amount of the analyte(s) of interest passing or escaping from an exposure control, and to help identify the reason (e.g., poor design, leaks, wear, damage, inadequate maintenance, overloading, or accidents). Surface sampling before and after housekeeping or decontamination can be used evaluate the cleaning methods or materials.
- *Compliance with regulations and standards* – To satisfy regulatory or legal requirements and determine if exposures and/or contaminant surface concentrations in the workplace are below regulatory or guidance limits.
- *Education and training* – To educate workers and managers in the importance of the hierarchy of controls, which includes elimination and substitution, engineering controls, and administrative (e.g., training, policy and procedures, housekeeping, and good work practices) controls and personal protective equipment.
- *Complaint or concern investigation* – To look into concerns of workers, management, regulatory agencies, or other interested parties.

Results from surface sampling and analysis should not be used to the exclusion of other information concerning potential chemical, radiological, and biological hazards; rather, surface sampling data should be used to augment data from other sources of contamination or exposure. For instance, additional sources of exposure information may include occupational air sampling, bioassay and biomonitoring results, clinical observations, quality and process control data, records of facility operations, visual inspections, and material balance studies. Different types of samples can be paired together to increase sampling strategy efficiency. For example, direct reading qualitative and semi-quantitative colorimetric methods using wipes, or swabs and a reagent such as those for lead (Pb) (NIOSH 9105) and hexavalent chromium [Cr(VI)] (NIOSH 9101) can be used alone. However, they can also be used for on-site screening, to discern where surface samples for subsequent quantitative analysis should be collected. Direct reading screening methods exist for methamphetamine and fentanyl on surfaces and can be carried out using colorimetry and/or immunochemical assay techniques [Angelini et al. 2019; Snawder et al. 2011]. These techniques (Table 1) can be used to complement surface wipe measurement methods for methamphetamines.

Consider these technical factors and variables when sampling a surface for any contaminant [adapted from Connor et al. 2016]:

Location and sample surface(s) considerations:

- Design and layout of area to be sampled
- Locations that are to be sampled relative to process and work
- Nature of surface to be sampled (e.g., surface texture, loading, shape)
- Surface size(s) and area(s) to sample
- Chemicals in use at site(s) that could be present
- Loading/contamination level: trace, highly contaminated, variability across surface, etc.

Sampling process considerations:

- Type and material of sampler to be used
- Validated sampling and analytical methods used
- Recovery efficiency from surface with given sampling method (typically unknown, unless trials are conducted or efficiencies have been published)
- Wetting agent to maximize recovery efficiency
- Exposure controls for investigators conducting sampling

Analytical considerations:

- Number of samples to be taken
- Presence and identification of possible interferences
- Chemistry (e.g., polarity, pH) of extraction solvent
- Dynamic range of analytical method: accuracy at low, medium, and high levels of analyte
- Extraction efficiency from surface sampling media
- Compatibility of extraction solution with analytical reagents
- Properties of the analytes
- Stability of analyte in extraction solvent/sampling medium or media
- Limits of detection and quantitation for analyte

One should also consider the history of the surface being sampled, for instance, the time and duration of its last use, any contaminating process, and the time and method of its last cleaning. The analyte's possible origins should also be considered and documented beforehand. This information can be used to determine the timing and technique for sampling the surface, relative to any contaminating processes and housekeeping activities. It can be helpful to understand this history during data interpretation.

Table 1. NIOSH methods for sample collection from surfaces in workplaces and related environments*

Method No.	Sampling Media/Substrate	Target Analyte(s)	Comments
NIOSH 9100	Wetted wipe	Pb	Harmonized with ASTM E1728; subsequent analysis by atomic spectrometry or electroanalysis
NIOSH 9101	Settled dust sample	Cr(VI)	Qualitative colorimetric screening method using diphenylcarbazide
NIOSH 9102	Wetted wipe	Elements	Harmonized with ASTM D6966; subsequent analysis by atomic spectrometry
NIOSH 9105	Wetted wipe	Pb	Qualitative colorimetric screening method using rhodizonate
NIOSH 9106	Solvent-wetted wipe	Methamphetamine and related drugs and compounds	Harmonized with ASTM D6661; liquid-liquid extraction sample preparation followed by gas chromatography-mass spectrometric analysis
NIOSH 9109	Solvent-wetted wipe	Methamphetamine and related drugs and compounds	Harmonized with ASTM D6661; solid-phase extraction sample preparation followed by gas chromatography-mass spectrometric analysis
NIOSH 9110	Wetted wipe	Be	Harmonized with ASTM D7202; subsequent analysis by molecular fluorescence
NIOSH 9111	Solvent-wetted wipe	Methamphetamine	Harmonized with ASTM D6661; desorption using sulfuric acid followed by liquid chromatography-mass spectrometric analysis

*Methods available at www.cdc.gov/niosh/nmam. Pb = lead; Be = beryllium; Cr(VI) = hexavalent chromium

3 Collection methods

Sample collection methods include the sample medium and technique appropriate for use based on the physical nature of surface to be sampled. The following materials, qualities, or conditions are

examples of what to consider to better understand representative surfaces, contamination types and amount, and sample media that are of interest for surface (including dermal) sampling [Ashley et al. 2011]:

- Physical nature of surfaces
  - Hard or soft
  - Smooth or rough
  - Porous or nonporous
  - Fragile or durable substrates
- Cleanliness of surfaces
  - Oily or coated surfaces
  - Grossly contaminated surfaces
- Skin (exposed and/or protected)
- Clothing and personal protective equipment
- Bulk materials, for example, soils, deposited dusts, spilled materials

Available sample media can be made from a variety of materials (e.g., polyvinyl alcohol, quartz fiber, mixed cellulose ester, polycarbonate membrane, cellulose sponge, continuous filament cloth, macrofoam sponge, polyurethane foam) and come in several formats, such as dry or wetted wipes, swabs, and filters. When vacuum sampling, a container or a filter is needed. Sampling can also be done using rinses, typically for dermal sampling, or adhesive tapes. Collecting multiple analytes can require distinct media or sample preparation for each analyte or class of analyte and, thus, need multiple, nonoverlapping surface samples.

a. Collection efficiency

Understanding measurement accuracy, variability, and sample collection efficiency is fundamental when collecting surface samples. Collection efficiency is the amount of analyte collected and measured from a surface material divided by the total amount deposited on the area sampled. It is reported as a percentage, so the result is multiplied by 100. Together, sample medium, wetting agent, and collection technique will affect collection efficiency and the analytical/quantitative results. Collection efficiency can also be affected by the degree to which a contaminant is physically or chemically bound to the surface being sampled.

