Journal of ASTM International, Vol. 8, No. 6
Paper ID JAI103678
Available online at www.astm.org

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Review of Standards for Surface and Dermal Sampling*,†

ABSTRACT: This article summarizes the body of available standards for sampling of chemical and biological agents on workplace surfaces, including skin. These standards consist of voluntary consensus standards such as those promulgated by ASTM International, the International Organization for Standardization (ISO), and the European Committee for Standardization (CEN), as well as methods produced by U.S. Federal agencies such as the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA). Gaps in availabilities of standards are discussed along with activities underway to address needs in the field of occupational and environmental hygiene. In many cases, the available standards have been developed largely in response to regulatory requirements. For example, ASTM International standards, which describe requirements for wiping surfaces and methodologies for determining metals and metalloids such as lead and beryllium, were produced primarily in response to regulatory requirements for sampling settled dust for these elements in the United States. Methods for collection of asbestos samples, vacuum sampling, dry wipe sampling, and bulk sampling have also been promulgated. Standardized methods for non-metal contaminants and biological agents are more limited in availability. In particular, there is a lack of standardized methodologies for dermal sampling and limited standard guidance on selection of appropriate surface sampling methods and data evaluation. Activities are currently ongoing within ASTM International and ISO to address some of the gaps, but additional activity is needed to address remaining requirements for consensus standards.

KEYWORDS: dermal exposure, sampling, skin, standard, surface, workplace

Introduction

Consistency in methods for sampling and analysis of chemical and biological agents from surfaces in occupational settings through standardization of methodologies is generally desired. However, incongruities in sampling and measurement practices often occur among those collecting and analyzing surface and dermal samples [1,2]. If sampling and analysis methods are not standardized, analytical results from different investigators, locations, and/or points in time might not be comparable. Variations in surface and dermal sampling practices are of special concern, since the greatest contribution to measurement uncertainty in the overall sampling and analysis process is ordinarily associated with sample collection. Efforts to control measurement uncertainty through method standardization have been realized for various hazardous agents in occupational settings. As a consequence, a number of standardized methods for surface sampling of hazardous substances in workplaces have been promulgated.

Several standardized protocols for surface and dermal sampling have been produced by governmental agencies in the United States, for example, by the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH). Voluntary consensus standards bodies such as ASTM International have also published a number of standardized protocols for the collection of surface samples. International voluntary consensus standards are considered by many to be the most technically sound protocols for use in their particular fields of application [3]. In part because consensus standards allow for stakeholder input and are recognized as having high credibility, the National Technology Transfer and Advancement Act (NTTAA; Public Law 104-113) was enacted in the United

Manuscript received December 6, 2010; accepted for publication April 28, 2011; published online July 2011.
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* Presented at the ASTM International Symposium on Surface and Dermal Sampling, 14–15 October 2010, San Antonio, TX (USA).
† This article was prepared by US government employees and contractors as part of their official duties and legally may not be copyrighted in the United States of America.

States in the mid-1990s. This law directs U.S. Federal agencies to: (a) rely on consensus standards in their guidelines, regulations, and activities and (b) participate in the development of relevant consensus standards. In accordance with the NTTAA, an earnest goal of experts from U.S. governmental agencies is to work with the private sector to provide a suite of consensus standards describing surface and dermal sampling methods for chemical and biological agents. As a starting point, many of the consensus standards under development are based initially on existing agency methods, guides, and procedures. Ultimately, it is intended that the use of consensus standards will enhance data comparability for surface and/or dermal samples obtained from different investigators, locations, and times.

Rationale for Surface Sampling (Non-Dermal)

Surface sampling results are one of the many sources of information regarding the health and safety conditions in workplaces or other locales. Information obtained from surface sampling should not be used to the exclusion of other information concerning potential chemical, radiation, 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, as applicable: occupational air sampling; bioassay and biomonitoring results; clinical observations; quality and process control data; records of facility operations; visual inspections; and material balance studies. In an effort to address issues of this kind, an ASTM International consensus standard guide for surface sampling of metals has recently been published, which describes strategies for collecting surface samples for subsequent determination of metals and metalloids [4]. Many of the considerations outlined in this standard are applicable to other potentially hazardous agents besides metals, e.g., radiation hazards and biological agents.

