OSHA Technical Manual (OTM) Section II: Chapter 2

[Updated: February 11, 2014]

Surface Contaminants, Skin Exposure, Biological Monitoring and Other Analyses

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I. Introduction

The purpose of this chapter is to provide guidance to OSHA Compliance Safety and Health Officers (CSHOs) and to the industrial hygiene community on the potential for skin exposure to chemicals in the workplace and the available means of assessing the extent of skin exposure. This chapter provides guidance for the use and interpretation of surface wipe sampling for assessing potential contamination which may lead to biological uptake through inhalation, ingestion, or dermal exposure. This chapter discusses methods for assessing skin contamination, such as dermal dosimeters (e.g., sorbent pads) and dermal wipe sampling, and provides guidance for monitoring of biological uptake. Finally, this chapter provides guidance for certain specialized analyses unrelated to dermal exposure, such as soil analysis, materials failure analysis, explosibility determinations, and identification of unknowns.

Skin exposure to chemicals in the workplace is a significant problem in the United States. Both the number of cases and the rate of skin disorders exceed recordable respiratory conditions. In 2010, 34,400 recordable skin diseases or disorders were reported by the Bureau of Labor Statistics (BLS) at a rate of 3.4 illnesses per 10,000 full-time employees, compared to 19,300 respiratory conditions with a rate of 1.9 illnesses per 10,000 full-time employees (BLS, 2011).

In addition to causing skin diseases, many chemicals that are readily absorbed through the skin can cause other health effects and contribute to the dose absorbed by inhalation of the chemical from the air. Skin absorption can occur without being noticed by the worker. This is particularly true for non-volatile chemicals that are hazardous and which remain on work surfaces for long periods of time. The number of occupational illnesses caused by skin absorption of chemicals is not known. However, of the estimated 60,000 deaths and 860,000 occupational illnesses per year in the United States attributed to occupational exposures, even a relatively small percentage caused by skin absorption would represent a significant health risk (Boeniger, 2003).

Biological monitoring refers to testing which is conducted to determine whether uptake of a chemical into the body has occurred. Biological monitoring tests assess a sample of a worker's urine, blood, exhaled breath, or other biological media to evaluate the presence of a chemical or its metabolite, or a biochemical change characteristic of exposure to a particular chemical. Biological exposure guidelines such as the American Conference of Governmental Industrial Hygienists (ACGIH) Biological Exposure Indices (BEIs) are numerical values below which it is believed nearly all workers will not experience adverse health effects. The BEI values correspond to the biological uptake that would occur in workers exposed to airborne concentrations at the ACGIH Threshold Limit Value (TLV). When biological monitoring indicates that workers have been exposed to a chemical, but the airborne concentrations are below any exposure limits, it suggests that exposures are occurring by another route, such as dermal absorption and/or ingestion.

Where other exposure routes are suspected, surface wipe sampling may be useful. Surface wipe sampling in areas where food and beverages are consumed and stored (including water bubblers, coolers, and drinking fountains) can be used to assess the potential for ingestion or dermal exposure. Such wipe sampling results can be used to support citations for violations of the Sanitation standard, 29 CFR 1910.141, or the applicable housekeeping provisions of the expanded health standards, such as Chromium (VI), 29 CFR 1910.1026. To assess the potential for skin absorption, surface wipe sampling in work areas may be used to show the potential for contact with contaminated surfaces. Such results could be used to support violations of the Personal Protective Equipment (PPE) standard, 29 CFR 1910.132(a), or applicable provisions of the expanded health standards, such as the Methylenedianiline standard, 29 CFR 1910.1050. For direct assessment of skin contamination, skin wipe sampling or dermal dosimetry may be used.

In addition, Section V of this chapter, Other Analyses, provides guidance for submitting samples to the Salt Lake Technical Center (SLTC) for specialized analyses including:

- Soil analysis in support of the Excavation standard (29 CFR 1926 - Subpart P - Excavations).
- Materials failure analysis.
- Explosibility determinations including:
  - Combustible dust analysis
  - Flash points
  - Energetic reactivity of chemicals
  - Autoignition temperatures
- Biological sampling for organisms (or chemicals associated with their presence) such as:
  - Fungi
  - Bacteria (such as Legionella)
  - Endotoxin (component of the outer membrane of certain gram-negative bacteria)
- Mass spectrometry analysis for identification of unknown materials in:
  - Industrial processes
  - Indoor air samples
  - Contaminated water samples

Many of these tests are labor intensive and custom in nature. Always discuss the need for specialized analysis with the SLTC prior to collecting or sending samples.

Appendix D discusses techniques for combustible dust sampling. Such sampling is conducted where the potential for rapid combustion/burning (deflagration) or violent burning with rapid release of pressure (explosion) is suspected due to the presence of accumulations of settled dust. Bulk samples of settled dust are collected and sent to the SLTC. Lab analysis is used to determine whether the composition of the dust poses an explosion hazard.

II. Basics of Skin Exposure

A. Effects on the Skin

Skin contact with chemicals can result in irritation, allergic response, chemical burns, and allergic contact dermatitis. Irritant dermatitis may be caused by a variety of substances such as strong acids and bases (primary irritants). Some examples of chemicals which are potent irritants include: ammonia, hydrogen chloride, and sodium hydroxide. Generally, primary irritants produce redness of the skin shortly after exposure with the extent of damage to the tissue related to the relative irritant properties of the chemical. In most instances, the symptoms of primary irritation are observed shortly after exposure; however, some chemicals produce a delayed irritant effect because the chemicals are absorbed through the skin and then undergo decomposition within aqueous portions of the skin to produce primary irritants. Ethylene oxide, epichlorohydrin, hydroxylamines, and the chemical mustard agents, such as bis (2-chloroethyl) sulfide, are classic examples of chemicals which must first decompose in the aqueous layers of the skin to produce irritation.

Allergic contact dermatitis, unlike primary irritation, is caused by chemicals which sensitize the skin. This condition is usually caused by repeated exposure to a relatively low concentration chemical which ultimately results in an irritant response. Frequently, the sensitized area of skin is well defined, providing an indication of the area of the skin which has been in contact with the sensitizing material.

A wide variety of both organic and inorganic chemicals can produce contact dermatitis. Some examples of these chemicals include: aromatic nitro compounds (e.g., 2,4-dinitrochlorobenzene), diphenols (e.g., hydroquinone, resorcinol), hydrazines and phenylhydrazines, piperazines, acrylates, aldehydes, aliphatic and aromatic amines, epoxy resins, isocyanates, many other organic chemicals, and metals (e.g., hexavalent chromium). These substances can also produce contact sensitization. Allergic contact dermatitis is present in virtually every industry, including agriculture, chemical manufacturing, rubber industry, wood, painting, bakeries, pulp and paper mills, healthcare and many others. Also associated with both irritant and allergic contact dermatitis are metalworking fluids (see OSHA's Safety and Health Topics page on Metalworking Fluids).

Lastly, there is a class of chemicals which can produce allergic reactions on the skin after exposure to sunlight or ultraviolet (UV) light. These chemicals are called photosensitizers. Polynuclear aromatic compounds from coke ovens and the petroleum-based tars are examples of chemicals which can be photoactivated on the skin to cause an irritant response.

B. Skin Absorption

In addition to the effects that chemicals can directly have on the skin, the skin also acts as a pathway for chemicals to be absorbed into the body. The skin primarily consists of two layers—the epidermis and the dermis. The outer layer of the epidermis is composed of a compacted layer of dead epidermal cells called the stratum corneum which is approximately 10 − 40 micrometers thick. The stratum corneum is the primary barrier for protection against chemical penetration into the body. Its chemical composition is approximately 40 percent protein, 40 percent water, and 20 percent lipid or fat. Because skin cells are constantly being produced by the body, the stratum corneum is replaced by the body approximately every two weeks.

Chemical absorption through the stratum corneum occurs by a passive process in which the chemical diffuses through this dead skin barrier. Estimates of the amount of chemicals absorbed through the skin as discussed below assume that the chemicals passively diffuse through this dead skin barrier and are then carried into the

body by the blood flow supplied to the dermis.

A number of conditions can affect the rate at which chemicals penetrate the skin. Physically damaged skin or skin damaged from chemical irritation or sensitization or sunburn will generally absorb chemicals at a much greater rate than intact skin. Organic solvents which defat the skin and damage the stratum corneum may also result in an enhanced rate of chemical absorption. If a chemical breakthrough occurs while wearing gloves or other protective clothing, the substance becomes trapped against the skin, leading to a much higher rate of permeability than with uncovered skin. A worker who wears a glove for an extended period of time experiences enhanced hydration to the skin simply because of the normal moisture which becomes trapped underneath the glove. Under these conditions, chemical breakthrough or a pinhole leak in a glove can result in greater chemical absorption due to increased friction, contact time with the substance and increased temperature resulting in a higher overall absorption through the skin. In another example, a worker may remove a glove to perform a task which requires increased dexterity, exposing the skin to additional chemical exposure even after redonning the glove.

C. Risk Assessment (Establishing a Significant Risk of Skin Exposure)

Risk is determined from the degree of hazard associated with a material, together with the degree of exposure. Note that dermal exposures may vary widely between workers based on individual hygiene practices. The dermal hazard can be ranked based upon the degree of skin damage or systemic toxicity associated with the chemical of interest. Those settings with both a high degree of potential exposure and a high degree of dermal hazard would warrant the closest attention, and justify collecting sampling data to document the potential exposure, such as wipe sampling, skin sampling, or biological monitoring.

In estimating the potential exposure, consider the following:

- The risk of chemical splash.
- Significant differences in work practices between individuals.
- Use of gloves versus hand tools when in direct contact with chemicals.
- Use of shared tools.
- Cleaning frequencies for tools and equipment, including doorknobs, telephones, light switches, keyboards and actuators on control panels.

The dermal exposure potential can be ranked based upon the:

- Frequency and duration of skin contact.
- The amount of skin in contact with the chemical.
- The concentration of the chemical.
- The likely retention time of the material on the skin (e.g., highly volatile or dry powdery materials are not likely to remain in contact with the skin, whereas materials with a higher molecular weight and sticky materials will remain in contact with the skin and thus be available for dermal exposure).
- The potential for dermal absorption, as described below.

The absorption of chemicals through the skin can have a systemic toxic effect on the body. In certain instances dermal exposure is the principal route of exposure, especially for chemicals which are relatively non-volatile. For example, biological monitoring results of coke oven workers coupled with air monitoring of the workers' exposure demonstrated that 51 percent of the average total dose of benzo[a]pyrene absorbed by coke oven workers occurred via skin contact (VanRooij et al., 1993). Studies of workers in the rubber industry suggest that exposure to genotoxic chemicals present in the workplace is greater via the skin than via the lung (Vermeulen et al., 2003).

Dermal exposures will contribute significantly to overall exposure for those chemicals with low volatility and high dermal penetration, such as many pesticides. One indicator of the volatility of a chemical is the Vapor Hazard Ratio (VHR). The VHR is the ratio between the vapor pressure (at a given temperature and pressure) and the

airborne exposure limit for a chemical; the lower the VHR, the less significant the airborne exposure to vapor and the greater the potential for dermal penetration.

A common indicator of dermal absorption potential is the relative solubility of a material in octanol and water, often called the octanol-water partition coefficient (K_{ow}). This partition coefficient is often expressed in the logarithmic form as Log K_{ow}. Chemicals with a log K_{ow} between -0.5 and + 3.0 are the most likely to penetrate the skin (Ignacio and Bullock, 2006). Chemicals must have some degree of lipid (fat) solubility to absorb into the stratum corneum. To penetrate into thelayer of skin, they must have some degree of solubility in water.

Note also that skin penetration may be increased under conditions of high humidity. When temperatures are elevated, sweating may contribute to increased skin absorption. Wearing ineffective or compromised gloves, for example, may actually increase dermal penetration. Proper selection and maintenance of chemical protective gloves, as required by the PPE standard (29 CFR 1910.132), are essential to ensure effective protection. Subsection E provides additional information regarding glove permeability.

Chemicals for which dermal exposures are recognized as making a significant contribution to overall worker exposure include pesticides, formaldehyde, phenolics, coal tar, creosote, and acrylamide in grouting operations.

Appendix A lists chemicals with systemic toxicity for which skin absorption is recognized as making a significant contribution to occupational exposure. This list includes only chemicals that have OSHA PELs or ACGIH TLVs and a "skin designation" or "skin notation," and is not intended to be a comprehensive list. This exposure may occur by contact with vapor, aerosols, liquid, or solid materials, and includes contact with the skin, mucous membranes and the eyes. Where high airborne concentrations of vapor or aerosol occur involving a chemical noted for dermal absorption, the issue of exposed skin should be considered carefully. Note also that certain chemicals, such as dimethyl sulfoxide (DMSO) are known to facilitate dermal absorption of other chemicals.