Collection efficiency differs from sampler extraction efficiency. Sampler extraction efficiency is the fraction of total analyte recovered from the sampling media and measured during analysis. It is determined using analyte deposited directly on the sampling media. Collection efficiency can be characterized through experiments prior to sampling. When available, characterization can be found through literature reviews about the target analyte, sampling

surface characteristics (e.g., porosity, material) and sampling data, and sampling method. OSHA describes one method of characterizing collection efficiency that entails sampling a smooth and nonporous surface deposited with a known amount of analyte [OSHA 2000]. OSHA suggests that a collection efficiency of below 50% for a method on an ideal surface would be insufficient and an alternative wetting agent or sampling medium should then be evaluated [OSHA 2000]. ASTM established a minimum of 75% collection efficiency for wipe sampling materials for Pb and beryllium (Be) in surface dust [ASTM 2020, 2021c].

The collection efficiency for a specific collection method can be impacted by surface conditions as well as the manner the contaminant deposited on the surface (e.g., settling, impaction, static forces). Ideally, sampling collection efficiencies should be characterized using the same physical form as the material present on workplace surfaces. For example, when conducting collection efficiency experiments, analytes of interest may need to be deposited on a surface in a manner similar to workplace conditions rather than using a liquid spike of the analyte. Collection efficiencies are included in some published surface sampling methods or in research cited in the method [ASTM 2017a,b, 2018a,b, 2020, 2021c; Dufay and Archuleta 2006; EPA 1995b; ISO 2011; Millson et al. 1994; NIOSH 2003, 2011a,b; Roberts et al. 1991; Wheeler and Stancliffe 1998]. The collection efficiency depends on several factors, such as the collection method, surface type, and surface condition (e.g., cleanliness, temperatures, skin). Collection efficiencies from surfaces for the agent and sampling method should be evaluated and documented, along with results, absent previously reported research or methods for the employed collection method (sampling media, wetting agent, sampling technique) and surface type.

Sequential or serial sampling—taking and analyzing multiple samples of a templated area or hands—can be an option to increase collection from a surface, particularly if the amount of contaminant (or debris) on the surface is high. However, limited research evaluating or characterizing serial sampling is available. Some work has evaluated recovery from dermal surfaces using multiple wipes [Beaucham et al. 2019; Boeniger 2006]. Thus far, this practice has not been included in many standard and reference surface sampling methods, while others (e.g., NIOSH 9106, NIOSH 9212, ASTM D6661-17) allow its use with appropriate documentation and/or for specific purposes, such as estimating residual contamination at regular sampling [ASTM 2017b; NIOSH 2011a].

b. Sampling with wet or dry media

Wetting sampling media often improves collection efficiency and should be considered and evaluated for appropriateness [Ashley et al. 2009]. Wipes can be wetted with a variety of

liquids (e.g., deionized/distilled water, ascorbic acid, phosphate buffers, alcohols, or organic solvents). Sampling methods for elements (metals and metalloids) normally entail the use of wipes wetted with water, whereas surface wipe sampling for methamphetamine and related compounds uses wipes dosed with solvents such as methanol or isopropanol (2-propanol). While wetting agents may be chosen to increase the absorptive capacity of the media for a particular media relative to dry media, their desorptive properties (i.e., the ability to remove the agent from the media for analysis) vary [Venables and Schmuttenmaer 2000]. Review available literature and method documentation before selecting sampling media and deciding whether it will be used wet or dry, and with which wetting agent.

A hierarchy of sample collection methods is generally referred to when choosing surface sampling media for metals [ASTM 2021b]. First, consider wetted wipe sampling, particularly if collecting material from smooth, hard, nonporous, and nonelectrified substrates. As an example, wipe sampling has been shown to be an effective means for assessing aerosol deposition in occupational settings [Nygren 2006]. Sometimes wetted wipe sampling may not be desirable, and dry sample collection techniques are required. For example, when surface materials or components must be protected against potential damage from the wetting agents or when the wetting agents may cause the contaminant to migrate into a porous or complex surfaces (e.g., wood, concrete, carpet). In these situations, less aggressive methods (such as nondrying or noncorrosive) or methods more compatible with the substrate being sampled are sometimes called for. These can include mild vacuuming, tape lifting, rinsing methods, or the use of dry swabs. For example, museum artifacts preserved using mercury or arsenic should be sampled with methods that preserve the surface's integrity [Makos 2001; Sirois 2001].

When sampling surfaces quantitatively as a surrogate for possible exposure, the sample collection method should not degrade the sample surface in a way that contributes to an inaccurate overestimation of analyte available on the surface. For samples that undergo microscopy, dry collection methods such as tape lifting would often be appropriate. Select dermal surface sampling methods (i.e., medium, wetting agent, and technique) that minimize irritation, damage, and other health effects and prevent the contaminant or wetting agent from migrating across the dermal barrier [ASTM 2011b; ISO 2011; Ness 1994]. For example, to sample polycyclic aromatic hydrocarbons (PAHs) on skin, one might use corn or sunflower oil rather than hexane [Fent et al. 2014; Fent et al. 2017; OSHA 2000; Väänänen et al. 2005].

Collection efficiencies using wetted wipes for collecting lead oxide dust from smooth, hard surfaces, have been evaluated and exceed 75% [Chavalitnitikul and Levin 1984; EPA 1995b]. In related work, a comparison of wet vs. dry sampling was performed on hard, smooth

surfaces spiked with Be [Dufay and Archuleta 2006]. They found that wetted wipe sampling usually results in a much higher collection efficiency (64%–106%) than does sample collection using dry wipes (14%–43%). In earlier studies, a comparison of wipe sampling methods for Be was carried out wherein dry, water-wetted, and alcohol-based wipe methods were evaluated for how effective each was in removing beryllium-containing dust from painted surfaces [Kerr 2004]. The study found alcohol to be most effective for removing Be dust from oily surfaces, while dry wipes were least effective for this purpose. These studies have served to provide necessary data in support of standardized wipe sampling protocols for metals (e.g., ASTM D6966).

Wetted wipes have been studied for assessing antibiotics and antineoplastic drugs surface contamination. Using cellulosic wipes wetted with ethanol, recoveries of various antibiotic substances from different surface materials were analyzed with high-performance liquid chromatography-mass spectrometry (HPLC-MS) [Nygren and Lindahl 2011]. Sampling recoveries from smooth surfaces were determined acceptable (i.e., quantitative or semi-quantitative) for several antibiotics, but the high reactivity of certain agents led to low or erratic recoveries for some substances.

Surface sampling studies of pesticide residues showed wetted wipes offered the highest recovery efficiencies. A comparison study between solvent-moistened wipes and a press sampler found solvent-wetted wipe sampling from hard surfaces removed 84%–97% of all pesticides while a press sampler recovered only 17%–55% [Bernard et al. 2008]. A press sampler consists of a handle, sampling block, and cassette assembly that uses springs to press a sampling material, cotton or polyurethane in this study, against the surface being sampled.