Reasons for conduct of surface sampling are based on a number of general considerations. Drivers for sampling, that is, the purposes for carrying out a sampling campaign, normally fall into one of the following three areas: (a) evaluation of the potential health risk from the contaminant(s) or chemical agent, radiation hazard or biological species of concern; (b) hazard management, or evaluation of the source(s) of the contaminant or chemical species, radiation hazard or biological agent, extent of exposure area, and effectiveness of controls; and (c) hazard compliance, or evaluation for compliance with regulations or policies. Goals for the sampling campaign, which define how the generated data will be used, and a sampling strategy, should be clearly thought out and documented before any samples are collected. Of significant importance are the data quality objectives that define the minimum performance requirements for the collection and analysis of the samples. A related concern is the potential variability in surface contamination, which impacts the representativeness of collected samples. Sufficient numbers of samples and sampling areas of adequate size are required for defensible data to be obtained.

Besides workers' potential exposures, take-home contamination is also of particular concern [5]. Sampling and analysis of workers' clothing, vehicles, and home environments must be carried out to assess take-home contamination and to prevent exposures to family members.

The following are examples of purposes for surface sampling, as based on general considerations introduced above [4].

1. *Hazard identification and evaluation*—Estimation of the expected and/or or maximum concentrations of analyte(s) of interest in the workplace or other locale. The information obtained is used to evaluate risk, to recommend worker protection requirements, and to assess the probability of adverse health effects, including dermal responses such as contact dermatitis.
2. *Exposure assessment*—Collection of exposure data for when the existence of a health hazard is known or postulated. Assessment may be focused on groups or populations of workers and/or family members, rather than on an individual worker. It requires, within limitations, the use of instrumentation and methods that offer the lowest available analytical reporting limits for the contaminant(s) of concern.
3. *Facility characterization*—Determination of the surface contamination levels of one or more analyte(s) of interest within a facility at an initial or baseline point, during or after process operations, or as part of facility decommissioning.
4. *Housekeeping*—Determination of the effectiveness of housekeeping actions. For example, wipe samples are often collected from cleaned surfaces to assess whether the cleaning procedure was effective in removing the contaminant(s) of interest.

5. *Selection of engineering controls*—Determination, for analyte(s) of interest that are not totally contained, of the collection or capture efficiencies of control devices necessary to bring specific contaminant concentrations below applicable limits at specific sampling locations; and for evaluation of the effectiveness of spill cleanup procedures.
6. *Evaluation of engineering controls*—Measurement of the quantities of analyte(s) of interest passing or escaping from a control device due to leaks, wear, damage, inadequate maintenance, overloading, or accidents.
7. *Evaluation of exposure pathways*—Measurements used as part of an evaluation of the potential contribution of (an) agent(s) of interest on surfaces to total worker, or workers' families', exposures. Assessment of the potential for take-home contamination might entail sampling of workers' clothing, shoes, and other items.
8. *Selection of personal protective equipment*—Determination of requirements for personal protective equipment in order for (a) worker(s) to inhabit a contaminated or potentially contaminated area for a specific period of time.
9. *Compliance with regulations and standards*—Measurements required to satisfy regulatory or legal requirements, to determine if exposures and/or contaminant surface concentrations in the workplace are below regulatory or established occupational exposure limits.
10. *Source identification*—Determination of the contribution from each of many potential sources to the presence of analyte(s) of interest, based on the unique characteristics of each of the agents of concern.
11. *Education and training*—Sampling, often accompanied with screening analysis, used to educate workers and managers in the importance of sound control practices such as engineering controls, personal protective equipment, and good housekeeping.
12. *Investigation of complaints*—Resolution of concerns expressed by workers, management, or other stakeholders.

Thus, in view of the above considerations, it is crucial to define the purpose(s) for collection of surface samples prior to conducting sampling. Defensibility of the data obtained is of primary concern. The use of standardized protocols is more likely to enable potential data inter-comparisons and foster acceptance of the reported results.

Sampling for Assessment of Dermal Exposure

Considerations for the assessment of occupational dermal exposures have been proposed based on numerous scientific studies [6,7]. In view of this, the European Standards Committee (CEN) promulgated a standard technical report that outlines criteria for assessment of occupational dermal exposure [8]. A conceptual model of dermal exposure was outlined based on the extensive body of relevant scientific literature [6]. This model forms the basis of a protocol for choosing candidate measurement methods that can be used to assess dermal exposure contaminants and pathways. Dermal exposure assessment is often carried out through direct sampling from skin via wipe sampling, tape stripping, rinsing techniques, or in situ measurement methods, for example, Ref. [7]. Indirect dermal exposure assessment methods include, for example, patch sampling and sampling of clothing or gloves [6–8].