For chemicals which are absorbed through the skin and which are hazardous, the levels of exposure on the skin must be maintained below a level at which no adverse effects would be observed. One of the simplest ways of determining this amount is to estimate the amount of a chemical which can be absorbed into the body based upon an air exposure limit. For example, the OSHA permissible exposure limit (PEL) for methylenedianiline (MDA) is 0.1 parts per million (ppm), or 0.81 milligrams per cubic meter of air (mg/m^3). If we assume that the average worker breathes 10 m^3 of air in an eight-hour workday, and further assume that all of the MDA is absorbed from the air at the PEL, then the maximum allowable dose to the body per workday becomes:

(0.81 mg/m^3) x (10 m^3) = 8.1 mg maximum allowable dose to the body for MDA

In addition to using OSHA PELs, ACGIH TLVs or other occupational exposure limit (OEL) can also be used to establish the maximum allowable dose in the same manner. This method assumes that the toxic effects of the chemical are systemic and that the toxicity of the chemical is independent of the route of exposure. Note that the concept of a maximum allowable dose cannot be used to enforce compliance with the OSHA PELs for air contaminants (29 CFR 1910.1000) through back-calculation of a measured dermal exposure.

The lethal dose to the skin which results in death to 50 percent of exposed animals (LD_{50} dermal) is also a useful comparative means of assessing dermal exposure hazards. The OSHA acute toxicity definition (defined in 29 CFR 1910.1200 Appendix A, Section A.1.1) as it relates to skin exposure refers to those adverse effects that occur following dermal administration of a single dose of a substance, or multiple doses given within 24 hours. Substances can be allocated to one of four acute dermal toxicity categories according to the numeric cut-off criteria specified in Table 1 below. Acute toxicity values are expressed as approximate LD_{50} dermal values or as acute toxicity estimates or ATE (see Appendix A of 29 CFR 1910.1200 for further explanation on the application of ATE. Refer to Table A.1.2 in Appendix A for Conversions to ATEs).

Table 1. Classification Criteria for Acute Dermal Toxicity*

Exposure Route	Category 1	Category 2	Category 3	Category 4
Dermal LD_{50} (mg/kg bodyweight; rat or rabbit preferred animal species)	≤ 50	> 50 and ≤ 200	> 200 and ≤ 1,000	> 1,000 and ≤ 2,000

* Dermal administration of a single dose of a substance, or multiple doses given within 24 hours. See 29 CFR 1910.1200 Appendix A for classification criteria for mixtures.

Source: Adapted from 29 CFR 1910.1200 Appendix A

If available, the no observable effect level (NOEL) can also be useful in establishing a safe exposure level. Skin notations or skin designations for chemicals listed with ACGIH TLVs or the OSHA PELs are also useful guides; however, many chemicals (e.g., hexone, xylene and perchloroethylene) which can pose a dermal hazard are not designated.

D. Estimating the Extent of Absorption of Chemicals Through Skin

For exposure to chemicals which are recognized as systemic toxins, that is, chemicals which are toxic once absorbed into the bloodstream, the route of exposure to the chemical may not be important. Hence, the maximum allowable dose can be used as a basis for determining if a chemical poses a skin exposure hazard.

The extent of absorption of a chemical through the skin is a function of the area of the exposed skin, the amount of the chemical, the concentration of the chemical on the skin, the rate of absorption (flux rate) into the skin, and the length of time exposed (Kanerva et al., 2000). Assume, for example, that a worker has contact on the interior portion of both hands to a solution of phenol (10 percent solution by weight) for two hours. Approximately how much phenol would be absorbed? The flux rate, J, is determined by:

$J = (K_p)$ (Concentration of Chemical on Skin)

Where K_p is skin permeability coefficient of compound in water (cm/hr)

Kp for phenol = 0.0043 cm/hr (K_p values are available in the EPA Dermal Risk Assessment Guide; EPA/540/R/99/005, 2004)

Thus, at a concentration of 10 percent by weight (10 g/100 cm^3; 10,000 mg/100 cm^3; or 100 mg/cm^3 where 1 cm^3 of water weighs 1 g and 1 g equals 1,000 mg):

J = (0.0043 cm/hr) x (100 mg/cm^3) = 0.43 mg/(cm^2•hr)(flux rate)

Hence, under these conditions, 0.43 mg of phenol will be absorbed through the skin per cm^2 of exposed skin per hour.

Therefore, the absorbed dose of phenol through the skin of a worker's two hands (both hands exposed with an approximate area of 840 cm^2) would be determined as follows:

Absorbed Dose = (840 cm^2) x (0.43 mg/(cm^2•hr)) (2 hr) = 722 mg absorbed over a two-hour period.

This compares to an allowable dose (PEL = 19 mg/m^3) via the lung for an eight-hour exposure of 190 mg [(19 mg/m^3) x (10 m^3)]. Hence, this two-hour exposure via the skin would represent absorption of phenol which is 3.8 times the allowable dose via the lung.

The following hypothetical example illustrates the relative importance of skin absorption as a factor in exposure. Let us assume that a worker is wearing gloves and the gloves are exposed to a phenol solution. Let us further assume that the penetration through the gloves is detected by a hand wipe sample, and that 75 mg of phenol is reported present from a water hand rinse of the worker's hands taken before lunch. Let us further assume that the amount of phenol detected inside the glove at the lunch break represents a uniform constant exposure which occurred shortly after the beginning of the work shift. Finally, let us further assume that the 75 mg of phenol is present in approximately 10 milliliter (mL) of water (perspiration) present on the surface of the skin. How much phenol was absorbed in the eight-hour period?

First, we determine the flux rate: J = (0.0043 cm/hr) x (75 mg/10 cm^3) = 0.0322 mg/(cm^2•hr) (flux rate)

Absorbed Dose = (840 cm^2) x (0.0322 mg/(cm^2•hr)(8 hr) = 216 mg of phenol absorbed

Hence, the estimated amount of phenol absorbed into the body is greater than the maximum dose of phenol permitted to be absorbed via the lung, which is 190 mg.

E. Glove Permeability

Permeation is the process by which a chemical moves through a protective clothing material on a molecular basis. This process includes the: 1) Sorption of molecules of the chemical into the contacted (challenge side) surface of the test material; 2) Diffusion of the sorbed molecules in the material; and 3) Desorption of the molecules from the opposite (collection side) surface of the material. Glove manufacturers publish breakthrough data which reflect the length of time which occurs before a chemical permeates through a particular type of glove material. These tests are performed using American Society for Testing and Materials (ASTM) Method F739 (Standard Test Method for Permeation of Liquids and Gases through Protective Clothing Materials under Conditions of Continuous Contact) in which a pure or neat chemical is placed on one side of a section of the glove material and the time it takes to penetrate through the glove material is measured by analyzing the air on the other side of the glove material to detect chemical breakthrough. ASTM F739 measures the initial breakthrough of the chemical through the glove material (normalized or standardized as a rate of 0.1 µg/cm^2/minute) and the rate of permeation. The cumulative amount of chemical that permeates can also be measured or calculated.

Unfortunately, these breakthrough times can be misleading because actual breakthrough times will typically be less than reported by the manufacturer. This is the case because permeation rates are affected by temperature (as temperature increases, permeation rates increase) and the temperature of skin is greater than the test temperature, resulting in an increased permeability rate. Secondly, glove thinning occurs along pressure points where a worker may grip a tool or otherwise exert pressure on an object while wearing a glove. Glove degradation and reuse of gloves can also dramatically reduce a glove's impermeability to chemicals. Additionally, only limited breakthrough data for solvent mixtures is available and in many cases the breakthrough time for a solvent mixture is considerably less than would be predicted from the individual breakthrough times for each of the individual solvent components. Finally, batch variability can also result in wide variations in breakthrough times from one glove to the next (Klingner and Boeniger, 2002). Further, it is difficult to generalize glove breakthrough data from one manufacturer to the next, or even between one model of glove and another from the same manufacturer. This is particularly true for disposable gloves, since different fillers may be used in the formulation of different gloves, resulting in different breakthrough performance.

As a result of these limitations, it is necessary that the employer evaluate glove selection and use to prevent worker exposure as specified in 29 CFR 1910.132(d). Guidance on conducting in-use testing methods for glove selection is available (Boeniger and Klingner, 2002).

III. Wipe Sampling, Field Portable X-Ray Fluorescence Sampling, Dermal Sampling and Biological Monitoring

A. Surface Wipe Sampling

Surface wipe sampling is conducted to assess the presence of a contaminant on surfaces in the workplace that may lead to worker exposure. Surfaces contaminated with a hazardous liquid, particles, or dried residue may be contacted by workers, leading either to dermal exposure or transfer to foodstuffs and accidental ingestion. Settled dusts containing toxic material may be disturbed and resuspended, resulting in inhalation exposure.

In instances where surface contamination is suspected and the employer has not required the use of effective PPE for workers in these areas, wipe sampling may be an effective means of documenting that a skin hazard exists. Wipe sampling can help establish that a significant amount of surface contamination is present in areas in which workers are not effectively protected by PPE. Wipe samples taken inside the sealing surface of "cleaned" respirators can establish the absence of an effective respiratory protection program.

In areas where exposures to toxic metals such as lead (Pb) occur, wipe sampling of settled dust can demonstrate that a reservoir for potential exposure exists; resuspension of such settled dusts can lead to inhalation exposure. This is particularly true if improper housekeeping techniques are used, such as: dry sweeping; blowing off surfaces with compressed air; or using a shop vac instead of a HEPA-rated vacuum cleaner.

In break areas, the presence of surface contamination can lead to contamination of foodstuffs and hence, accidental ingestion of toxic material. The same is true for contamination on drinking fountains. Contamination found on the clean side of a shower or locker area could suggest the potential for take-home contamination, resulting in additional toxic exposures occurring while away from work. All of these types of wipe sampling results can be used to support violations of the housekeeping requirements found in the expanded health standards in Subpart Z of 29 CFR 1910.

In many instances, several wipe samples taken in an area suspected of being contaminated may be useful. For example, some surfaces which would be expected to be contaminated with chemicals because of airborne deposition of a non-volatile chemical may actually be relatively free of surface contamination because of frequent contact of the surface by workers (i.e., frequently contacted surfaces may be expected to be "clean" because of contaminant removal by frequent worker contact). Wipe samples of frequently contacted surfaces in conjunction with less frequently contacted surfaces in the same vicinity can be useful to establish the likelihood that skin exposure is occurring in "clean" areas in which PPE is not being used, or is being improperly used.

Housekeeping deficiencies may also be demonstrated by wipe samples which show major differences in surface contamination between work areas that have been routinely cleaned and areas which have not been recently cleaned. This sampling would allow the CSHO to demonstrate the employer's failure to maintain a clean work area. A reference control wipe sample or samples taken from areas in which exposure is not anticipated will also help to establish the relative amount of surface contamination.

Surface wipe sampling can be conducted qualitatively, for example, wiping irregular surfaces such as a doorknob, tool handle or faucet handle, or quantitatively, in which an area of specified size is wiped. Wiping an area of a specified size is necessary to determine the concentration of a contaminant on a surface. This is needed for estimating the amount of contamination to which workers are potentially exposed. The customary size of the surface area to be wiped is a 10 cm x 10 cm square, i.e., 100 cm^2. The 100 cm^2 value approximates the surface area of a worker's palm. Thus, the amount of contaminant in a 100 cm^2 sample could all be transferred to a worker's hand upon contact.

In industries such as the pharmaceutical industry, a common rule of thumb is to use the maximum allowable dose (based on the chemical's airborne exposure limit in units of $\mu g/m^3$) and the approximate area of a worker's hand (100 cm^2) to arrive at an acceptable value for surface contamination in work areas (i.e., a housekeeping standard). For example, if the eight-hour TWA exposure limit for a chemical is 1 $\mu g/m^3$, the maximum allowable dose for that chemical is 10 µg. As noted in Section II.C., the chemical's eight-hour time-weighted average (TWA) airborne exposure limit is multiplied by 10 m^3, the volume of air inhaled by an average worker in an eight-hour workday, to determine the maximum acceptable dose (i.e., 1 $\mu g/m^3$ x 10 m^3 = 10 µg). The maximum acceptable dose is then

divided by the area of a worker's hand to determine the acceptable surface limit of 10 µg/100 cm^2 or 0.1 µg/cm^2. By this rule of thumb, the amount of contaminant picked up by one hand contacting the contaminated surface is equivalent to the toxic dose allowed by the eight-hour TWA airborne exposure limit (determined by multiplying by the 10 m^3 of air breathed by an average worker in an eight-hour workday).

For highly toxic materials, hazardous levels of surface contamination will often be invisible to the unaided eye, while limits of detection for wipe sampling will be considerably more sensitive. For example, the limit of visible residue for active pharmaceutical ingredients is typically 1–5 µg/cm^2, whereas good surface wipe sampling techniques can have limits of detection in the low nanogram range. This underscores the essential value of surface wipe sampling in areas where highly toxic materials such as lead or chromium (VI) are present.

B. Field Portable X-Ray Fluorescence Sampling

X-ray fluorescence (XRF) provides real-time measurements of elemental metal on surfaces. This may be useful to measure metal in settled dust on contaminated surfaces, or in surface coatings such as on painted metal or wood. A real-time XRF analyzer and operator are available from the Health Response Team. XRF uses the interaction of x-rays with a target material to determine the elements present and their relative concentrations. When the target material has been excited by being bombarded with high-energy x-rays (or gamma rays), the material emits secondary or fluorescent x-rays that are characteristic of each element present. The rate of generation of the emitted fluorescent x-rays is proportional to the elemental concentration and is used to quantify the results.

Because x-rays will penetrate an object, the XRF will detect metals both on the surface and within the substrate of the material. To determine the quantity of removable metal contamination on a work surface, a reading is first taken on the uncleaned surface. The surface is then cleaned with a metal removal wipe until all visible dust, dirt, and debris is removed. After cleaning, a second reading is taken at the same spot and its value is subtracted from the initial reading to determine the surface concentration of metals.