Studies of wipe materials and wetting agents for collecting pesticide residues from hard surfaces have shown that isopropanol-wetted cellulosic wipes yielded acceptable recoveries for a variety of pesticides and their residues, as well as related organic compounds [Cettier et al. 2015; Deziel et al. 2011]. In other work, wipe materials and solvents were evaluated for surface sampling of chemical warfare agents and for wipe recoveries from representative surfaces [Willison 2012, 2015]. These wipe sampling protocols are harmonized with a relevant voluntary consensus standard for sampling nonvolatile organic compounds, ASTM D6661 (Table 2).

Table 2. Selected ASTM standards for sample collection from surfaces in workplaces and related environments*

ASTM Standard Designation	Sampling Media/Device	Target Substrate(s) Sampled	Comments
ASTM D5438	Modified upright vacuum cleaner	Floors	Applicable to sampling from carpets; multiple analytes
ASTM D5755	Micro-vacuum sampler	General surfaces	Applicable to collection of asbestos fibers
ASTM D6333	Polyurethane foam roller	Floors	Applicable to collection of pesticide residues
ASTM D6480	Low-fiber/continuous filament wipe	Smooth surfaces	Applicable to collection of asbestos fibers
ASTM D6602	Cotton balls, wipes or tape lift	General surfaces	Applicable to sampling of soot, carbon black, biofilms, etc.
ASTM D6661	Solvent-wetted wipe	Smooth surfaces	Applicable to sampling of non-volatile organic compounds
ASTM D6966	Wetted wipe	Smooth surfaces	Various wetting agents can be used; applicable to metals and metalloids
ASTM D7144	Sampling cassette with collection nozzle	Rough, porous, uneven surfaces; fragile surfaces	"Micro-vacuum" dust sampling for metals and metalloids; potentially applicable to other agents
ASTM D7296	Dry wipe	Fragile surfaces	Applicable to Be—special cases; potentially extendable to other analytes
ASTM D7707	Be wipe specification	Smooth surfaces	Applicable to Be sampling; potential applicability to other elements; regulatory applications
ASTM D7789	Swab sampler (sterile)	General surfaces	Applicable to sampling of fungi
ASTM D7910	Adhesive tape	General surfaces	Applicable to sampling of fungi
ASTM E1216	Adhesive tape	Smooth surfaces	Applicable to multiple analytes; poor collection efficiency for ultrafine particles; might damage fragile substrates
ASTM E1728	Wetted wipe	Smooth surfaces	Applicable to Pb sampling; regulatory applications
ASTM E1792	Pb wipe specification	Smooth surfaces	Applicable to Pb sampling; potential applicability to other elements; regulatory applications
ASTM E2458	Swab sampler	General surfaces	Applicable to suspected biological agents in powders

*Standards available at www.astm.org. Pb = lead; Be = beryllium

c. Vacuum sampling

Consider vacuum sampling when the surface cannot be wiped, when surface wipe methods are not expected to have acceptable collection efficiencies, or when the analyte or the physical

form is best collected via vacuum. Vacuum sampling is generally preferred for soft or rough, porous surfaces and has been done for a variety of agents, including bacterial spores. Vacuum-based sampling methods have been evaluated for their ability to recover *Bacillus* spores from surfaces [Calfee et al. 2013; Calfee et al. 2019]. Relative and absolute recoveries of a *Bacillus anthracis* surrogate for four commonly used vacuum sampling devices from three representative surface types (carpet, concrete, and upholstery) were measured after dosing the surfaces with aerosolized spores. Generally, higher relative recoveries were obtained by using a micro-vacuum sampling filtration method, which is harmonized with a consensus standard technique (ASTM D7144; Table 2). These and similar data can be used to support the validation of standardized vacuum sampling techniques [Creek et al. 2006] for microbiological samples.

The ASTM International high-volume vacuum collection method for worn carpeted surfaces (ASTM D5438; Table 2) has been evaluated using reference material. Dust collection efficiencies of about 80% and greater were reported for various types of carpets, and recoveries were higher from new carpets [Svendsen et al. 2006]. Previous investigations of vacuum collection systems reported low collection efficiencies of dust on carpets (<75%) and effective collection (>75%) on smooth, hard surfaces [EPA 1995b]. A study evaluated a low-air volume "micro-vacuum" collection method developed by ASTM International (ASTM D7144; Table 2) [Ashley et al. 2007]. Here, collection efficiencies from a variety of representative substrates were reported based on gravimetric analysis. Although recoveries were generally lower (<75%), researchers emphasized that standardizing the micro-vacuum sampling technique should ensure data comparison through harmonization of the sampling device and collection procedure. However, losses were reported because significant amounts of material were captured within the collection nozzles of the micro-vacuum samplers. Improving the design of vacuum samplers, where the collection inlet is incorporated into the body of the samplers, may improve collection efficiencies in the future [Creek et al. 2006]. While removing the material from within the collection nozzles may be possible, in practice this is difficult to achieve.

In air sampling, researchers have identified material losses to the sampling cassette's walls. Guidance has been developed to recover those losses, such as using conductive cassettes, improving the cassette design, using cassette inserts, or wiping or washing the inside of the cassette [ASTM 2021a; NIOSH 2016a]. Similar corrective measures can be considered to minimize cassette and collection nozzle losses during vacuum surface sampling.

d. Dermal sampling

Dermal sampling, including removal and interception techniques, can be one component of a dermal exposure assessment [Boeniger et al. 2015; Semple and Cherrie 2003]. Hundreds of chemicals have been identified to have risks for significant dermal exposures (i.e., transdermal absorption, systemic toxicity, or allergic sensitization). However, the importance of dermal exposures has been often overlooked or underestimated relative to inhalational exposures largely because of the lack of dermal exposure criteria [ACGIH 2021; NIOSH 2010]. An extensive bibliography on occupational dermal health effects has been compiled [NIOSH 2009]. This document serves as a general resource for information on occupational dermal exposures and health effects.

Numerous studies have proposed what to consider for occupational dermal exposure assessments [Fenske 1993; Frasch et al. 2014; Schneider et al. 1999]. In view of this, the International Organization for Standardization (ISO) published a standard technical report (ISO/RD 14294:2011) outlining criteria for the assessment of occupational dermal exposure [ISO 2011]. This international standard complements the dermal sampling methods listed in Table 3. In general, there are four main objectives for assessing dermal exposure [Fenske 1993]:

1. Research on the adverse health effects of chemical exposures to include (a) conducting epidemiological investigations and risk assessments, (b) studying possible associations between skin exposure and adverse health effects, (c) developing exposure-response relationships for risk assessment, and (d) estimating disease burden due to skin exposures.
2. Evaluation of exposure processes and pathways to assist in developing, implementing, and evaluating exposure control measures or interventions.
3. Compliance, compensation claims, forensics, or litigation (if applicable).
4. Education and training, including intervention protocols that might include the use of screening techniques to aid in workers' understanding of their (and, potentially, their household members') exposure pathways.