In general, four objectives for assessing dermal exposure can be highlighted [6]:

1. Research on adverse health effects of chemical exposures, including: (a) epidemiological investigations and risk assessment; (b) investigation of possible associations between skin exposure and adverse health effects; (c) development of exposure-response relationships for risk assessment; and (d) estimation of disease burden due to skin exposures.
2. Evaluation of exposure processes and pathways to assist in the development, implementation, and evaluation of exposure control measures or interventions.
3. Compliance, compensation claims, 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 family members') exposure pathways.

Many of the considerations for carrying out dermal sampling mirror those outlined earlier for collection of non-dermal surface samples. Over 650 chemicals with "skin" notation have been identified [9], but the importance of dermal exposure is often underestimated or ignored.

Standardized Surface and Dermal Sampling Techniques

Representative substrates and sample media of interest that are applicable to surface and dermal sampling include, but are not necessarily limited to, the following:

- Hard/smooth/nonporous surfaces
- Soft/rough/porous substrates
- Fragile substrates
- Oily or coated surfaces
- Grossly contaminated surfaces
- Skin (exposed and/or protected)
- Clothing and personal protective equipment
- Patches, swabs, and tape
- Bulk materials, e.g., soils, deposited dust, and spilled materials

As an example, sampling techniques for metals have been promulgated that address sample collection from many of the above surface substrates. For maximum collection efficiency of metals (and excluding collection of bulk samples), "wet" sampling techniques using wipes are generally preferred [10,11]. However, there are situations where wet sampling of certain components and equipment are not desirable, and dry sampling techniques are required. For example, due to technical considerations, surfaces of certain materials and components must be protected against damage from the action of wetting agents and/or sample collection; hence, sampling methods that are less aggressive are sometimes required. For nonmetals, depending on the chemical or biological agent of concern, analogous considerations may be applicable.

In the case of surface sampling for metals, a hierarchy of sample collection methods is generally recommended [4]. At the outset, when it is determined that surface samples must be obtained, wet wipe sample collection methods are usually considered first. Such techniques are routinely applicable to smooth, hard, nonporous surfaces, and also to dermal sampling. Other sampling methods for various surfaces (including skin and clothing) consist of vacuuming methods, dry wiping protocols, tape stripping, rinsing techniques, and the use of swabs for collection of biological agents.

Table 1 summarizes standardized procedures for surface and dermal sampling that have been produced by OSHA [12] and NIOSH [13]; applications to sampling and analysis of metals and organics are exemplified. Dermal sampling by use of patch samples or rinsates has been described briefly in several OSHA and NIOSH methods (Table 1). Such techniques are presently planned for further development as voluntary consensus standards within the ASTM International subcommittee on workplace exposure monitoring.

A number of ASTM International voluntary consensus standards pertaining to surface sample collection in workplace and building environments have been promulgated, and they are summarized in Table 2. ASTM standards have been published describing wet wipe sample collection of metals [14,15]. An ASTM surface tape stripping method has also been promulgated, and this technique is applicable to multiple analytes [16]. A tape stripping method for sampling of fungal spores is presently under development within ASTM International. When the surface to be sampled is rough or porous, and wet wipe sampling or tape stripping is deemed to be impractical, the use of vacuum collection methods is often considered in lieu of wiping or stripping techniques [17,18]. In rare cases where the surface to be sampled is energized, fragile, or reactive, and beryllium is the only analyte of interest, dry wipe sampling is an option for sample collection of this metal [19]. The use of wipes meeting the specifications of ASTM E1792 [20], while developed for wipe sampling materials for lead on surfaces, may be appropriate for sample collection of other metals. A related ASTM specification for wipe sampling materials for beryllium is presently under development.

TABLE 1—*OSHA [12] and NIOSH [13] procedures for sample collection from surfaces in occupational settings.*

Methods	Sampling Media/Device	Target Substrate(s) Sampled	Comments
OSHA ID-125G and ID-206	"Wet" or "dry" filter or wipe	Smooth surfaces, dermal samples	Alcohol wipes widely used; mainly applicable to metals
NIOSH 9100, 9101, 9102, 9105 and 9110	"Wet" wipes	Smooth surfaces, dermal samples	Metallic analytes: Pb, Cr(VI), Be, elements
OSHA Technical Manual (various)	Patch samples, hand rinsates	Dermal samples	Various protocols; also clothing, gloves, etc.; multiple analytes
NIOSH 3600, 3601, 9200, 9201, 9202 and 9205	Patch samples, hand rinsates	Dermal samples	Applicable to pesticides, metalworking fluids, etc.; may apply to other agents