The same sampling and citation strategies used for wipe sampling apply to XRF sampling. The advantage of XRF over wipe sampling is its rapid (approximately one minute per reading) sampling rate and the real-time results. For laboratory confirmation of XRF results, the area sampled with the XRF can be wipe-sampled using the traditional methods described in this chapter and submitted to the SLTC for analysis.

C. Dermal Sampling

Skin sampling is used to estimate the amount of material which contacts the skin and is relevant both for materials that affect the skin, such as corrosive materials, and for materials which absorb through the skin and have systemic effects.

Dermal exposure may be assessed through either direct or indirect methods. Direct methods measure the amount of material which contacts the skin, for example, through wipe tests which remove and recover the material from exposed skin, or use of sorbent patches (dosimeters) which are placed over the skin and capture material which would have contaminated the skin. Indirect methods measure the amount of contaminant that enters the body. Indirect methods are also known as biological monitoring.

D. Biological Monitoring

Biological monitoring is used to assess uptake into the body of a contaminant of concern. Biological monitoring is defined by the American Industrial Hygiene Association Committee on Biological Monitoring as "the assessment of human exposure through the measurement of internal chemical markers of exposure, such as the chemical agent itself and/or one of its metabolites or an exposure related biochemical change unrelated or related to disease, in human biological samples" such as urine, blood, or exhaled breath (AIHA, 2004). Biological monitoring by itself does not indicate the route of exposure to the material. Airborne sampling, skin sampling, and/or surface sampling would be needed to pinpoint the source of exposure.

Biological monitoring can be a useful technique for determining if dermal exposure is a significant contributor to the worker's overall exposure. For example, in a work environment in which the air exposure to a specific chemical is well controlled, an abnormally elevated biological monitoring result will likely indicate that skin or ingestion is a major mode of exposure. Coupled with evidence of surface contamination, and documentation of poor or non-existent personal protection against chemical skin exposure, biological monitoring can be a valuable means of documenting dermal exposure to a chemical. Biological monitoring could also be used to assess the effectiveness of PPE, such as chemical protective clothing or gloves, or the effectiveness of cartridge change schedules for air-purifying respirators. Prior to conducting biological monitoring, determine the variables that may affect the results including the potential for interferences (e.g., diet, over-the-counter drugs, personal care products, existing medical conditions, other).

Biological monitoring data can hypothetically be used to back-calculate an estimate of the corresponding airborne exposure that would have resulted in observed biological exposure. This requires the availability of adequate exposure modeling for the toxic material of interest. For example, this is done in cases of overt carbon monoxide poisoning, as described below in Section IV.C.1.

Biological monitoring by itself does not indicate that a toxic or adverse health effect has occurred, only that the material has entered the body. Biological exposure guidelines, such as the ACGIH BEIs, are numerical values below which it is believed nearly all workers will not experience adverse health effects. Where measured levels exceed a BEI, this finding provides evidence that exposures have occurred which can result in an adverse health effect. Further, a number of the OSHA expanded health standards in Subpart Z contain biological monitoring provisions. Appendix B summarizes the 2012 ACGIH BEIs and the biological monitoring guidelines contained in the OSHA expanded health standards.

In addition, NIOSH offers guidance for biological monitoring, which may be found at the following link: NIOSH Biological Monitoring Summaries. The NIOSH Biomonitoring Summaries provide a brief overview of the usage, environmental pathways, sources of exposure, toxicology, health effects, and human exposure information for most of the chemicals or chemical groups evaluated in the National Report on Human Exposure to Environmental Chemicals.

Finally, there are many studies in the peer-reviewed literature that report exposure levels for numerous chemicals measured as biological matrices for workers in a variety of occupations and industries. These studies can be useful, in a comparative fashion, for assessing the extent of exposure between exposed and unexposed workers when the workplace in the study involves the same conditions (e.g., chemical exposure, type of work) as the workplace being inspected.

IV. Sampling Methodology

A. Surface Wipe Sampling

The most common surface testing technique is surface wipe sampling. The Chemical Sampling Information (CSI) file contains wipe sampling information for many of the chemicals regulated by the expanded health standards, including the type of wipe to use.

Frequently, the wipe is dipped in distilled water or other suitable solvent prior to wiping the surface of interest. This technique facilitates transfer of the contaminant from the surface to the wipe. It is best to use a minimum of water/solvent on the wipe so that all of the water/solvent will be picked up by the wipe and not left behind on the sampled surface.

The percent recovery of the contaminant of interest from the sampled surface may vary with the characteristics of the surface sampled (e.g., rough or smooth), the solvent used, and the technique of the person collecting the sample. Consequently, surface wipe sampling may be only semi-quantitative. No OSHA standards currently

specify acceptable surface limits. Results of surface wipe sampling are used qualitatively to support alleged violations of housekeeping standards and requirements for cleanliness of PPE. Enforcement guidance is described in more detail in Section VI.

Templates may be used to define a relatively constant surface area for obtaining a wipe sample, but are not always helpful. Templates can only be used on flat surfaces, and they can cause cross-contamination if the template is not thoroughly cleaned between each use. Constructing single-use 10-cm x 10-cm templates is recommended (e.g., using cardstock or file folders). The CSHO may want to sample a much larger surface area than the area covered by a template (e.g., the CSHO may want to determine the cleanliness of a lunch table or other large surface area). In all cases, the CSHO should measure the dimensions of the area being sampled and record this value on the OSHA Information System (OIS) sampling worksheet because the mass amount of chemical measured by the laboratory will be used to determine the mass per unit area for the wipe sample.

Appendix C provides general procedures for collecting surface wipe samples, including wipe sampling procedures for hexavalent chromium.

Other surface testing techniques include direct-reading swab and wipe tests and vacuum dust collection to collect bulk samples of dust for analysis. Swab and wipe test kits with colorimetric indicators are available for contaminants, including lead, chromate, cadmium, amines, aliphatic and aromatic isocyanates, and others. These nonquantitative assessments can be used to provide an immediate indication in the field of the presence of a contaminant on a surface or the general level of surface contamination. The presence of contamination can be used to provide evidence for housekeeping deficiencies.

Lead, chromate and other test swabs are self-contained units with a fiber tip at one end and glass ampoules with reactive materials inside the swab barrel. The swabs are activated by squeezing at the crush points marked on the barrel of the swab, shaking well to mix the reagents, and then squeezing until the reactive liquid comes to the tip of the swab. While squeezing gently, the tip of the swab is rubbed on the surface to be tested for 30 to 60 seconds. The tip of the swab turns color in the presence of the chemical (for example pink to red for lead and pink to purple for chromates). Color development depends on the concentration of chemical present. Potential limitations associated with swabs include:

- Interferences in color development from chemicals or other materials that may be present (e.g., dark colored dust or dirty surfaces obscuring color development on the lead swab tip; rubbing too long or too hard causing a metallic film to collect on the lead swab tip which obscures the color change; bleeding occurring on the lead swab tip when the test surface is painted red; and high concentrations of mercuric chloride or molybdate interfering with the color development of chromate swabs).
- Delayed results (e.g., up to 18 hours for the detection of lead chromate in marine and industrial paints).
- Destruction or damage to the testing surface to assess multiple layers on metal parts or painted surfaces.

Contact the SLTC to discuss wipe sampling before considering use of these methods.

B. Skin Sampling Methods

Skin sampling methods are classified as "interception" and "removal" methods. Interception methods use a "dosimeter" such as a sorbent pad placed on the skin or clothing, which "intercepts" the contaminant before it reaches the skin. After the exposure period ends, the dosimeter is removed, and either extracted in the field to recover and stabilize the analyte of interest, or sealed and sent for laboratory analysis to determine the mass of contaminant collected on the pad. In some cases, direct reading pads are available which undergo a colorimetric change when exposed to the contaminant of interest.

"Removal" methods remove the contaminant of interest after it has deposited on the skin. Either the skin is rinsed with distilled water or mild washing solution and the rinsate is collected and analyzed for the contaminant of interest, or the skin is wiped with a dry or wetted wipe, and the analyte of interest is then extracted from the wipe.

One approach is to place the hands inside a bag that is partially filled with the washing solution, such as distilled water, distilled water with surfactant, or isopropanol diluted with distilled water. The hand is then dipped in the solution and shaken a specified number of times to recover the contaminant from the hand.

Both of these types of methods are generally qualitative in nature. The percent recovery may be variable or not quantitatively established. Further, no OSHA standards currently specify quantitative limits for dermal exposure. Qualitative documentation of the presence of a contaminant on the skin is sufficient to determine whether PPE is inadequate, whether due to inappropriate selection, maintenance, or cleaning.

When considering dermal sampling, consult OSHA's webpages at the following link: Dermal Dosimetry.

1. Direct Reading Patches/Charcoal Felt Pads
   In some instances, direct reading patches and/or bandage-type patches can be worn inside a glove to demonstrate directly through a color change that an exposure has occurred. In other instances, charcoal felt patches or bandages can be worn which can be analyzed by a laboratory to establish the presence of glove permeation by volatile organic chemicals. These charcoal pads may also be used for detection of less volatile organic chemicals. However, poor sample recoveries from a charcoal surface for higher molecular weight substances may result in underestimating the extent of skin exposure for these types of chemicals.

   When sampling inside a glove, OSHA recommends that workers being sampled wear disposable gloves inside their normal PPE, with the indicator/charcoal felt pads being placed on the disposable glove surface. Placing the pad on the disposable glove between the skin surface and the regular PPE eliminates any potential skin exposure from the chemicals used in the colorimetric pads, and also reduces any effects that perspiration might have on the sampling pads.

   For inside-the-glove sampling, it also is advisable to use a control pad to measure the concentration of airborne volatile chemicals. This control pad should be attached to the worker's clothing while the worker performs his/her normal tasks. The glove sample result would then be corrected for the amount of the organic chemical in the airborne sample to determine the amount of organic chemical actually permeating the protective glove relative to the amount of organic chemical entering the glove opening. This procedure, therefore, would allow the sampler to identify the possible route of glove contamination.

2. Wipe Sampling of Skin
   Skin wipe samples taken on potentially exposed areas of a worker's body are a useful technique for demonstrating exposure to a recognized hazard. For water-soluble chemicals, a wipe pad moistened with distilled water can be used to wipe the skin. Generally, the best procedure is to allow workers to use the wipe pad to clean their skin surfaces, and then have them insert the wipe pad into a clean container, which is labeled and sealed. Hands, forearms, faces, and possibly feet may be exposed to contaminants that a wipe sample of the skin can be used to establish exposure. Include a blank water sample and use only distilled water, or another source of water approved by the laboratory, for analysis purposes.

C. Biological Monitoring Methodology

In the event that a CSHO believes biological monitoring would be valuable to assess and evaluate worker exposure to a substance or mixture of substances, he or she should first contact their Regional Office, the SLTC and the Office of Occupational Medicine to determine the most effective approach and technique to obtain the desired result. Biological sampling requires special consideration and will be addressed on a case-by-case basis.

Biological monitoring results can be used to demonstrate significant skin absorption, ingestion or airborne exposures. For instance, when wipe/skin sampling has indicated exposure, a voluntarily obtained worker biological sample may prove useful in documenting that skin exposure to the chemical of concern has occurred. Ideally, it is

desirable to have samples from a number of workers who are suspected of being exposed. Also, control samples from individuals who do not have skin exposure, or are suspected of much less exposure, are valuable. Note that skin sampling conducted just prior to biological monitoring may result in decreased biological uptake.

1. Carboxyhemoglobin Evaluation
   Biological monitoring can also be used to estimate the degree of exposure after an emergency. Table 2 shows the relationship between airborne carbon monoxide (CO) concentrations and steady state carboxyhemoglobin (COHb) levels.

Table 2. Carbon Monoxide (CO) Concentration Versus Blood Carboxyhemoglobin (COHb) Levels*

CO Concentration (ppm)	Steady-State Blood COHb Levels (percent)
0.1	0.25
0.5	0.32
1	0.39
2	0.50
5	1.0
10	1.8
15	2.5
20	3.2
40	6.1
60	8.7
80	11
100	14
200	24
400	38
600	48
800	56
1,000	61

CO Concentration (ppm)	Steady-State Blood COHb Levels (percent)
*Predicted using the Coburn-Forster-Kane (CFK) model. Source: ATSDR, 2009	

Post-exposure COHb measurements can be used to back-calculate airborne CO concentrations in order to determine whether a citation is warranted. COHb values provided by a non-OSHA medical professional are submitted to the SLTC for evaluation using a special algorithm online worksheet on the OSHA Intranet. COHb values may be determined either from a blood sample, a breath analyzer, or a Pulse CO-OximeterTM finger measurement. No physical samples are sent to the SLTC, but chain-of-custody must be documented in the OIS.

The SLTC employs a modified, more accurate version of the Coburn-Forster-Kane equation than the closed-form version used in the 1972 NIOSH Criteria Document. The SLTC equation calculates the eight-hour TWA. Poisoning cases generally involve levels above five percent COHb. The calculation also provides an incident-specific sampling and analytical error designed to deal with the uncertainties in the data. The calculation is performed at the SLTC and the results are critically assessed for accuracy by the SLTC staff prior to reporting. The SLTC carbon monoxide experts are available to assist CSHOs in acquiring data and in interpreting results.

The following are suggestions to help ensure that the most accurate calculations will be performed.