Table 3. Standardized guidance and procedures for sample collection from dermal surfaces

Method(s)	Sampling Media/Procedure	Target Analyte(s)	Comments
ASTM D7822	Wetted wipe	Elements on delineated area of skin	Subsequent analysis by atomic spectrometry or equivalent technique(s)
ISO/TR 14294	Wipes, patch samples, dermal rinses, gloves, clothing, etc.	Multiple analytes on dermal or interception surfaces	Guidance on sampling strategies and specific dermal exposure assessment protocols
NIOSH* 3600, 3601, 9200, 9201, 9202, 9205	Patch samples, hand rinses	Multiple analytes on dermal surfaces	Applicable to pesticides, metalworking fluids, etc.; may apply to other agents
NIOSH* 9100, 9102, 9110	Wetted wipe	Elements on delineated area of skin	Harmonized with ASTM D7822; subsequent quantitative analysis
NIOSH* 9101, 9105	Wipe: nonwetted (Cr(VI)); prewetted (Pb)	Cr(VI) or Pb on dermal surfaces	Qualitative colorimetric screening techniques
OSHA (various) [OSHA 2003b]	Patch samples, hand rinses	Multiple analytes on dermal surfaces	Various sampling and analytical protocols; also clothing, gloves, etc.

*NIOSH methods available at www.cdc.gov/niosh/nmam. Pb = lead; Cr(VI)= hexavalent chromium

Conceptual models of dermal exposure have been outlined based on the body of relevant scientific literature [Boeniger et al. 2015; Fenske 1993]. Specific models include RISKOFDERM, DeRmal Exposure Assessment Methodology, the American Industrial Hygiene Association (AIHA) conceptual model for dermal exposure assessment, and the ECETOC Targeted Risk Assessment model [Boeniger et al. 2015; ECETOC 2004, 2009, 2010; van Wendel de Joode et al. 2005]. Other exposure models, such as the EPA ChemSTEER and Consumer Exposure Models, have dermal components [EPA 2013, 2019]. The models can form the bases for choosing measurement methods for assessing dermal exposures and pathways. Dermal exposure assessment is often carried out through direct sampling from skin via wipe sampling, tape stripping, rinsing techniques, or direct reading (in situ) measurement methods [Frasch et al. 2014; Schneider et al. 1999]. Indirect dermal exposure assessment

methods include interception methods such as patch sampling and sampling of clothing or gloves [Fenske 1993; Frasch et al. 2014; ISO 2011; Schneider et al. 1999].

Characterizing dermal exposure via sampling, particularly of volatile compounds, can entail skin tape sampling and interception sampling. Skin taping removes a thin layer of skin cells for subsequent analysis. Interception sampling techniques include the application of sorptive samplers on the skin or clothing that are worn during work and then removed for analysis [OSHA 2014]. Volatile and semivolatile compounds may not completely remain on the skin to be sampled using removal sampling techniques, leading to an underestimate of exposure if the volatile fraction is not accounted for. Residence time on the skin can impact collection efficiency [ASTM 2019]. Conversely, sampling methods or media that capture volatile fractions that never made contact with the skin can lead to overestimation of exposure.

Many of the considerations for carrying out dermal sampling mirror those outlined earlier for collecting nondermal surface samples. When planning hand or skin wipe sampling, consider the source of the analyte. For agents found both inside and outside the occupational environment, such as flame retardants, preshift hand washing can reduce the risk of attributing non-occupational contamination to the workplace, and preshift dermal sampling can reveal the amount of contamination present before the participant enters the workplace.

Standardized methods that pertain to dermal sample collection and analysis are summarized in Table 3. Applications to the sampling and analysis of metals and organics are exemplified in a number of these protocols. Techniques for dermal wipe sampling for subsequent elemental analysis are published in ASTM D7822 [ASTM 2019]. Dermal sampling protocol using patch samples or rinses has been described briefly in several OSHA and NIOSH methods (Table 3). Many dermal sampling techniques need to be further standardized, particularly for organic analytes (such as pharmaceuticals) and reactive species (such as isocyanates) [ASTM 2011b].

NIOSH researchers studied the effectiveness of dermal wipe sampling for Pb using different wipe sample media [Boeniger 2006]. More than half of the leaded dust (≈60%) was recovered after collecting a sample with one wipe; successive wiping increased lead dust removal (≈90%) from hands. In related research, effective decontamination of Pb on workers' hands using a specially formulated handwipe was shown to perform better than ordinary soap and commercial skin cleansers [Esswein et al. 2011; NIOSH 1996]. Such techniques can also be useful to decontaminate Pb and other metals in workplace environments. To date, apart from exceptions shown in Table 3, dermal sampling procedures have not been well standardized. This has led to difficulties in evaluating and comparing data from a variety of different studies [Brouwer et al. 2000; ISO 2011].

Data collected by dermal sample techniques are often confounded by multiple factors. These can include the reactivity of the agent(s) of concern, the ability of the analyte to pass through the skin, the variability of contaminant levels between different areas of the body, and variances in skin surfaces [Fenske 1993; Schneider et al. 1999]. Nevertheless, dermal sampling methods for chemicals (e.g., pesticides, metalworking fluids) and biological agents (e.g., bacteria, viruses) should be harmonized to the extent possible. This task remains an important area for further research and development.

Under Section 4 of the Toxic Substances and Control Act of 2016 (TSCA), the EPA can require chemical manufacturers and importers to develop and submit information on existing chemicals for subsequent risk evaluation. Test orders can require dermal wipe sampling to complement other exposure and skin permeation testing, but do not proscribe the sampling method [EPA 2021a].

e. Sampling area and technique

Sampling techniques are often standardized by the sample area, sampling pattern, and the number of passes across a fixed sample area. Normally, the minimum area for sample collection is 100 square centimeters (cm^2), which is about 16 square inches (in^2). This is typically delineated using templates of standard sample areas (i.e., 100 cm^2, 4 in^2, 1 ft^2). Using a template and a specified sample area are particularly important to compare samples or to follow regulatory or consensus limits, such as Be, Pb, and polychlorinated biphenyls (PCBs)[10 CFR § 850, 1999; 40 CFR § 761, 1978].

To prevent cross contamination between samples, use a new, disposable template for each sample. Although it is not best practice, reusable templates may be used and cleaned between samples, unless disallowed by the published method being followed. To the same end, gloves should be worn and changed between samples, particularly when the sampling media is handled during sampling [OSHA 2000]. For samples where a handle is attached to the media (e.g., swab sample) and where the tip is broken into a sample container for storage before analysis, gloves aren't essential to prevent cross-contamination. Most NIOSH surface sampling methods are harmonized with related ASTM standards (Table 2).