TABLE 2—*ASTM International standards for sample collection from surfaces in workplaces and buildings.*

Standard	Sampling Media/Device	Target Substrate(s) Sampled	Comments
ASTM E1728 [14]	"Wet" wipe	Smooth surfaces	Applicable to Pb sampling; regulatory applications
ASTM D6966 [15]	"Wet" wipe	Smooth surfaces	Various wetting agents can be used; applicable to metals
ASTM E1216 [16]	Adhesive tape	Smooth surfaces	Poor collection efficiency for ultrafines; may damage fragile substrates; multiple analytes
ASTM D5438 [17]	Modified upright vacuum cleaner	Floors	Sampling from carpets; multiple analytes
ASTM D7144 [18]	Sampling cassette with collection nozzle	Rough, porous, uneven surfaces; fragile surfaces	"Micro-vacuum" dust sampling for metals; may be applicable to other agents
ASTM D7296 [19]	"Dry" wipe	Fragile surfaces	Applicable to beryllium only; special cases
ASTM E1792 [20]	Pb wipe specification	Smooth surfaces	Applicable to Pb sampling; may use for other metals; regulatory applications
ASTM D5756 [21]	"Micro-vacuum" sampler	General surfaces	Applicable to collection of asbestos fibers
ASTM D6480 [22]	Cloth: clean room wipe	Smooth surfaces	For collection of asbestos fibers
ASTM D6661 [23]	Solvent-wetted wipe	Smooth surfaces	Applicable to sampling of organic compounds
ASTM E2458 [24]	Swab sampler	General surfaces	Suspected biological agents in powders
ASTM D6333 [25]	Polyurethane foam roller	Floors	Applicable to pesticide residues

In addition, ASTM procedures for surface sampling of asbestos by vacuum sampling [21] or wiping, [22] wipe sampling of organic compounds [23], swab collection of biological agents [24], and collection of pesticide residues from floors [25] have been published (Table 2). Consensus surface sampling methods for lead [26], beryllium [27] and asbestos [28] have been developed largely in response to regulations in the United States. Besides the aforementioned ASTM standard surface sampling guide for metals [4], an analogous standard sampling guide for asbestos has also been developed [29].

Other ASTM standards relating to surface sampling and assessment of surface contamination have been developed to address applications in clean rooms and aerospace (Table 3) [30–33]. While these are specialized uses, there may be situations where the standards could be employed in contamination assessment in occupational and other environments.

The International Organization for Standardization (ISO) has promulgated a trio of international standards that address the measurement of surface contamination by radioactive materials [34–36]. These standards entail the measurement of radiation sources on surfaces of equipment and facilities, but they do not apply to the evaluation of radioactive contamination on skin and clothing. Methods for direct and indirect measurement of radionuclides collected from surfaces are described in these ISO standards.

Generic techniques for dermal sampling have been described in a European standard, EN TS 15729 [37]. This standard technical specification is a companion document to the aforementioned dermal sampling strategies technical report [8] that was developed by the same group. Currently, a draft ISO guidance document is under development that is based on these European standards and should soon be finalized.

Performance Data

In several cases, performance data have been published regarding collection efficiencies of some of the various surface sampling methods cited above. For instance, wet wipe sampling has been evaluated for the collection of lead oxide dust from smooth, hard surfaces, with sample collection efficiencies exceeding

TABLE 3—*ASTM International standard procedures for surface sampling in aerospace and clean room applications.*

Standard	Sampling Media/Device	Target Substrates Sampled	Comments
ASTM F303 [30]	Rinse method	Aerospace components	Collection of particulate matter for assessment of cleanliness
ASTM F51 [31]	Particle sizing instrument	Clean room garments	Evaluation of contamination from fibers and particles
ASTM E2088 [32]	"Witness" surface	Clean room surfaces	Measurement of particle deposition
ASTM F24 [33]	Optical particle counter	Electronic components	Assessment of surface contamination

75 % routinely attained [38,39]. A minimum collection efficiency of 75 % has been specified for lead-containing settled dust that is sampled from smooth surfaces [20], and this criterion is generally applicable to other analytes. However, sampling from rough, porous or fragile surfaces cannot guarantee high collection recoveries, hence it is desired to harmonize the sampling procedures to the extent possible so as to enable reliable data comparisons.