- Before going on site, download, print and read the Carbon Monoxide Worksheet ("Submitting Data for the Carbon Monoxide Calculation at the OSHA Salt Lake Technical Center (SLTC)") on the OSHA Intranet. Take the worksheet to the site.
- If possible, call one of the SLTC carbon monoxide experts before going to the site, especially if methylene chloride is used. The Carbon Monoxide Worksheet lists the SLTC contact persons on the worksheet.
- Collect vital statistics for the victim(s) (age, weight, sex, living or deceased).
- Detail smoking activity (first-hand, second-hand tobacco smoke).
- Document oxygen saturation-affecting conditions such as pre- and post-exposure activity levels and oxygen therapy.
- Provide accurate timelines (how long the worker was exposed, when the worker was removed, how long resuscitation was performed, the time between removal and when the COHb was taken, etc.).
- List signs and symptoms of suspected exposure.
- Review the document for accuracy and completeness before submitting it to the SLTC.

2. Hydrogen Sulfide

For evaluation of suspected hydrogen sulfide (H2S) overexposures, blood thiosulfate monitoring is recommended (Ballerino-Regan and Longmire, 2010). Blood sulfide levels are useful only if obtained within two hours of exposure, and sulfhemoglobin levels are **not** useful for documenting H2S exposure. Urinary thiosulfate levels are frequently used as a biomarker, however, a quantitative relationship between hydrogen sulfide exposure levels and urinary thiosulfate levels has not been established (ATSDR, 2006). Urine thiosulfate elevation does not occur in the case of rapid fatalities but may be elevated in nonfatally exposed workers. Analysis of COHb may also be useful, since this is a reported metabolite of H2S (NIOSH 2005-110, 2004).

For biological monitoring, proper sampling containers and a protocol for handling and shipping samples need to be followed. In general, a qualified laboratory which is experienced in the analysis of biological samples will provide sample vials, shipping containers, and the technical expertise to properly collect, store

and ship specimens.

3. Review of Employer Biological Monitoring Results
   In instances in which an employer has been conducting biological monitoring, the CSHO shall evaluate the results of such testing. The results may assist in determining whether a significant quantity of the toxic material is being ingested or absorbed through the skin. However, the total body burden is composed of all modes of exposure (e.g., inhalation, ingestion, absorption and injection). For the CSHO to assess the results of the biological monitoring, all the data (including any air monitoring results) must be evaluated to determine the source(s) of the exposure and the most likely mode(s) of entry.

   Results of biological monitoring which have been voluntarily conducted by an employer shall **not** be used as a basis for citations. In fact, OSHA promotes the use of biological monitoring by employers as a useful means for minimizing exposures and for evaluating the effectiveness of control measures.

   Citations, in consultation with the Regional Office, would be appropriate when biological monitoring results indicate an unacceptable level of exposure, and the employer is unable to demonstrate that meaningful efforts to reduce or control the exposure(s) were taken.

V. Other Analyses

Soil Analysis in Support of the Excavation Standard

Soil analyses at the SLTC is performed to support CSHOs' inspection and compliance responsibilities with respect to trenching and excavation standards such as 29 CFR 1926 Subpart P. It also supports citations and legal proceedings. For further information refer to OSHA's Trenching and Excavation Topic Page.

A representative soil sample from a trench or excavation is sent to the SLTC for analysis. Soil should be placed in a heavy-duty, tear-resistant plastic bag, secured, and sealed with tape to be airtight. Place the first plastic bag in a second heavy-duty plastic bag for additional protection. Sample size can vary from one pint for very fine-grained samples to two quarts for coarse gravel. A typical sample should be approximately one quart and weigh about three pounds. Do not place any sampling documentation in the bag with the soil.

This soil sample is examined and tested according to OSHA Method ID-194. This fully validated method was developed specifically for the OSHA Excavation standard (29 CFR 1926 Subpart P). The required tests take a minimum of four days before results can be provided. The SLTC sample results specify the soil type as well as the textural and structural classification. The soil classification will be Type A, Type B, or Type C, corresponding to the descriptions listed in the Excavation standard (29 CFR 1926 Subpart P, Appendix A). When requested, moisture content can also be provided.

Any questions arising from this analysis can be answered by trained soil experts at the SLTC. This analysis helps CSHOs as well as the inspected establishment personnel understand how to properly protect workers from cave-ins and how to properly evaluate protection measures used to comply with existing regulations.

VI. Enforcement Recommendations

There are currently no surface contamination criteria or quantifications for skin absorption included in OSHA standards. CSHOs should consult OSHA's Field Operations Manual (FOM) for guidance (e.g., see Chapter 4, Section XIV on citing improper personal hygiene practices based on the absorption hazard). The expanded health standards in Subpart Z generally contain housekeeping provisions that address the issue of surface contamination. Exposures to various chemicals are addressed in specific standards for general industry, construction, and shipyard employment. For example:

- Formaldehyde, see 29 CFR 1910.1048 (paragraph (j) contains the housekeeping requirements).
- Methylenedianiline, see 29 CFR 1910.1050 (paragraph (f) provides that regulated areas must be established for areas with dermal exposure potential and paragraph (l) contains housekeeping requirements).

- Acrylonitrile, see 29 CFR 1910.1045 (paragraph (k) provides that surfaces must be kept free of visible liquid acrylonitrile).

The housekeeping provisions are generally the most stringent for the metals, which in solid form may contaminate surfaces and become available for ingestion or inhalation if housekeeping practices are poor. OSHA standards for the following metals contain provisions stating that "surfaces be maintained as free as practicable of accumulations of" the toxic metal and housekeeping requirements such as a prohibition on use of compressed air for cleaning surfaces:

- Arsenic, see 29 CFR 1910.1018 (standard includes strict housekeeping requirements in paragraphs (k) and (m)).
- Lead, see 29 CFR 1910.1025 (standard contains strict housekeeping requirements in paragraphs (h) and (i)).
- Chromium (VI), see 29 CFR 1910.1026 (standard contains strict housekeeping requirements in paragraphs (i) and (j)).
- Cadmium, see 29 CFR 1910.1027 (standard includes strict housekeeping requirements in paragraphs (j) and (k)).

Useful information on dermal exposure standards can be found at Dermal Exposure - OSHA Standards Safety and Health Topics Page.

Despite the lack of specific criteria or quantitative data for use in the enforcement of elevated exposures to surface and skin chemical hazards in the workplace, it is well established that skin exposure and ingestion of chemicals is a significant mode of occupational exposure. In instances in which a hazard can be established which is not addressed in a specific OSHA standard, the compliance officer may consider a 5(a)(1) General Duty Clause citation to address this concern. Use of the General Duty Clause is discussed in the FOM.

In lieu of issuing a 5(a)(1) citation, it is suggested that alternative citations be issued under one or more of the following OSHA standards:

- Sanitation, see 29 CFR 1910.141. In instances where a high degree of surface contamination is evident, or clear evidence exists to establish skin exposure of workers to a recognized hazard, then 29 CFR 1910.141(a)(3) can be cited. That is, the CSHO can establish that the employer has failed to keep the workplace "clean to the extent that the nature of the work allows."
- Hazard Communication, see 29 CFR 1910.1200. 29 CFR 1910.1200(h) can be cited based upon the evidence collected by the CSHO to demonstrate that the employer failed to adequately inform and train workers on the hazards present in the workplace.
- Personal Protective Equipment, see 29 CFR 1910, Subpart I. A specific citation may be issued for deficiencies in PPE under 29 CFR 1910.132, which requires that the employer evaluate the hazards, select proper PPE, and train workers on proper use of the PPE.
- Respiratory Protection, see 29 CFR 1910.134. The respiratory protection standard contains specific cleaning provisions in paragraph (h).
- Occupational Exposure to Hazardous Chemicals in Laboratories, see 29 CFR 1910.1450.
- Paragraph (f) contains the hazard communication requirements to adequately inform and train workers on the hazards present in the laboratory.
- Paragraph (e)(3) specifies occupational safety and health requirements that must be included in the Chemical Hygiene Plan. It also requires the employer to include the measures that will be taken to ensure the protection of laboratory workers.
- Paragraph (a)(2)(ii) requires that any prohibition of eye or skin contact specified in an expanded health standard be observed.

Pertinent standards dealing with construction (29 CFR 1926) and shipyard employment (29 CFR 1915).

VII. Custom Services Provided by SLTC

The following services are available on a case-by-case basis at the SLTC. Concurrence from the Area Director in an email (or via other means) sent to the SLTC management must be received before the SLTC can commit to providing some of these services.

1. Mass Spectrometry
   The mass spectrometry laboratory at the SLTC has a number of unique tools to help CSHOs resolve difficult field sampling and analytical issues. For example, mass spectrometry can be used to identify unknown or suspected organic substances found in industrial processes, indoor air quality complaints, and contaminated water. It can also be used to identify secondary substances that are given off from a heated material (i.e., thermal decomposition products).

   One of the major functions of the mass spectrometry laboratory is identification and confirmation of analytes measured in gas chromatography (GC) analysis performed at the SLTC. The same separation and identification techniques used to confirm the identity of known analytes are also useful to identify an unknown material, investigate possible contamination or batch uniformity in a material from an industrial process, or to check for conformity with a Safety Data Sheet.

   Volatile organic chemicals in contaminated water can be quantitated by several different processes, including purge and trap, equilibrium headspace analysis, or a novel approach involving thermal desorption called "Twister." The "Twister" technology is simple to use and highly sensitive.

   Thermal Desorption/Gas Chromatography/Mass Spectrometry (TD/GC/MS) is also useful for investigation of low-level or transient odors, and indoor air quality-type complaints. The SLTC can provide sampling tubes containing three resin beds designed to collect a broad range of volatile analytes. The entire collected sample is thermally desorbed into the GC column, providing analysis with maximum sensitivity.

   Using a device called a direct insertion probe and a technique called pyrolysis, some thermally labile compounds can be introduced directly into the mass spectrometer source before heat is applied. With another instrument called a PyroprobeTM, materials can be heated to temperatures as high as 1,400°C, with subsequent introduction of decomposition products into the GC column. Products released from materials involved in a fire, heated by a welder or blowtorch, or from any process involving heating can be studied in this way.

2. Materials Analysis
   The SLTC provides a variety of services to determine the cause of materials failure. Materials failure analysis examines the extent to which the properties of materials or their use contribute to significant investigations, including fatalities. This procedure often involves collaboration of experts in multiple disciplines including metallurgical engineering, materials science, explosibility, and both organic and inorganic chemistry.

   The SLTC has assisted in the investigation of several diverse catastrophes. These investigations have included chemical, gas, and dust explosions and disasters caused by incompatible chemicals and processes; metal and plastic failures; wire, synthetic and natural fiber rope failure; scaffold planking failure; plastic, fiberglass and metal piping failure; radio tower support failure; safety equipment failure; and chain and equipment overloading.

   SLTC's services include assistance in searching for industry standards that help support citations, and assistance with finding an accredited laboratory to perform any analysis that is not done at the SLTC. The SLTC tailors the assistance to the particular investigation. The SLTC can either arrange to fully investigate the accident on site, or to review results from an independent laboratory.

3. Sampling for Biological Pathogens

SLTC provides biological (both organism and chemical by-product) sampling and analysis coordination as a service to CSHOs. The SLTC has developed a standard operating procedure to assure consistent sample handling and analysis. Samples collected and analyzed through this procedure are compliant with the SLTC quality control system and chain-of-custody requirements. SLTC offers contracting services for fungi, bacteria such as Legionella, and endotoxin analysis. Other services can be arranged on a case-by-case basis.

Again, before collecting samples for microbiological analysis, CSHOs are requested to contact the SLTC for sampling requirements, technical support, assessment, and analytical coordination. The SLTC staff will review sampling and analysis plans with CSHOs and make recommendations where appropriate. The purpose of this process is to ensure that prudent sampling is performed.

4. Explosibility Analysis
   Because of the complexity of this field, it is strongly recommended that CSHOs contact the SLTC before taking explosibility samples. Doing this allows the explosibility experts to assist CSHOs in taking appropriate samples, and in tailoring the analysis to provide support for the specific inspection.

   The SLTC provides an assortment of analytical and technical information services in support of inspections involving potential explosion hazards. Analytical testing is performed in support of OSHA inspections pertaining to hazardous classified locations, grain handling, dust collection systems, confined spaces, and housekeeping. Informational support is offered for litigation, interpretation of analytical results (both in-house testing results and results from contract laboratories), and guidance for sampling and standard applicability. Explosibility experts can help investigate industrial incidents involving explosions. This help may include normal explosibility testing, and research into the reactive nature of the materials in question.

   The SLTC can provide analyses for flash points, energetic reactivity of chemicals, and autoignition temperatures. This testing is useful in support of a wide variety of inspections. Procedures for combustible dust sampling are discussed in detail in Appendix D.

VIII. References

AIHA, 2004. "Biological Monitoring – A Practical Field Manual". American Industrial Hygiene Association (AIHA) Biological Monitoring Committee, Shane Que Hee, Editor. Fairfax, Virginia: AIHA Press.

ATSDR, 2009. "Draft Toxicological Profile for Carbon Monoxide, September 2009". U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry (ATSDR). Available online at: //www.atsdr.cdc.gov/ToxProfiles/tp.asp?id=1145&tid=253. Accessed January 25, 2013.