Methods may call for the surface area to be sampled/wiped in a "Z or S" pattern in two or three complete passes with the media being folded between passes to prevent analyte loss back to the surface and to use the entire medium collection surface. Swab techniques might call for turning the swab during sampling. The passes on a surface within a template are typically in different directions (i.e., one sampling pass being perpendicular to the subsequent pass). For

example, NIOSH sampling methods for Bacillus anthracis spores from smooth, nonporous surfaces instruct the sample collector to take multiple passes and use the full surface area of the sample media [NIOSH 2012]. NIOSH developed two methods: one using a cellulose sponge and a 100 in^2 template, the other using a macrofoam swab and a 4 in^2 template. Both techniques use a buffer that inactivates halogen disinfectants and quaternary ammonium compounds and require a specific sampling pattern. Each was meant for a particular type of surface, distinct from each other. NIOSH researchers created videos to demonstrate and train sampling staff [NIOSH 2015].

f. Other sampling considerations

Details should be decided upon during the planning process. For example, sample storage and transportation needs should be accounted for. Samples may have to be refrigerated to maintain analyte stability while awaiting analysis. Any possible analytical interferences present at the site should be reported to the analytical laboratory. Samples for a reactive or unstable compound may need to be treated with a stabilizing or derivatizing agent immediately after sampling [OSHA 2000]. Some sampling materials, like the wetting agent or analyte, may have shipping label and safety regulatory requirements.

Additionally, a job hazard analysis should be done for the sampling process to determine which exposure controls are needed during surface sample collection. For example, sample collectors should use gloves to prevent skin absorption of hexane-wetted gauze during surface wipe sampling for PCBs. The sample collector's exposures should be characterized and not exceed occupational exposure limits or safety limits (e.g., recommended exposure limits [RELs], permissible exposure limits [PELs], threshold limit values [TLVs®], concentrations immediately dangerous to life or health [IDLH]). Such exposures could be related to the operations in the workplace undergoing assessment or to sampling (e.g., volatile solvent wetting agents). Sample collectors should be trained on the selected sampling technique and exposure controls that should be used to protect the sample collector. Generally, at minimum, gloves should be worn during the entire sample collection process to prevent both exposure to possibly hazardous agents and external contamination of the sample or surface being sampled.

4 Sampling strategies

a. Number and statistical considerations in selecting a sampling approach

Developing a sampling strategy requires careful selection of sampling location and number to meet sampling goals. Two primary sampling strategy categories when it comes to sample location and number are judgement sampling and random sampling. Traditionally, selection of sample locations and numbers has relied on targeted judgement. In targeted judgement sampling (also called professional judgement, best engineering judgement, or targeted sampling), information about the process and history of the workplace is used to choose sample locations. Typically, work surfaces employees have contact with and that are determined to most likely be contaminated or to have the highest contamination are selected for sampling. Targeted judgement sampling commonly includes surfaces that may pose the greatest risk of exposure for workers. These surfaces can be used for initial site characterization to identify the extent of contamination and locations for cleaning and re-sampling. However, because the selected surfaces are not random, the results of this type of sampling are intrinsically biased. Therefore, statistical conclusions cannot be made as to how much amount analyte is on unsampled surfaces. Targeted judgement sampling is useful in emergent situations and for screening ahead of random sampling. Additionally, the success of this strategy to identify contaminated areas relies on the accuracy of the judgments being made about the contaminating process. The accuracy of professional judgement to identify areas of high surface contamination has not been systematically assessed in peer-reviewed literature, but professional judgement of air sampling concentrations has been shown to improve with experience, education, and trainings [Logan et al. 2011].

The number of samples collected should be determined by the purpose of the sampling, need and ability to collect representative samples, and statistical considerations. If it is determined that as a single sample is unlikely to be representative of the range of surface contamination levels, taking multiple samples on a single surfaces may need to be investigated. Surface sampling is limited to the amount of surface area available, potentially constraining the number of surface samples that can be taken. The precision of surface contamination estimates increases with the number of samples collected. The accuracy of the sampling may or may not increase with the number of samples collected. Some published consensus methods state that sample numbers should be sufficient to perform desired statistical comparisons [ASTM 2018c, 2021b].

When planning, it is essential to consider how certain measurements would impact how the results are used. For example, values for censored data (results below a specified reporting limit) need to be agreed upon before sampling and may increase the number of samples needed to perform statistical comparisons. Be regulations call for sufficient sampling to meet a minimum confidence level [DOE 1999]. For some surfaces, the surface area will dictate the number of samples that can be collected. The Pacific Northwest National Laboratory (PNNL) has developed a software tool, Visual Sample Plan (https://www.pnnl.gov/projects/visual-sample-plan), that can assist in decisions about the number of samples needed to meet given sampling objectives.

1.) Statistical sampling approaches

In cases where statistical confidence is needed as to the cleanliness or contamination of both sampled and unsampled surfaces in a building or workplace, random sampling strategies can provide information to make statistics-based statements about contamination or cleanliness. Random sampling is also called probabilistic sampling. Purely random sampling strategies may be very costly and time-intensive to fully characterize surface contamination and to meet precision objectives without the benefit of targeted or professional judgement.

Hybrid approaches combining random sampling and targeted judgement strategies [EPA 2021c, d; Sego et al. 2007; Seiler et al. 1987] can increase efficiency by using professional judgement in the design and reducing sampling cost and time. Targeted judgement and random techniques can be performed in sequence to increase efficiency. Hybrid approaches include stratified random sampling and some ranked set sampling [EPA 2021c]. The EPA outlines goals, sampling scenarios, and associated appropriate environmental sampling strategies that can be applied to surface sampling [EPA 2021c]:

- **Judgmental sampling**: where sample locations are selected using professional judgement and prior information and fewer samples are taken relative to random or hybrid techniques.
- **Simple random sampling**: sampling locations are selected randomly (via random number generator or equivalent).
- **Stratified random sampling**: location and/or process information is used to create groups that are independently and randomly sampled.
- **Systematic and grid sampling**: an initial sampling point is selected randomly and then subsequent sampling locations are chosen using a fixed pattern (e.g., temporal, distance, geometric pattern).

- **Ranked set sampling**: screening sampling is conducted on a random sample, locations and grouped according to relative contamination, and then subsequent samples are taken from those groups.
- Adaptive **cluster sampling**: random sampling is followed by adjacent sampling near the original sample if the results are of interest, such as above a laboratory reporting limit or predetermined threshold.