In related work, a comparison of wet versus dry sampling was carried out on hard, smooth surfaces spiked with beryllium [40]. It was found that wet wipe sampling ordinarily 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 beryllium was carried out wherein dry, wet, and alcohol wipe methods were evaluated for their application in removing beryllium-containing dust from painted surfaces [41]. This investigation found alcohol to be most effective for removing beryllium dust from oily surfaces, while (not surprisingly) dry wipes were least effective for this purpose. These studies have served to provide necessary back-up data in support of standardized wipe sampling protocols for metals, e.g., ASTM D6966 [15].

The ASTM International high-volume vacuum collection method (ASTM D5438 [17]) for worn carpeted surfaces has been evaluated using reference material spikes, and good dust collection efficiencies (≈80 % and greater) have been reported for various types of carpets [42]. Previous investigations of this high-volume vacuum collection system on new carpets also reported effective collection (>75 %) of leaded dust from such substrates [43]. The more recently developed ASTM International low-air volume "micro-vacuum" collection method (ASTM D7144 [18]) was evaluated [44], and collection efficiencies from a variety of representative substrates were reported based on gravimetric analysis. Although recoveries were generally non-quantitative (<75 %), it was emphasized that standardization of the micro-vacuum sampling technique should ensure data comparability through harmonization of the sampling device and collection procedure. However, losses due to capture of significant amounts of material within the collection nozzles of the micro-vacuum samplers were reported [44]. This observation will hopefully lead to the design and development of improved samplers, where the collection inlet is incorporated into the body of the sampler [45]. While removal of material from within the collection nozzles may be possible, in practice this is difficult to achieve.

In other research, assessment of dermal wipe sampling using different sample collection media has been carried out using lead as an analyte [46]. Most leaded dust (≈60 %) is recovered after sample collection with one wipe, although successive wiping increases overall dust removal (to ≈90 %) from workers' hands. Unfortunately to date, dermal sampling procedures have not been well standardized, and this has led to difficulties in evaluating and comparing data from a variety of different studies [47]. Data obtained by means of dermal sample collection techniques are often confounded by factors such as reactivity of the agent(s) of concern, analyte transport through skin, spatial variability of contaminant levels, and variance in the nature of skin surfaces [6,7]. Nevertheless, dermal sampling methods for chemical (e.g., pesticides, metalworking fluids) and biological agents (e.g., bacteria, viruses) need to be harmonized to the extent possible, and this remains an important area for further research and development.

Bulk Sample Collection

While methods for obtaining bulk samples are outside the scope of this article, they are briefly mentioned here since these techniques often complement surface and/or dermal sampling. An excellent source of information on bulk sampling methods for soils, solid waste, water, field equipment, etc., is the U.S. Environmental Protection Agency, which has published a comprehensive document [48] that covers issues such as: (a) Sampling strategies and design; (b) Sampling techniques, media, and equipment; (c) Standardized sampling procedures developed through voluntary consensus (notably ASTM International standards); and (d) Data quality considerations pertaining to sample collection, sample handling, and transport. A great many relevant ASTM International standards on collecting bulk samples have also appeared in compendium publications on environmental sampling [49,50]. Additional study is needed regarding when it is more appropriate to use bulk sampling in lieu of surface sampling. Performance data and guidelines are limited in this area.

Summary

The purpose of this article was to highlight the available standardized collection methods that are applicable to surface and dermal sampling. Within the arena of surface and dermal sample collection, our goal is

to encourage the development of voluntary consensus standards in the areas of interest for which such standards are presently unavailable. Methods for surface sampling from smooth, hard surfaces are now reasonably well standardized, as evidenced by the availability of relevant international voluntary consensus standards. Additionally, vacuum sampling methods for collecting dust from rough, porous (and other) surfaces have also been standardized in the form of ASTM International procedures. General bulk sampling methods (not specific to dermal exposure hazards) are also well standardized, and the use of voluntary consensus standards is encouraged. However, dermal sampling methods for chemical and biological agents require better harmonization and evaluation. Efforts are currently underway to fill these gaps.

Acknowledgments

The writers thank the members of ASTM International Committee D22 for their continued contributions and support. Drs. Aaron Sussell, Martha Waters, Bob Streicher, and Ken Brown kindly reviewed the draft manuscript. Mention of company names or products does not constitute endorsement by the Centers for Disease Control and Prevention, the U.S. Department of Energy, or their contractors. The contents and conclusions of this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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