BLS, 2012. "Workplace Injuries and Illnesses – 2011". Bureau of Labor Statistics, U.S. Department of Labor (DOL) (25 October 2012). Available online at: //www.bls.gov/news.release/pdf/osh.pdf. Accessed January 25, 2013.

Boeniger, M.F. and T.D. Klingner, 2002. "In-Use Testing and Interpretation of Chemical-Resistant Glove Performance". Applied Occupational and Environmental Hygiene 17(5): 368–378.

Boeniger, M.F., 2003. Invited Editorial. "The Significance of Skin Exposure". The Annals of Occupational Hygiene 47(8): 591–593.

EPA, 2004. "Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)". Publication No. EPA/540/R/99/005; OSWER 9285.7-02EP; PB99-963312. Office of Superfund Remediation and Technology Innovation, U.S. Environmental Protection Agency . Available online at: //cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=183584&inclCol=eco. Accessed January 25, 2013.

Ignacio J.S. and W.H. Bullock (eds), 2006. "A Strategy for Assessing and Managing Occupational Exposures, Third Edition". Fairfax, Virginia: American Industrial Hygiene Association (AIHA) Press.

Kanerva, L., P. Elsner, J.E. Wahlberg, and H.I. Maibach, 2000. "Handbook of Occupational Dermatology". Berlin Heidelberg: Springer-Verlag.

Klingner, T.D. and M.F. Boeniger, 2002. "A Critique of Assumptions about Selecting Chemical-Resistant Gloves: A Case for Workplace Evaluation of Glove Efficacy". Applied Occupational and Environmental Hygiene 17(5): 360–367.

NIOSH 2205-110, 2004. "Specific Medical Tests or Examinations Published in the Literature for OSHA-Regulated Substances". DHHS (NIOSH) Publication No. 2005-110 (December). U.S. National Institute for Occupational Safety and Health. Available online at: //www.cdc.gov/niosh/docs/2005-110/medstart.html. Accessed January 25, 2013.

VanRooij, J.G., M.M. Bodelier-Bade, and F.J. Jongeneelen, 1993 "Estimation of Individual Dermal and Respiratory Uptake of Polycyclic Aromatic Hydrocarbons in 12 Coke Oven Workers." British Journal of Industrial Medicine 50(7): 623–632.

Vermeulen, R., R. Bos, J. Pertijs, and H. Kromhout, 2003. "Exposure Related Mutagens in Urine of Rubber Workers Associated with Inhalable Particulate and Dermal Exposure." Occupational and Environmental Medicine 60(2): 97–103.

Appendix A
Chemicals Noted for Skin Absorption

Table A-1. OSHA PELS and ACGIH TLVS With Skin Designations/Notations

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
1910	**1926/1915**	**TWA**	**STEL/C [See footnote 4]**		
Acetone cyanohydrin, as CN	75-86-5				C 5 mg/m^3
Acetonitrile	75-05-8			20 ppm	
Acrolein	107-02-8				C 0.1 ppm
Acrylamide	79-06-1	0.3 mg/m^3	SAME	0.03 mg/m^3	
Acrylic acid	79-10-7			2 ppm	
Acrylonitrile; see 1910.1045	107-13-1			2 ppm	
Adiponitrile	111-69-3			2 ppm	
Aldrin	309-00-2	0.25 mg/m^3	SAME	0.05 mg/m^3	
Allyl alcohol	107-18-6	2 ppm; 5 mg/m^3	SAME	0.5 ppm	

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
Allyl bromide	106-95-6			0.1 ppm	0.2 ppm
Allyl chloride	107-05-1			1 ppm	2 ppm
4-Aminodiphenyl; see 1910.1011	92-67-1			(L)	
Ammonium perfluorooctanoate	3825-26-1			0.01 mg/m^3	
Aniline and homologs	62-53-3	5 ppm; 19 mg/m^3	SAME	2 ppm	
Anisidine (o-, p-isomers)	29191-52-4	0.5 mg/m^3	SAME	0.5 mg/m^3	
ANTU (alpha Naphthylthiourea)	86-88-4			0.3 mg/m^3	
Azinphos-methyl	86-50-0	0.2 mg/m^3	SAME	0.2 mg/m^3 (IFV)	
Benzene; see 1910.1028. See Table Z-2 for the limits applicable in the operations or sectors excluded in 1910.1028(d)	71-43-2			0.5 ppm	2.5 ppm
Benzidine; See 1910.1010	92-87-5			(L)	
Benzotrichloride	98-07-7				C 0.1 ppm
Beryllium and beryllium compounds (as Be)	7440-41-7			0.00005 mg/m^3 I	
Bromoform	75-25-2	0.5 ppm; 5 mg/m^3	SAME	0.5ppm	
2-Butoxyethanol	111-76-2	50 ppm; 240 mg/m^3	SAME	20ppm	
n-Butylamine	109-73-9	(C)5 ppm; (C)15 mg/m^3	SAME		C 5ppm
tert-Butyl chromate (as CrO3); see 1910.1026	1189-85-1				C 0.1 mg/m^3

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
n-Butyl glycidyl ether (BGE)	2426-08-6			3 ppm	
o-sec-Butylphenol	89-72-5			5 ppm	
Captafol	2425-06-1			0.1 mg/m^3	
Carbaryl (Sevin)	63-25-2			0.5 mg/m^3 (IFV)	
Carbon disulfide	75-15-0		20 ppm; 60 mg/m^3	1 ppm	
Carbon tetrachloride	56-23-5		10 ppm; 65 mg/m^3	5 ppm 31 mg/m^3	10 ppm
Catechol	120-80-9			5 ppm	
Chlordane	57-74-9	0.5 mg/m^3	SAME	0.5 mg/m^3	
Chlorinated camphene	8001-35-2	0.5 mg/m^3	SAME	0.5 mg/m^3	1 mg/m^3
Chloroacetone	78-95-5				C 1 ppm
Chloroacetyl chloride	79-04-9			0.05 ppm	0.15 ppm
o-Chlorobenzylidene malononitrile	2698-41-1				C 0.05 ppm
Chlorodiphenyl (42% Chlorine) (PCB)	53469-21-9	1 mg/m^3	SAME	1 mg/m^3	
Chlorodiphenyl (54% Chlorine) (PCB)	11097-69-1	0.5 mg/m^3	SAME	0.5 mg/m^3	
1-Chloro-2-propanol	127-00-4			1 ppm	
2-Chloro-1-propanol	78-89-7			1 ppm	
beta-Chloroprene	126-99-8	25 ppm; 90 mg/m^3	SAME	10 ppm	
2-Chloropropionic acid	598-78-7			0.1 ppm	
Chlorpyrifos	2921-88-2			0.1 mg/m^3 (IFV)	

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
Citral	5392-40-5			5 ppm (IFV)	
Coumaphos	56-72-4			0.05 mg/m^3 (IFV)	
Cresol, all isomers	1319-77-3	5 ppm; 22 mg/m^3	SAME	20 mg/m^3 (IFV)	
Crotonaldehyde	4170-30-3				C 0.3 ppm
Cumene	98-82-8	50 ppm; 245 mg/m^3	SAME	50ppm	
Cyanides (as CN)	(4)	5 mg/m^3	SAME (1915 no skin designation)		
Cyclohexanol	108-93-0			50 ppm	
Cyclohexanone	108-94-1			20 ppm	50 ppm
Cyclonite	121-82-4		1.5 mg/m^3	0.5 mg/m^3	
2,4-D (Dichlorophen-oxyacetic acid)5	94-75-7	10 mg/m^3			
Decaborane	17702-41-9	0.05 ppm; 0.3 mg/m^3	SAME	0.05 ppm	0.15 ppm
Demeton (Systox)	8065-48-3	0.1 mg/m^3	SAME	0.05 mg/m^3 (IFV)	
Demeton-S-methyl	919-86-8			0.05 mg/m^3 (IFV)	
Diazinon	333-41-5			0.01 mg/m^3 (IFV)	
2-N-Dibutylaminoethanol	102-81-8			0.5 ppm	
Dibutyl phenol phosphate	2528-36-1			0.3 ppm	

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
Dibutyl phosphate	107-66-4			5 mg/m^3 (IFV)	
Dichloroacetic acid	79-43-6			0.5 ppm	
3,3'-Dichlorobenzidine; see 1910.1007	91-94-1			(L)	
1,4-Dichloro-2-butene	764-41-0			0.005 ppm	
Dichlorodiphenyltri-chloroethane (DDT)	50-29-3	1 mg/m^3	SAME		
Dichloroethyl ether	111-44-4	(C)15 ppm; (C)90 mg/m^3	SAME	5 ppm	10 ppm
1,3-Dichloropropene	542-75-6			1 ppm	
Dichlorvos (DDVP)	62-73-7	1 mg/m^3	SAME	0.1 mg/m^3 (IFV)	
Dicrotophos	141-66-2			0.05 mg/m^3 (IFV)	
Dieldrin	60-57-1	0.25 mg/m^3	SAME	0.1 mg/m^3 (IFV)	
Diesel fuel, as total hydrocarbons	68334-30-5; 68476-30-2; 68476-31-3; 68476-34-6; 77650-28-3			100 mg/m$^{3(IFV)}$	
Diethanolamine	111-42-2			1 mg/m^3 (IFV)	
Diethylamine	109-89-7			5 ppm	15 ppm
2-Diethylaminoethanol	100-37-8	10 ppm; 50 mg/m^3	SAME (1915 no skin designation)	2 ppm	
Diethylene triamine	111-40-0		(C)10 ppm; (C)42 mg/m^3	1 ppm	

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
Diisopropylamine	108-18-9	5 ppm; 20 mg/m^3	SAME	5 ppm	
Dimethyl acetamide	127-19-5	10 ppm; 35 mg/m^3	SAME	10 ppm	
bis(2-Dimethylaminoethyl)ether (DMAEE)	3033-62-3			0.05 ppm	0.15 ppm
Dimethylaniline (N,N-Dimethylaniline)	121-69-7	5 ppm; 25 mg/m^3	SAME	5 ppm	10 ppm
Dimethyl carbamoyl chloride	79-44-7			0.005 ppm	
Dimethyl-1,2-dibromo-2,2-dichloroethyl phosphate (Naled)	300-76-5			0.1 mg/m^3 (IFV)	
Dimethyl disulfide	624-92-0			0.5 ppm	
Dimethylformamide	68-12-2	10 ppm; 30 mg/m^3	SAME	10 ppm	
1,1-Dimethylhydrazine	57-14-7	0.5 ppm; 1 mg/m^3	SAME	0.01 ppm	
Dimethyl sulfate	77-78-1; 77-78-3	1 ppm; 5 mg/m^3	SAME	0.1 ppm	
Dinitrobenzene (all isomers)	528-29-0; 99-65-0; 100-25-4	1 mg/m^3	SAME	0.15 ppm	
Dinitro-o-cresol	534-52-1	0.2 mg/m^3	SAME	0.2 mg/m^3	
Dinitrotoluene	25321-14-6	1.5 mg/m^3	SAME	0.2 mg/m^3	
Dioxane (Diethylene dioxide)	123-91-1	100 ppm; 360 mg/m^3	SAME	20 ppm	
Dioxathion	78-34-2			0.1 mg/m^3 (IFV)	
Dipropylene glycol methyl ether (2-Methoxymethylethoxy)propanol)	34590-94-8	100 ppm; 600 mg/m^3	SAME	100 ppm	150 ppm

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
Diquat	2764-72-9; 85-00-7; 6385-62-2			0.5 mg/m^3 (I); 0.1 mg/m^3 (R)	
Disulfoton	298-04-4			0.05 mg/m^3 (IFV)	
Endosulfan	115-29-7		0.1 mg/m^3	0.1 mg/m^3 (IFV)	
Endrin	72-20-8	0.1 mg/m^3	SAME	0.1 mg/m^3	
Epichlorohydrin	106-89-8	5 ppm; 19 mg/m^3	SAME	0.5 ppm	
EPN	2104-64-5	0.5 mg/m^3	SAME	0.1 mg/m^3 (I)	
Ethion	563-12-2			0.05 mg/m^3 (IFV)	
2-Ethoxyethanol (Cellosolve)	110-80-5	200 ppm; 740 mg/m^3	SAME	5 ppm	
2-Ethoxyethyl acetate (Cellosolve acetate)	111-15-9	100 ppm; 540 mg/m^3	SAME	5 ppm	
Ethyl acrylate	140-88-5	25 ppm; 100 mg/m^3	SAME	5ppm	15ppm
Ethylamine	75-04-7			5 ppm	15 ppm
Ethyl bromide	74-96-4			5 ppm	
Ethyl chloride	75-00-3			100 ppm	
Ethylene chlorohydrin	107-07-3	5 ppm; 16 mg/m^3	SAME		C 1 ppm
Ethylenediamine	107-15-3			10 ppm	
Ethylene dibromide	106-93-4		(C)25 ppm; (C)190 mg/m^3	—	—