2.) Selecting sampling locations

Before developing a sampling strategy, information about the sampling site and processes must be gathered. The following should be considered and documented within any type of sampling strategy, and can be used to select sampling locations when using hybrid or targeted judgement approaches:

- Location of the worker
- Potential sources and routes of exposure
- Workplace processes and any controls releasing or removing the contaminant
- Physical state of the agent (e.g., particulate)
- Mechanisms of transport (e.g., natural or mechanical ventilation, liquid transport) and deposition (sedimentation or diffusion)
- Housekeeping methods and frequency
- Cleaning and contamination history (e.g., when was the surface last cleaned)
- Possible interferences
- Need for comparisons within and/or between work locations
- Regulatory requirements

When designing hybrid and targeted judgement sampling plans, the surface cleaning and contamination history should be documented in any type of sampling strategy and considered when choosing sampling locations. Engineering and administrative controls (such as local exhaust ventilation and housekeeping procedures) should be documented along with process activities that can result in contamination. This information should be identified beforehand and thoroughly noted during sampling to best interpret sampling results. Gather information about cleaning practices in the areas being sampled, for example, cleaning method, materials used, date last cleaned, cleaning frequency, and if attempts to determine cleaning efficacy have been made. For instance, if certain surfaces are identified as surrogates for air deposition or material migration, the time elapsed since the sampled surfaces were last cleaned should recorded to be able to make comparisons across locations. Further, researchers should understand where, when, and how often the contaminating processes occur relative to the surface sampled. Lastly,

document the extent of contact between workers and the surface being sampled either quantitatively (e.g., measures or estimated surface area of skin exposed, number, frequency, or duration of contact) or qualitatively (e.g., noting presence or absence of contact). These data or information could be used in risk assessment and to identify exposure controls or interventions, but that is beyond the scope of this chapter. This auxiliary information can be used as justification for surface selection during targeted judgement or hybrid sampling.

When assessing the efficacy of housekeeping and controls used to contain contamination to specific workspaces (e.g., not moving tools outside of a contaminated zone or placing showers and locker rooms to separate clean and contaminated areas), samples may need to be taken from locations that are occupied by workers but removed from the process generating the agent being sampled. Examples include breakrooms, bathrooms, office or nonindustrial spaces, locker rooms, or work vehicles.

b. Case study: Sampling for *Bacillus anthracis*

A hybrid approach would be appropriate when sampling for *Bacillus anthracis* spores after a suspected release or contamination event. The Government Accountability Office (GAO) led a multi-agency project to evaluate anthrax sampling procedures in a post-release environment. The GAO called upon agencies to develop statistical surface sampling strategies for *Bacillus anthracis* to increase confidence in negative results. Respondents to this request published proposed sampling strategies for sampling and clearance of suspected contaminated areas [GAO 2005; Piepel et al. 2013; Sego et al. 2007]. Response to a release event may require two phases of surface sampling. The first phase is site characterization to determine if and where surfaces are contaminated. The second phase is verification that decontamination was effective to a nondetect or acceptable level [Sego et al. 2007]. Alternatively, targeted judgement sampling can be used in parallel with random sampling to reduce the number of random samples needed to achieve confidence that an area or room is uncontaminated [Sego et al. 2007].

c. Sampling strategies for regulatory compliance

Some regulations dictate when and where sampling must be conducted. For example, states and local authorities have surface limits for methamphetamine in remediated sites that were previously clandestine methamphetamine production sites [EPA 2021e], and post-remediation sampling is required. As more states adopt fentanyl laboratory remediation requirements, fentanyl and fentanyl-analogue wet sampling methods are being developed with the intent of optimizing collection efficiency and lowering limits of quantitation [Ciesielski et

al. 2021]. In contrast, the Occupational Health and Safety Administration (OSHA) regulations for Pb and Be on workplace surfaces are not explicit and instruct employers to maintain workplace surfaces "as free as practicable" of the contaminant; they do not dictate a particular sampling strategy nor specific limits that must be met [OSHA 2020]. However, a 1993 Compliance Directive recommends the use of the Department of Housing and Urban Development (HUD) acceptable decontamination level for Pb on floors in evaluating changing area, storage facilities, lunchrooms, and eating areas—indicating that those locations should be sampled for comparison to that limit [OSHA 1993, 2003a].

d. Composite sampling

Composite sampling is where individual samples are collected and then combined and analyzed together. Generally, this technique is used to reduce the number of analyses required, thereby reducing analytical costs while maintaining a representative number of samples. The decision to use composite sampling is based first on whether the resulting data will fit the sampling strategy goals. Composite sampling should not be used when the results for individual sampling locations are necessary, as that information is lost during composite analysis. All samples included in the composite should be from the same surface or type of surface being evaluated. Sample compositing is most often done in the workplace when the analyte is expected to be low. Compositing can increase the likelihood that a laboratory detection or reporting limit is reached or establish that surfaces are not contaminated if composited sample results remain below the reporting limit or below selected criteria for action.

If it is decided that composite sampling can be used to meet the sampling strategy goals, then these choices should be determined: analysis method, sample media, and criteria for comparison and re-sampling. Samples that make up a composite sample should be taken with the same media and technique and in the same sampling area [HUD 2012; NIOSH 2011a]. Applying limits or criteria designed for discrete samples (noncomposited) is not typically appropriate for composite samples. Conditions for surface resampling should be decided on before carrying out composite sampling. In the United States, the residential Pb clearance regulatory requirements explicitly allow for the compositing of up to four wipe samples, if they were all taken of the same component, as long as the samples are tested by a laboratory recognized by the National Lead Laboratory Accreditation Program [ASTM 2011a; HUD 2012]. Composite sampling can be used for post-clean-up of methamphetamine sampling, particularly when contamination is expected to be uniform [EPA 2021e].

The limit of detection for composite samples may be higher than that for discrete samples because of the increased volume of desorption liquid required for a large sampling media material [NIOSH 2011b]. NIOSH recommends that the composite results be reported over the total sample area, rather than averaged to the area of a single sample [NIOSH 2011c]. If the sampling goals require information about the average contamination, then an average contamination over a single sample area is useful [EPA 1995a]. However, if the goal is to compare results to criteria meant for a single sample, calculating the maximum possible amount of contaminant on a single sample would be more appropriate for comparison. If that maximum possible amount of contaminant exceeds an action level or limit, then resampling of those areas or similar areas is necessary because composited surface samples cannot be analyzed separately after they have been combined. Additional samples would need to be taken to elucidate the variation in surface contamination. Therefore, the plan should account for whether a surface has sufficient area to be resampled and how that would be done, depending on composite sample results.

Compositing wipe samples can lead to analytical difficulties [NIOSH 2003]. For example, compositing samples may lead to increased background signal or analytical noise, ending with increased total dissolved solid concentrations that may require dilution for analysis, depending on the analysis technique and/or instrument configuration. When considering composite sampling, verify that the analytical laboratory has the capacity to analyze composite samples, and if so, that it can be done with the necessary sensitivity to meet the sample strategy objectives [EPA 2018].

5 Criteria for surface contamination

In the United States, national regulatory surface contamination levels have been established for Pb, Be, and PCBs [DOE 1999; EPA 2021b; 10 CFR § 850, 1999; 40 CFR § 745.227, 2000; 40 CFR § 761, 1978]. To comply with residential EPA Pb contamination regulations, clearance surface samples must be collected using documented methodologies that incorporate adequate quality control procedures and are reviewed by a certified inspector or risk assessor [40 CFR § 745.227] [OSHA 2020, 2003a]. Very low Be surface regulatory levels for housekeeping and decontamination have been established to reduce the risk of Be sensitization through contact with the skin [Rondeau 2009]. Not all regulations for Pb and Be surface levels are explicit. For example, OSHA requires work surfaces to be "as free as practicable" from Pb and Be [OSHA 2020]. Specific criteria have not been established by OSHA for these contaminants, but some interpretation guidance has been provided [OSHA 2003a]. The regulations establishing Be surface contamination limits do not provide for a required standard sample collection method, leaving the sampling methodology up to

individual sites, although the analysis must be conducted by a laboratory accredited by AIHA or equivalent. DOE has provided an implementation guidance to professionals on exposure sampling, including surface sampling [DOE 2010].