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
Ethylene glycol dinitrate	628-96-6	(C)0.2 ppm; (C)1 mg/m^3	SAME	0.05 ppm	
Ethyleneimine; see 1910.1012	151-56-4			0.05 ppm	0.1 ppm
N-Ethylmorpholine	100-74-3	20 ppm; 94 mg/m^3	SAME	5 ppm	
Fenamiphos	22224-92-6			0.05 mg/m^3 (IFV)	
Fensulfothion	115-90-2			0.01 mg/m^3 (IFV)	
Fenthion	55-38-9			0.05 mg/m^3 (IFV)	
Fonofos	944-22-9			0.1 mg/m^3 (IFV)	
Formamide	75-12-7			10 ppm	
Furfural	98-01-1	5 ppm; 20 mg/m^3	SAME	2 ppm	
Furfuryl alcohol	98-00-0			10 ppm	15 ppm
Heptachlor	76-44-8	0.5 mg/m^3	SAME	0.05 mg/m^3	
Heptachlor epoxide	1024-57-3			0.05 mg/m^3	
Hexachlorobenzene	118-74-1			0.002 mg/m^3	
Hexachlorobutadiene	87-68-3			0.02 ppm	
Hexachloroethane	67-72-1	1 ppm; 10 mg/m^3	SAME	1 ppm	
Hexachloronaphthalene	1335-87-1	0.2 mg/m^3	SAME	0.2 mg/m^3	
Hexafluoroacetone	684-16-2			0.1 ppm	

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
Hexamethyl phosphoramide	680-31-9			—	
n-Hexane	110-54-3			50 ppm	
2-Hexanone (Methyl n-butyl ketone)	591-78-6			5 ppm	10 ppm
Hydrazine	302-01-2	1 ppm; 1.3 mg/m^3	SAME	0.01 ppm	
Hydrogen cyanide [See footnote 6]	74-90-8	10 ppm; 11 mg/m^3	SAME		C 4.7 ppm
Hydrogen fluoride (as F)	7664-39-3			0.5 ppm	C 2 ppm
2-Hydroxypropryl acrylate	999-61-1			0.5 ppm	
Isooctyl alcohol	26952-21-6			50 ppm	
2-Isopropoxyethanol	109-59-1			25 ppm	
n-Isopropylaniline	768-52-5			2 ppm	
Kerosene/Jet fuels, as total hydrocarbon vapor	8008-20-6; 64742-81-0			200 mg/m^3 P	
Lindane	58-89-9	0.5 mg/m^3	SAME	0.5 mg/m^3	
Malathion Total dust	121-75-5	15 mg/m^3	SAME	1 mg/m^3 (IFV)	
Manganese cyclopentadienyl tricarbonyl, as Mn	12079-65-1			0.1 mg/m^3	
Mercury (as Hg)	7439-97-6	0.1mg/m^3	0.1 mg/m^3	0.1 mg/m^3	
Mercury (elemental and inorganic forms)	7439-97-6	0.1mg/m^3	0.1mg/m^3	0.025 mg/m^3	
Mercury (organo) alkyl compounds (as Hg)	7439-97-6	0.01mg/m^3	0.01 mg/m^3	0.01 mg/m^3	0.03 mg/m^3
Mercury (vapor) (as Hg)	7439-97-6	0.1mg/m^3	0.1 mg/m^3		

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
2-Methoxyethanol; (Methyl cellosolve)	109-86-4	25 ppm; 80 mg/m^3	SAME	0.1 ppm	
2-Methoxyethyl acetate (Methyl cellosolve acetate)	110-49-6	25 ppm; 120 mg/m^3	SAME	0.1 ppm	
Methyl acrylate	96-33-3	10 ppm; 35 mg/m^3	SAME	2 ppm	
Methylacrylonitrile	126-98-7			1 ppm	
Methyl alcohol	67-56-1			200 ppm	250 ppm
Methyl bromide	74-83-9	(C)20 ppm; (C)80 mg/m^3	SAME	1 ppm	
Methyl chloride	74-87-3			50 ppm	100 ppm
o-Methylcyclohexanone	583-60-8	100 ppm; 460 mg/m^3	SAME	50 ppm	75 ppm
2-Methylcyclopentadienyl manganese tricarbonyl, as Mn	12108-13-3			0.2 mg/m^3	
Methyl demeton	8022-00-2			0.05 mg/m^3 IFV	
4,4'-Methylene bis(2-chloroaniline)	101-14-4			0.01 ppm	
4,4'-Methylene dianiline	101-77-9			0.1 ppm	
Methyl hydrazine (Monomethyl hydrazine)	60-34-4	(C)0.2 ppm; (C)0.35 mg/m^3	SAME	0.01 ppm	
Methyl iodide	74-88-4	5 ppm; 28 mg/m^3	SAME	2 ppm	
Methyl isobutyl carbinol	108-11-2	25 ppm; 100 mg/m^3	SAME	25 ppm	40 ppm

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
Methyl isocyanate	624-83-9	0.02 ppm; 0.05 mg/m^3	SAME	0.02 ppm	
1-Methyl naphthalene	90-12-0			0.5 ppm	
2-Methyl naphthalene	91-57-6			0.5 ppm	
Methyl parathion	298-00-0			0.02 mg/m^3 (IFV)	
Methyl vinyl ketone	78-94-4				C 0.2 ppm
Monochloroacetic acid	79-11-8			0.5 ppm (IFV)	
Monocrotophos	6923-22-4			0.05 mg/m^3 (IFV)	
Monomethyl aniline (N-Methyl aniline)	100-61-8	2 ppm; 9 mg/m^3	SAME	0.5 ppm 2.2 mg/m^3	
Morpholine	110-91-8	20 ppm; 70 mg/m^3	SAME	20 ppm	
Naphthalene [See footnote 7]	91-20-3			10 ppm	15 ppm
Natural rubber latex, as inhalable allergenic proteins	9006-04-6			0.0001 mg/m^3 I	
Nicotine	54-11-5	0.5 mg/m^3	SAME	0.5 mg/m^3	
p-Nitroaniline	100-01-6	1 ppm; 6 mg/m^3	SAME	3 mg/m^3	
Nitrobenzene	98-95-3	1 ppm; 5 mg/m^3	SAME	1 ppm	
p-Nitrochlorobenzene	100-00-5	1 mg/m^3	SAME	0.1 ppm	
4-Nitrodiphenyl; see 1910.1003	92-93-3			(L)	

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
Nitroglycerin	55-63-0	(C)0.2 ppm; (C)2 mg/m^3	SAME	0.05 ppm	
N-Nitrosodimethylamine; see 1910.1016	62-75-9			(L)	
Nitrotoluene (all isomers)	88-72-2; 99-08-1; 99-99-0	5 ppm; 30 mg/m^3	SAME	2 ppm	
Octachloronaphthalene	2234-13-1	0.1 mg/m^3	SAME	0.1 mg/m^3	0.3 mg/m^3
Paraquat, respirable dust	4685-14-7; 1910-42-5; 2074-50-2	0.5 mg/m^3 0.1 mg/m^3 (R)	SAME		
Parathion	56-38-2	0.1 mg/m^3	SAME (1915 no skin designation)	0.05 mg/m^3 (IFV)	
Pentachloronaphthalene	1321-64-8	0.5 mg/m^3	SAME	0.5 mg/m^3	
Pentachlorophenol	87-86-5	0.5 mg/m^3	SAME	0.5 mg/m^3	
2,4-Pentanedione	123-54-6			25 ppm	
Phenol	108-95-2	5 ppm; 19 mg/m^3	SAME	5 ppm	
Phenothiazine	92-84-2			5 mg/m^3	
p-Phenylene diamine	106-50-3	0.1 mg/m^3	SAME	0.1 mg/m^3	
Phenyl glycidyl ether (PGE)	122-60-1			0.1 ppm	
Phenylhydrazine	100-63-0	5 ppm; 22 mg/m^3	SAME	0.1 ppm	
Phenyl mercaptan	108-98-5			0.1 ppm	
Phorate	298-02-2			0.05 mg/m^3 (IFV)	

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
Phosdrin (Mevinphos)	7786-34-7	0.1 mg/m^3	SAME	0.01 mg/m^3 (IFV)	
Picric acid	88-89-1	0.1 mg/m^3	SAME (1915 no skin designation)	0.1mg/m^3	
Propargyl alcohol	107-19-7		1 ppm	1 ppm	
Propylene glycol dinitrate	6423-43-4			0.05 ppm	
Propylene imine	75-55-8	2 ppm; 5 mg/m^3	SAME	0.2 ppm	0.4 ppm
Sodium fluoroacetate	62-74-8	0.05 mg/m^3	SAME	0.05 mg/m^3	
Sulprofos	35400-43-2			0.1 mg/m^3 (IFV)	
TEDP (Sulfotepp)	3689-24-5	0.2 mg/m^3	SAME	0.1 mg/m^3 (IFV)	
Temephos	3383-96-8			1 mg/m^3 (IFV)	
TEPP (Tetraethyl pyrophosphaate)	107-49-3	0.05 mg/m^3	SAME	0.01 mg/m^3 (IFV)	
Terbufos	13071-79-9			0.01 mg/m^3 (IFV)	
1,1,2,2-Tetrachloro-ethane	79-34-5	5 ppm; 35 mg/m^3	SAME	1 ppm	
Tetrachloronaphthalene	1335-88-2	2 mg/m^3	SAME	2 mg/m^3	
Tetraethyl lead (as Pb)	78-00-2	0.075 mg/m^3	0.1 mg/m^3	0.1 mg/m^3	
Tetrahydrofuran	109-99-9			50 ppm	100 ppm
Tetramethyl lead (as Pb)	75-74-1	0.075 mg/m^3	0.15 mg/m^3	0.15 mg/m^3	

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
Tetramethyl succinonitrile	3333-52-6	0.5 ppm; 3 mg/m^3	SAME	0.5 ppm	
Tetryl (2,4,6-Trinitro-phenylmethyl-nitramine)	479-45-8	1.5 mg/m^3	SAME	1.5mg/m^3	
Thallium, soluble compounds (as Tl)	7440-28-0	0.1 mg/m^3	SAME	0.02 mg/m^3 (I)	
Thioglycolic acid	68-11-1			1 ppm	
Tin, organic compounds (as Sn)	7440-31-5			0.1 mg/m^3	0.2 mg/m^3
o-Tolidine	119-93-7			—	
Toluene-2,4-diisocyanate (TDI) [See footnote 8]	584-84-9	(C)0.02 ppm; (C)0.14 mg/m^3		0.005 ppm	0.02ppm
o-Toluidine	95-53-4	5 ppm; 22 mg/m^3	SAME	2 ppm	
m-Toluidine	108-44-1			2 ppm	
p-Toluidine	106-49-0			2 ppm	
1,1,2-Trichloroethane	79-00-5	10 ppm; 45 mg/m^3	SAME	10 ppm	
Trichloronaphthalene	1321-65-9	5 mg/m^3	SAME	5 mg/m^3	
1,2,3-Trichloropropane [See footnote 9]	96-18-4			10 ppm	
Triethylamine	121-44-8			1 ppm	3 ppm
Trimellitic anhydride	552-30-7			0.0005 mg/m^3 IFV	0.002 mg/m^3 IFV
2,4,6-Trinitrotoluene (TNT)	118-96-7	1.5 mg/m^3	SAME	0.1 mg/m^3	

Substance	CAS Number [See footnote 1]	OSHA PELs [See footnote 2]		ACGIH TLVs [See footnote 3]	
Triorthocresyl phosphate	78-30-8			0.1 mg/m^3	
Vinyl cyclohexene dioxide	106-87-6			0.1 ppm	
m-Xylene α,α'-diamine	1477-55-0				C 0.1 mg/m^3
Xylidine	1300-73-8	5 ppm; 25 mg/m^3	SAME	0.5 ppm (IFV)	

[1] The chemical abstracts service (CAS) number is for information only. For an entry covering more than one metal compound measured as the metal, the CAS number for the metal is given - not CAS numbers for the individual compounds.

[2] The OSHA PELs provided under "1910" refer to General Industry, 29 CFR 1910.1000 Table Z-1; "1926" refers to Construction, 29 CFR 1926.55, Appendix A; and "1915" refers to Shipyards, 29 CFR 1915.1000. The PELs are 8-hour time-weighted average (TWA) concentrations unless otherwise noted; a (C) designation denotes a ceiling limit. They are to be determined from breathing-zone air samples. If an entry is only listed in mg/m^3, the value is exact; when listed with a ppm entry, it is approximate. "SAME" indicates the value for 1926 and 1915 is equal to that listed for 1910 unless otherwise noted.

[3] The ACGIH TLVs are from the ACGIH publication *2012 TLVs® and BEIs® Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices*. "TWA" refers to 8-hour, TWA concentrations; "STEL" refers to "short-term exposure limit," a 15-minute TWA concentration; "C" indicates ceiling limit; a concentration that should not be exceeded during any part of the working exposure; "I" indicates inhalable fraction (particle aerodynamic diameter ranging from 0 to 100 micrometers; "IFV" indicates inhalable fraction and vapor; "(L)" indicates exposures by all routes should be carefully controlled to levels as low as possible; "P" indicates application restricted to conditions in which there are negligible aerosol exposures; and "R" indicates respirable fraction (particle aerodynamic diameter ranging from 0 to 10 micrometers).

[4] Values in this column are STEL values unless noted as ceiling limits with a "C" preceding the value.

[5] See ACGIH 2012 NIC—proposed change to 10 mg/m^3 I (TWA) with skin designation.

[6] ACGIH separates this listing into "hydrogen cyanide" and "cyanide salts," while OSHA does not differentiate between the two. Only the hydrogen cyanide TLV is listed here.

[7] See ACGIH 2012 NIC—proposed change to 5 ppm (TWA) with skin designation, no STEL.