Few consensus surface limits have been established for occupational exposures. Starting in 2019, the American Conference of Governmental Industrial Hygienists (ACGIH®) began publishing surface limit threshold limit values (TLV®-SL) for some chemicals. These limits are intended to supplement their published airborne limits, particularly for agents with known skin absorption and sensitization capacities [ACGIH 2021]. These limits are expressed as a mass per 100 cm^2 and may correspond with the dose permitted by the 8-hour time-weighted average TLV® unless data are available about effects related to dermal exposure alone. As of 2021, ACGIH® had established TLV®-SLs for two chemicals, *o*-phthalaldehyde and methyltetrahydrophthalic anhydride [ACGIH 2021].

Worker exposure to pharmaceutical substances through contact with the skin is a hazard being addressed, in part, by the development of guidelines for acceptable surface limits (ASLs) for such compounds [Kimmel et al. 2011]. Beyond the factors considered for sampling and analysis, some essential criteria to account for in establishing ASLs include skin penetration or dermal uptake, concentration of active pharmaceutical ingredient(s), mechanisms of toxicity and identified health outcomes, duration and frequency of contact, and individual susceptibility. In efforts to prevent dermal exposures, related "guidance values" for surface monitoring of antineoplastic drugs have been proposed for selected chemotherapy agents [Kiffmeyer et al. 2013; Schierl et al. 2009].

If limits are established for a given analyte, the sensitivity of the method should be able to quantitatively detect the analyte of interest well below the limit. This normally requires that the method detection limit (MDL) be at most one tenth of the limit. To reiterate, it is essential that the sampling and analytical method be considered when establishing limit values for chemical and biological agents on surfaces.

6 Consensus standards and other resources for published surface sampling methods

When identifying methods to meet sampling goals, using standardized protocols can enable data comparisons; foster consistency, defensibility, and reproducibility; and help maintain expected data quality. ASTM International have published consensus standards for surface sampling, including the *Standard Guide for Strategies for Surface Sampling of Metals and Metalloids for Worker Protection* (ASTM D7659) [ASTM 2021b]. Many of the considerations outlined in this standard are

applicable to other potentially hazardous agents besides metals, such as organics, radioactive materials, and biological agents.

U.S. government agencies are directed by the National Technology Transfer and Advancement Act (NTTAA) to contribute to the development of voluntary consensus standards. They are further instructed to include these standards in regulatory requirements in lieu of developing unique government regulations where practicable and consistent with applicable laws [OMB 2016]. Many published occupational exposure assessment consensus standards, and those under development, are based initially on existing government agency methods, guides, and procedures. Ultimately, it is intended that the use of consensus standards will enhance data comparability for surface or dermal samples obtained from different investigators, for various substances, from a variety of locations, surfaces, etc.

Various ASTM standards that apply to surface sampling in occupational settings and related locales have been published and are summarized in Table 2. ASTM standards describing wetted wipe sample collection for metals and metalloids have been published (ASTM D6966, ASTM E1728). Using ASTM wipe sampling methods, when carried out with wetted wipes meeting performance specifications (e.g., ASTM E1792 or ASTM D7707), have been shown to provide collection efficiencies of >75% for target metallic analytes (i.e., Pb and Be) [Dufay and Archuleta 2006; EPA 1995b]. ASTM has implemented a surface tape stripping method (ASTM E1216) that applies to multiple analytes and published a surface tape stripping method for sampling fungal spores (ASTM D7910).

When the sampling surface is rough or porous, and wet wipe sampling or tape stripping is deemed impractical, vacuum collection methods (e.g., ASTM D5438, ASTM D5755, and ASTM D7144) are used in lieu of wiping or stripping techniques [Creek et al. 2006]. In rare cases where the surface to be sampled is energized, fragile, or reactive, and if Be is the only analyte of interest, dry-wipe sampling (ASTM D7296) is an option for sample collection. In addition, ASTM has published procedures for the following: surface sampling of asbestos by vacuum sampling (ASTM D5755) or wiping (ASTM D6840), wipe sampling of organic compounds (ASTM D6661), swab collecting of fungi (ASTM D7789) and other biological agents (ASTM E2458), and collecting pesticide residues from floors (ASTM D6333) (Table 2). Consider the limitations in the published standards when developing a sampling plan. For example, ASTM 6661-17, a standard practice for collecting organic compounds from surfaces using wipe sampling, is not intended to be used to collect dust samples nor to conduct sampling to estimate human exposure to contaminated surfaces [ASTM 2017b].

Consensus surface sampling methods for Pb, Be, and asbestos were developed, largely in response to regulations in the United States [Ashley et al. 1996; Ashley et al. 2009; Kominsky and Millette 2011].

Besides the ASTM standard surface sampling guide for metals (ASTM D7659) already mentioned, ASTM also developed an analogous standard sampling guide for asbestos (ASTM D7390) [ASTM 2018c]. An ASTM standard having several different surface sampling and analytical applications describes various sample collection methods, such as tape stripping, wipes, cotton balls, for biofilms, carbon black, soot, etc. (ASTM D6602). This standard has been used in outdoor urban applications [Millette et al. 2011].

Other ASTM standards relating to surface sampling and assessing surface contamination have been developed to address applications in clean rooms and aerospace (Table 4). While these voluntary consensus standard protocols are targeted for specialized uses, there may be situations where the standards could be applied to assessing contamination in occupational, indoor, and other environments.

Table 4. ASTM International standard procedures for surface sampling in aerospace and clean room applications*

ASTM Standard Designation	Sampling Media/Device	Target Substrate(s) Sampled	Comments
ASTM F303	Rinse method	Aerospace components	Collection of particulate matter for assessment of cleanliness
ASTM F51	Particle sizing instrument	Clean room garments	Evaluation of contamination from fibers and particles
ASTM E2088	"Witness" test surface	Clean room surfaces	Measurement of particle deposition
ASTM F24	Optical particle counter	Electronic components	Assessment of surface contamination

*Standards are available at www.astm.org.

a. Radioisotopes

ISO has made available a three-part international standard, ISO 7503, that addresses the measurement of surface contamination by radioactive materials [ISO 2016]. These three standards entail the measurement of radioisotopes on surfaces of equipment and in facilities, but they do not apply to the evaluation of radioactive contamination on skin or clothing. Methods for direct and indirect measurement of radionuclides collected from surfaces are

described in these ISO standards. Part 1 of ISO 7503 describes general principles relating to the assessment of surface radioactive contamination by direct and indirect measurements. Part 2 of the standard addresses wipe testing measurement protocols, and Part 3 covers the calibration aspects of instruments used for the evaluation of radioactive surface contaminations.

b. Healthcare settings

Wipe sampling and analysis has been used effectively for surface monitoring of antineoplastic drugs and related drug residues in healthcare settings [Connor et al. 2016; Nygren 2006; Nygren and Lindahl 2011]. Guidance values for wipe sampling have been proposed for chemotherapy drugs such as cisplatin and 5-fluorouracil, based on extensive data from surface monitoring in pharmacies [Schierl et al. 2009]. Recommendations on surface "threshold guidance values" for antineoplastic drugs and related compounds can help pharmacists (and others potentially exposed workers) assess controls (e.g., safe material handling, cleaning/decontamination efficacy) and maintain contaminant-free work environments.

Research shows that implementing safety measures and monitoring work practices reduced contamination by antineoplastic drugs in healthcare settings, as determined through surface sampling [Kopp et al. 2013]. Field screening methods for on-site, near real-time monitoring of several antineoplastic drugs in surface samples have been developed and undergone some validation [Smith et al. 2016]. For exposure prevention efforts, these screening techniques can be used in complementary fashion with definitive fixed-site laboratory methods using mass spectrometric analysis [Pretty et al. 2012].

c. Reference and standard surface sampling and analytical methods

Table 1 lists existing NIOSH surface sampling and analytical methods, which NIOSH continues to review and update in the NIOSH Manual of Analytical Methods (NMAM). NMAM 5th edition (www.cdc.gov/niosh/nmam) should be consulted for the most up-to-date information on NIOSH methods [NIOSH 2022]. Another useful source with several surface sampling methods for industrial hygiene applications is the OSHA analytical methods manual [OSHA 2003b], which offers surface sample collection protocols for inorganic and organic analytes. OSHA has also released evaluation guidelines for surface sampling and analytical methods [OSHA 2000]. These guidelines are complementary to guidance and recommendations offered by other sources, such as NIOSH, ASTM, AIHA, ACGIH, ISO, and Brookhaven National Laboratory (BNL), among others.

BNL has disseminated guidance on surface sampling based on NIOSH 9100 and related standardized methods [BNL 2017]. The various sampling media, wetting agents, and templates, depending on the analyte(s) of interest and surface area to be sampled, are summarized below:

Sampling media

- Gauze, cotton (5 or 10 cm dia.)
- Filter paper, ashless (4–10 cm dia.)
- Premoistened wipe, e.g., cellulosic, polyvinyl alcohol (PVA)
- Filter, polyvinyl chloride (PVC) or quartz fiber (for Cr(VI) sampling)

Solvents

- Distilled water
- Alcohol: 2-propanol, ethanol, methanol
- n-Hexane

Templates

- 10 × 10 cm or 30 × 30 cm square
- 11.3 cm diameter circle (for 100 cm^2 area)

Required and recommended criteria for surface sampling for metals are summarized in BNL guidance [BNL 2017]. Elemental sampling normally entails the use of a wipe of a material that is appropriate for the agent, wetted with deionized water and a minimum sample collection area of 100 cm^2. These protocols for metals are harmonized with the standardized elemental sampling methods that are summarized in Table 2. An exception is when sampling Cr(VI), which is carried out in accordance with OSHA method W4001 [OSHA 2001]. This procedure uses dry, inert filters for surface sampling to prevent reduction of Cr(VI) by wetting agents during or after sample collection. The filters are placed into a basic carbonate buffer immediately after sampling to stabilize Cr(VI) in the collected sample. Recommendations for surface sampling of PAHs entail the use of an organic solvent as a wetting agent, in accordance with ASTM D6661 (Table 2).

The DOE established an action level for Be, and the EPA established an action level for Pb, both of which are regulatory, and thus have associated sampling methods or sampling guidance [DOE 1999; EPA 2021b].

7 Bulk sample collection

While methods for obtaining bulk samples (e.g., settled, rafter, or floor dusts) are beyond the scope of this chapter, we briefly mention them here as these techniques often complement surface and/or dermal sampling and may provide insights about particulates and aerosols that may have been airborne at one time. EPA provides information on bulk sampling methods for soils, solid waste, field equipment, etc. and published a comprehensive document covering issues including the following [EPA 2002]:

- Sampling strategies and design
- Sampling techniques, media, and equipment
- Standardized sampling procedures developed through voluntary consensus (notably ASTM International standards)
- Data quality considerations pertaining to sample collection, sample handling, and transport

Relevant ASTM standards on collecting bulk samples are in a compendium publication on environmental sampling [ASTM 2014]. Additional research is needed on situations when it is more appropriate to use bulk sampling in lieu of surface sampling. For occupational environments, performance data and guidelines on bulk sampling are rather limited.

8 Summary

Surface sampling considerations include first developing a sampling rationale and goals, and then constructing a strategy that supports the sampling objectives. Choosing appropriate sample collection media and using techniques that are validated and applicable to surface and dermal sampling in occupational settings are also critical sampling plan components. While this chapter highlights available standardized surface sample collection methods, it is not meant to be an exhaustive review; rather, it presents guidance and examples of pertinent research and related recommendations and standards. The NTTAA directs government agencies to contribute to the development of consensus standards and to utilize them when available and relevant [OMB 2016]. Methods for surface sampling from smooth, hard surfaces are now reasonably well-documented and standardized for several analytes, as evidenced by the availability of relevant international voluntary consensus standards for various contaminants. Additionally, vacuum sampling methods for collecting dust from rough, porous (and other) surfaces have also been standardized in the form of ASTM procedures (ASTM D5438, D5755, D7144).

Dermal sampling methods for chemical and biological agents require additional harmonization and evaluation despite some newer protocols and guidance documents. These final summary recommendations should be underscored. The following essential to consider for surface sampling and analysis before collecting samples:

- Existence and accessibility of sensitive and specific analytical methods for the analytes of interest, including accredited laboratory analytical capability and availability
- Existing validated sampling methods or research that document reliability or representativeness to measure: stability, reactivity, toxicity, volatility, etc.
- Characteristics of the surface(s) to be sampled: smooth or rough, hard vs. porous, inert or reactive, dermal, orientation and location
- Availability of sampling media: uncontaminated background, analyte and sampling recovery, chemical compatibility, ruggedness/durability
- Wetting agent or extraction solution: aqueous—neutral/acid/basic; organics—low/high polarity; recovery from extractant
- Loading/contamination level: trace; highly contaminated; variability across surface, etc.
- Dynamic range of analytical method: accuracy at low, medium, and high levels of analyte.
- Considerations for storage and transportation of samples (e.g., storage stability, temperature considerations, shipping regulations)
- Exposure controls (e.g., training, personal protective equipment) required for sample collection

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