[8] See ACGIH 2012 NIC—proposed change to 0.001 ppm IFV (TWA), 0.003 ppm IFV (STEL), skin designation.

[9] See ACGIH 2012 NIC—proposed change to 0.05 ppm (TWA), removal of skin designation.

Appendix B
Biological Exposure Guidelines

Table B-1. Adopted Biological Exposure Indices (BEIs) – ACGIH (2012)

Chemical	CAS No.	Determinant	Sampling Time	BEI®	Notation

Chemical	CAS No.	Determinant	Sampling Time	BEI®	Notation
B = Background	*Ns = Nonspecific*	*Nq = Nonquantitative*		*Sq = Semi-quantitative*	
Acetone	67-64-1	Acetone in urine	End of shift	50 mg/L	Ns
Acetylcholinesterase inhibiting pesticides	N/A	Cholinesterase activity in red blood cells	Discretionary	70% of individual's baseline	Ns
Aniline	62-53-3	Aniline in urine1	End of shift	—	Nq
		Aniline released from hemoglobin in blood	End of shift	—	Nq
		p-Aminophenol in urine1	End of shift	50 mg/L	B, Ns, Sq
Arsenic, elemental and soluble inorganic compounds (excludes gallium arsenide and arsine)	7440-38-2	Inorganic arsenic plus methylated metabolites in urine	End of workweek	35 µg As/L	B
Benzene	71-43-2	S-Phenylmercapturic acid in urine	End of shift	25 µg/g creatinine	B
		t,t-Muconic acid in urine	End of shift	500 µg/g creatinine	B
1,3-Butadiene	106-99-0	1,2 Dihydroxy-4-(N-acetylcyteinyl)-butane in urine	End of shift	2.5 mg/L	B, Sq
		Mixture of N-1- and N-2-(hydroxybutenyl) valine hemoglobin (Hb) adducts in blood	Not critical	2.5 pmol/g Hb	Sq
2-Butoxyethanol	111-76-2	Butoxyacetic acid (BAA) in urine1	End of shift	200 mg/g creatinine	—
Cadmium and inorganic compounds	7440-43-9	Cadmium in urine	Not critical	5 µg/g creatinine	B
		Cadmium in blood	Not critical	5 µg/L	B

Chemical	CAS No.	Determinant	Sampling Time	BEI®	Notation
Carbon disulfide	75-15-0	2-Thioxothiazolidine-4-carboxylic acid (TTCA) in urine	End of shift	0.5 mg/g creatinine	B, Ns
Carbon monoxide	630-08-0	Carboxyhemoglobin in blood	End of shift	3.5% of hemoglobin	B, Ns
		Carbon monoxide in end-exhaled air	End of shift	20 ppm	B, Ns
Chlorobenzene	108-90-7	4-Chlorocatechol in urine1	End of shift at end of workweek	100 mg/g creatinine	Ns
		p-Chlorophenol in urine1	End of shift at end of workweek	20 mg/g creatinine	Ns
Chromium (VI), water soluble fume	N/A	Total chromium in urine	End of shift at end of workweek	25 µg/L	—
		Total chromium in urine	Increase during shift	10 µg/L	—
Cobalt	7440-48-4	Cobalt in urine	End of shift at end of workweek	15 µg/L	B
		Cobalt in blood	End of shift at end of workweek	1 µg/L	B, Sq
Cyclohexanol	108-93-0	1,2-Cyclohexanediol in urine [See footnote 1]	End of shift at end of workweek	—	Nq, Ns
		Cyclohexanol in urine1	End of shift	—	Nq, Ns

Chemical	CAS No.	Determinant	Sampling Time	BEI®	Notation
Cyclohexanone	108-94-1	1,2-Cyclohexanediol in urine [See footnote 1]	End of shift at end of workweek	80 mg/L	Ns, Sq
		Cyclohexanol in urine [See footnote 1]	End of shift	8 mg/L	Ns, Sq
Dichloromethane	75-09-2	Dichloromethane in urine	End of shift	0.3 mg/L	Sq
N,N-Dimethylacetamide	127-19-5	N-Methylacetamide in urine	End of shift at end of workweek	30 mg/g creatinine	—
N,N-Dimethylformamide (DMF)	68-12-2	N-Methylformamide in urine	End of shift	15 mg/L	—
		N-Acetyl-S-(N-methylcarbamoyl) cysteine in urine	Prior to last shift of workweek	40 mg/L	Sq
2-Ethoxyethanol (EGEE) and 2-Ethoxyethyl acetate (EGEEA)	110-80-5; 111-15-9	2-Ethoxyacetic acid in urine [See footnote 1]	End of shift at end of workweek	100 mg/g creatinine	—
Ethyl benzene3	100-41-4	Sum of mandelic acid and phenylglyoxylic acid in urine	End of shift at end of workweek	(0.7 g/g creatinine)	Ns (Sq)
		(Ethyl benzene in end-exhaled air)	(Not critical)	(—)	(Sq)
Fluorides	109-86-4	Fluoride in urine	Prior to shift	2 mg/L	B, Ns
		Fluoride in urine	End of shift	3 mg/L	B, Ns
Furfural	98-01-1	Furoic acid in urine [See footnote 1]	End of shift	200 mg/L	Ns
n-Hexane	110-54-3	2,5-Hexanedion in urine [See footnote 2]	End of shift at end of workweek	0.4 mg/L	—
Lead [See footnote 4]	7439-92-1	Lead in blood	Not critical	30 µg/100 ml	—

Chemical	CAS No.	Determinant	Sampling Time	BEI®	Notation
Mercury [See footnote 5]	N/A	(Total inorganic mercury in urine)	Prior to shift	(35 µg/g creatinine)	(B)
		(Total inorganic mercury in blood)	(End of shift at end of workweek)	(15 µg/L)	(B)
Methanol	67-56-1	Methanol in urine	End of shift	15 mg/L	B, Ns
Methemoglobin inducers	N/A	Methemoglobin in blood	During or end of shift	1.5% of hemoglobin	B, Ns, Sq
2-Methoxyethanol (EGME) and 2-Methoxyethyl acetate (EGMEA)	109-86-4 and 110-49-6	2-Methoxyacetic acid in urine	End of shift at end of workweek	1 mg/g creatinine	—
Methyl n-butyl ketone	591-78-6	2,5-Hexanedione in urine [See footnote 2]	End of shift at end of workweek	0.4 mg/L	—
Methyl chloroform	71-55-6	Methyl chloroform in end-exhaled air	Prior to last shift of workweek	40 ppm	—
		Trichloroacetic acid in urine	End of workweek	10 mg/L	Ns, Sq
		Total trichloroethanol in urine	End of shift at end of workweek	30 mg/L	Ns, Sq
		Total trichloroethanol in blood	End of shift at end of workweek	1 mg/L	Ns
4,4'-Methylene bis(2-chloroaniline) (MBOCA)	101-14-4	Total MBOCA in urine	End of shift	—	Nq
Methyl ethyl ketone (MEK) [See footnote 6]	78-93-3	MEK in urine	End of shift	2 mg/L	(—)
Methyl isobutyl ketone (MIBK)	108-10-1	MIBK in urine	End of shift	1 mg/L	(—)

Chemical	CAS No.	Determinant	Sampling Time	BEI®	Notation
N-Methyl-2-pyrrolidone	872-50-4	5-Hydroxy-N-methyl-2-pyrrolidone in urine	End of shift	100 mg/L	(—)
Naphthalene [See footnote 7]	91-20-3	1-Naphthol1 + 2-Naphthol [See footnote 1]	End of shift	—	Nq, Ns
Nitrobenzene	98-95-3	Total p-nitrophenol in urine	End of shift at end of workweek	5 mg/g creatinine	Ns
		Methemoglobin in blood	End of shift	1.5% of hemoglobin	B, Ns, Sq
Parathion	56-38-2	Total p-nitrophenol in urine	End of shift	0.5 mg/g creatinine	Ns
		Cholinesterase activity in red cells	Discretionary	70% of individual's baseline	B, Ns, Sq
Pentachlorophenol (PCP) [See footnote 8]	87-86-5	(Total PCP in urine)	(Prior to last shift of workweek)	(2 mg/g creatinine)	(B)
		(Free PCP in plasma)	(End of shift)	(5 mg/L)	(B)
Phenol	108-95-2	Phenol in urine [See footnote 1]	End of shift	250 mg/g creatinine	B, Ns
Polycyclic aromatic hydrocarbons (PAHs)	varies with the compound or mixture	1-Hydroxypyrene (1-HP) in urine [See footnote 1]	End of shift at end of workweek	—	Nq
2-Propanol	67-63-0	Acetone in urine	End of shift at end of workweek	40 mg/L	B, Ns
Styrene	100-42-5	Mandelic acid plus phenylglyoxylic acid in urine	End of shift	400 mg/g creatinine	Ns
		Styrene in venous blood	End of shift	0.2 mg/L	Sq

Chemical	CAS No.	Determinant	Sampling Time	BEI®	Notation
Tetrachloroethylene	127-18-4	Tetrachloroethylene in end-exhaled air	Prior to shift	3 ppm	—
		Tetrachloroethylene in blood	Prior to shift	0.5 mg/L	—
Tetrahydrofuran	109-99-9	Tetrahydrofuran in urine	End of shift	2 mg/L	—
Toluene	108-88-3	Toluene in blood	Prior to last shift of workweek	0.02 mg/L	—
		Toluene in urine	End of shift	0.03 mg/L	—
		o-Cresol in urine [See footnote 1]	End of shift	0.3 mg/g creatinine	B
Toluene diisocyanate9	584-84-9; 91-08-7	Toluene diamine in urine [See footnote 1]	End of shift	5 µg/g creatinine	Ns
Trichloroethylene	79-01-6	Trichloroacetic acid in urine	End of shift at end of workweek	15 mg/L	Ns
		Trichloroethanol in blood [See footnote 1]	End of shift at end of workweek	0.5 mg/L	Ns
		Trichloroethylene in blood	End of shift at end of workweek	—	Sq
		Trichloroethylene in end-exhaled air	End of shift at end of workweek	—	Sq
Uranium	7440-61-1	Uranium in urine	End of shift	200 µg/L	—
Xylenes (technical or commercial grade)	95-47-6; 108-38-3; 106-42-3; 1330-20-7	Methylhippuric acids in urine	End of shift	1.5 g/g creatinine	—

[1] Denotes with hydrolysis.

[2] Denotes without hydrolysis; n-hexane, methyl n-butyl ketone and trichloroethylene.

[3] 2012 Notice of Intended Changes (NIC) revises ethyl benzene entry as follows: Sum of mandelic and phenylglyoxylic acids in urine; end of shift at end of workweek; 0.15 g/g creatinine; Ns.

[4] Note: Women of childbearing potential, whose blood Pb exceeds 10 µg/dl, are at risk of delivering a child with a blood Pb over the current Centers for Disease Control guideline of 10 µg/dl. If the blood Pb of such children remains elevated, they may be at increased risk of cognitive deficits. The blood Pb of these children should be closely monitored and appropriate steps should be taken to minimize the child's exposure to environmental lead. (CDC: Preventing Lead Poisoning in Young Children, October 1991; See BEI® and TLV® *Documentation* for Lead).

[5] 2012 NIC revises mercury entry as follows: Mercury in urine; prior to shift; 20 µg Hg/g creatinine.

[6] 2012 NIC revises methyl ethyl ketone entry as follows: Methyl ethyl ketone in urine; end of shift; 2 mg/L; Ns.

[7] 2012 NIC revises naphthalene entry as follows: 1-Naphthol (with hydrolysis) + 2-Naphthol (with hydrolysis); end of shift; no BEI®; Nq, Ns.

[8] 2012 NIC revises pentachlorophenol entry as follows: Pentachlorophenol (with hydrolysis) in urine; discretionary; no BEI®; Nq.

[9] 2012 NIC revises toluene diisocyanate entry as follows: Toluene diamine in urine (with hydrolysis) (sum of 2,4- and 2,6- isomers); end of shift; 5 µg/g creatinine; Ns.

Table B-2. OSHA General Industry Standard-Specific Biological Monitoring Requirements (29 CFR 1910)

OSHA Standard	Substance	Analyte(s)	Monitoring Frequency
Note: *This table provides a summary of biological monitoring requirements. For detailed information, refer to the listed standard.*			
1910.1017	Vinyl chloride	Serum specimen testing for: ▪ Total bilirubin ▪ Alkaline phosphatase ▪ Serum glutamic oxalacetic transaminase (SGOT) ▪ Serum glutamic pyruvic transaminase (SGPT) ▪ Gamma glustamyl transpeptidase	For workers exposed above the action level: ▪ Initial medical examination ▪ Every 6 months for each employee who has been employed in vinyl chloride or polyvinyl chloride manufacturing for 10 years or longer. ▪ Annually for all other employees. ▪ After exposure during emergency situations.

OSHA Standard	Substance	Analyte(s)	Monitoring Frequency
1910.1025	Lead	Blood sample testing for: ▪ Blood lead ▪ Zinc protoporphyrin (ZPP)	For workers who are or may be exposed at or above the action level for more than 30 days per year: ▪ At least every six months ▪ At least every two months for each worker whose last blood sampling and analysis indicated a blood lead level at or above 40 µg/100 g of whole blood (continuing until two consecutive blood samples and analyses indicate a blood lead level below 40 µg/100 g of whole blood). ▪ Within two weeks after receipt of results indicating a blood lead level exceeding the numerical criterion for medical removal (60 µg/100 g of whole blood). ▪ At least monthly during the removal period of each worker removed from exposure to lead due to an elevated blood lead level.
		Blood sample testing for: ▪ Blood lead ▪ Hemoglobin and hematocrit determinations, red cell indices, and examination of smear morphology. ▪ ZPP ▪ Blood urea nitrogen ▪ Serum creatinine ▪ Regular urinalysis with microscopic examination.	For workers who are or may be exposed at or above action level for more than 30 days per year: ▪ Initial exam ▪ Annually, if blood lead level is at or above 40 µg/100 g of whole blood at any time in the preceding 12 months.

OSHA Standard	Substance	Analyte(s)	Monitoring Frequency
		Pregnancy testing or laboratory evaluation of male fertility, if requested by worker.	▪ As soon as possible upon notification by worker of development of signs/symptoms of lead intoxication, worker desires medical advice on effects of current/past exposure on ability to procreate a healthy child, or worker has demonstrated difficulty in breathing during a respirator fitting test or during use. ▪ As medically appropriate for worker removed from exposure due to risk of material impairment of health or otherwise limited pursuant to final medical determination.
1910.1027	Cadmium	Urine testing for: ▪ Cadmium in urine (CdU), standardized to grams of creatinine (g/Cr) ▪ Beta-2 microglobulin in urine (B(2)-M), standardized to grams of creatinine (g/Cr), with pH specified Blood sample testing for: ▪ Cadmium in blood (CdB), standardized to liters of whole blood (lwb)	For currently and/or previously exposed workers, as specified in the standard: ▪ Initial exam ▪ At least annually
		During required periodic medical examinations workers should be additionally tested for: ▪ Blood urea nitrogen ▪ Complete blood count ▪ Serum creatinine ▪ Urinalysis – additional testing for albumin, glucose, and total and low molecular weight proteins.	▪ Within one year after initial exam, and at least biennially thereafter. ▪ At varying follow-up frequencies depending on whether currently or previously exposed and biological monitoring findings, as specified in the standard. ▪ After acute exposure during emergency situations. ▪ Upon termination, as specified in the standard.

OSHA Standard	Substance	Analyte(s)	Monitoring Frequency
1910.1028	Benzene	Complete blood count testing for: ▪ Leukocyte count with differential ▪ Quantitative thrombocyte count ▪ Hematocrit ▪ Hemoglobin ▪ Erythrocyte count and erythrocyte indices	For workers exposed under the exposure scenarios specified in the standard: ▪ Initial exam ▪ Annually ▪ Complete blood count repeated within two weeks of initial or periodic examination results indicating abnormal blood conditions specified in the standard.
		After exposure during emergency situations: ▪ Urinary phenol test (to be performed on end-of-shift urine sample within 72 hours of the emergency exposure).	After exposure during emergency situations: ▪ Complete blood count tests monthly for three months following exposure if phenol test is ≥ 75 mg phenol/Liter of urine.
1910.1029	Coke oven emissions	Urinalysis testing for: ▪ Sugar ▪ Albumin ▪ Hematuria Urinary cytology examination	For workers working in regulated areas at least 30 days per year: ▪ Initial exam ▪ Annual urinalysis testing ▪ Annual urinalysis testing plus urinary cytology examination for workers ≥ 45 years old or with ≥ five years employment in regulated areas. ▪ Upon termination if worker has not had examination within preceding six months.
1910.1030	Bloodborne pathogens	Blood sample testing for: ▪ Hepatitis B virus (HBV) and human immunodeficiency virus (HIV) (source individual) ▪ HBV and HIV (exposed individual)	Immediately after an exposure incident: ▪ Source individual - As soon as feasible, provided consent is obtained as necessary. ▪ Exposed worker - As soon as feasible after consent is obtained. If consent is not obtained for HIV serologic testing at time of baseline blood collection, the sample shall be preserved for at least 90 days, during which time it shall be tested as soon as feasible if consent is obtained.

OSHA Standard	Substance	Analyte(s)	Monitoring Frequency
1910.1044	1,2-Dibromo-3-chloropropane (DBCP)	Serum specimen testing for: ▪ Serum follicle stimulating hormone (FSH) ▪ Serum luteinizing hormone (LH) ▪ Serum total estrogen (females) Sperm count	For workers in regulated areas: ▪ Initial exam ▪ Annually
		After exposure during emergency situations: ▪ Sperm count or above hormone tests if worker has vasectomy or is unable to produce semen.	After exposure during emergency situations: ▪ As soon as practicable after exposure and repeated three months after exposure.
1910.1045	Acrylonitrile	Test of the intestinal tract, including fecal occult blood screening (for all workers 40 years of age or older, and for any other affected workers for whom, in the opinion of the physician, such testing is appropriate*).*	For workers who are or will be exposed at or above the action level: ▪ Initial exam ▪ Annually ▪ Upon termination if worker has not had examination within preceding six months.

OSHA Standard	Substance	Analyte(s)	Monitoring Frequency
1910.1047	Ethylene oxide (EtO)	Complete blood count testing for: ▪ White cell count (including differential cell count). ▪ Red cell count ▪ Hematocrit ▪ Hemoglobin	For workers who are or may be exposed at or above the action level for at least 30 days per year: ▪ Initial exam ▪ Annually ▪ At termination, or at reassignment to an area without such exposures. After exposure during emergency situations, as medically appropriate. As soon as possible after notification by a worker: ▪ Of development of signs or symptoms indicating possible overexposure. ▪ That worker desires medical advice concerning the effects of current or past exposure to EtO on the worker's ability to produce a healthy child.
1910.1050	Methylenedianiline (MDA)	▪ Liver function tests ▪ Urinalysis	For workers exposed at or above the action level for at least 30 days per year, subject to dermal exposure at least 15 days per year, or whom employers have reason to believe are being dermally exposed: ▪ Initial exam ▪ Annually After exposure during emergency situations and when workers develop signs/symptoms of exposure: ▪ Initial exam ▪ Repeat liver function tests on physician's advice. If tests are normal, repeat two to three weeks after initial tests. If both are normal, no further testing is required.

OSHA Standard	Substance	Analyte(s)	Monitoring Frequency
1910.1051	1,3-Butadiene (BD)	Complete blood count with differential and platelet count.	Annually for workers exposed at or above the action level for at least 30 days per year; or at or above the PELs for at least 10 days per year; Annually for workers even after transfer to non-BD exposure jobs (regardless of when transferred) if work history suggests BD exposure: ▪ At or above the PELs on ≥ 30 days per year for 10 or more years. ▪ At or above the action level for ≥ 60 days per year for 10 or more years. ▪ Above 10 ppm for ≥ 30 days in any past year. After exposure during emergency situations ▪ As quickly as possible, but no later than 48 hours after an emergency exposure, then monthly for three months.

OSHA Standard	Substance	Analyte(s)	Monitoring Frequency
1910.1052	Methylene chloride (MC)	The physician or other licensed healthcare professional shall determine the extent of any required laboratory surveillance based on the worker's observed health status and the medical and work history.	For workers exposed: at or above the action level for at least 30 days per year; at or above the eight-hour TWA PEL or the STEL for at least 10 days per year; or above the eight-hour TWA PEL or STEL for any length of time where a worker has been identified as being at risk from cardiac disease or some other serious MC-related health condition (and requests inclusion in the medical surveillance program): ▪ Initial exam ▪ Within 12 months of last surveillance for worker's age 45 years or older, or within 36 months of last surveillance for worker's less than 45 years old. ▪ Upon termination, or reassignment to an area with MC exposure consistently at or below the action level and STEL if the worker has not had surveillance within the preceding six months. ▪ Additional surveillance at frequency (other than above) when recommended in written medical opinion.
		After exposure during emergency situations (laboratory surveillance as indicated by the worker's health status).	After exposure during emergency situations.

Appendix C
Procedures for Collecting Wipe Samples

1. General Procedures for Collecting Wipe Samples
   Preloading a group of vials with sampling filters (consult the CSI files to determine the appropriate sampling media to use) is a convenient method to carry the sample media to the worksite. Note: Smear tabs should be inserted with the tab end out. Clean disposable gloves should be worn when handling the filters and smear tabs. The gloves should not be powdered.

   The following are general recommendations for taking wipe samples. Consult the CSI files for more specific instructions.

   - Record each location where a wipe sample was taken. Photographs, sketches, diagrams and other means of noting sampling locations are helpful.

- A new set of clean, disposable, powder-free gloves should be used for each sample to avoid contamination of the filter by previous samples (and the possibility of false positives) and to prevent contact with the substance.
- Withdraw the filter from the vial with your fingers or clean tweezers. If a damp wipe sample is desired, moisten the filter with distilled water or other solvent as recommended. Note: For skin sampling use only distilled water. Other solvents may be appropriate for wiping surfaces depending upon the type of chemical being sampled.
- Depending on the purpose of the sample, it may be useful to determine the concentration of contamination (e.g., in micrograms of agent per area). For these samples, it is necessary to record the area of the surface wiped (e.g., 100 cm^2).
- Firm pressure should be applied when wiping.
- Using the filter, wipe an area about 100 cm^2, rubbing the entire area side to side, then up and down. In many cases (such as knobs and levers) it may not be possible to wipe 100 cm^2. Where a precise determination of the contaminant loading (concentration) is desired, prepare single-use 10-cm x 10-cm templates from cardstock or file folders.
- Place the filter in a sample vial, cap and number it, and note the number at the sample location. Include notes which will provide any additional relevant details regarding the nature of the sample (e.g., "Fred Worker's respirator, inside"; "Lunch table").
- At least one blank filter treated in the same fashion, but without wiping, should be submitted for each sampled area.
- Some substances (e.g., benzidine, hexavalent chromium, and 4,4'-methylenedianiline) are unstable and may require a solution to be added to the vial as soon as the wipe sample is placed in the vial or may require other special sample handling. If such instability is suspected, check the CSI file for sample handling instructions or contact the SLTC for guidance.
- Submit the samples, each sealed with a Form OSHA-21, and in accord with any special procedures located in OTM Section II Chapter 4 (Sample Shipping and Handling), to the SLTC. Properly document the samples by completing the OIS sampling worksheet.

> Successful wipe sampling requires preparation and careful technique. It is best to practice these techniques in the office or other clean area before collecting samples in the field. Practice will enable the CSHO to get a sense of how much to wet the wipe, how delicate the wipes are, how to apply uniform pressure when wiping the surface, how to wipe evenly across the area to be sampled, how to fold the wipe to expose a clean surface for conducting a second pass, how to handle the wipes with tweezers or forceps, and how to avoid contaminating one’s gloves while sampling.

2. Wipe Sampling Procedures for Hexavalent Chromium
   Special wipe sampling techniques are necessary to prevent decomposition of hexavalent chromium (Cr(VI)) to trivalent chromium (Cr(III)) on the sampling media.

   - For wipe sampling on smooth surfaces, use 37-mm diameter PVC filters with 5-µm pore size (MSA part # 625413).
   - For wipe sampling on rough surfaces where PVC would be likely to tear, use 37-mm diameter binderless quartz fiber filters 0.45-mm thick (SKC part # 225-1809).
   - For chrome plating operations, to prevent decomposition of Cr(VI) to Cr(III) use:
   - Binderless quartz fiber filters *coated* with 1percent sodium hydroxide (NaOH). These filters do not require extraction in the field and are preferred for sample stability. Caution: Do not use coated quartz fiber filters for any operation other than chromium plating.

- PVC or uncoated binderless quartz fiber filters. *Immediately after sampling*, place the filter into a vial containing 5 mL of an aqueous stabilizing solution containing 10 percent sodium carbonate (Na_2CO_3) with 2 percent sodium bicarbonate ($NaHCO_3$) to eliminate the interference from the acid used in the chrome plating process.
- Always wear gloves when handling NaOH-treated filters due to their caustic nature. PVC or nitrile gloves are suggested based on review of chemical resistance data.
- Use clean polytetrafluoroethylene (PTFE)-coated (e.g., Teflon-coated) or plastic tweezers. Do not use metal tweezers to handle the filters as they will deposit Cr(VI) onto filters.
- Before sampling, label 20-mL glass scintillation vials with PTFE lined caps, one for each sample, and each with a unique sample number. These vials should be empty and dry. Exception: If using PVC or uncoated binderless quartz fiber filters for chrome plating operations, prefill the vials with 5 mL of stabilizing solution (10 percent Na_2CO_3 with 2 percent $NaHCO_3$).
- Prepare a diagram of the area or rooms to be wipe-sampled along with the locations of key surfaces.
- Use un-wetted filters to avoid interferences due to possible metals contamination in tap water.
- Wipe an area of known dimension such as a 10-cm x 10-cm square area.
- Record the surface area sampled on the OIS sampling worksheet when concentration determination is desired.
- Apply firm pressure when wiping. Start at the outside edge and progress toward the center making concentric squares of decreasing size. Fold the filter with the contaminant side inward and repeat.
- Without allowing the filter to come into contact with any other surface, fold the filter with the exposed side inward. Place the filter in a sample vial and cap.
- Place a corresponding number at the sample location on the diagram. Include notes with the sketch giving any further description that may prove useful when evaluating the sample results (e.g., a description of the surface sampled such as pencil, doorknob, safety glasses, lunch table, inside respirator, worker names, etc.).
- Submit at least one blank wipe filter, treated in the same fashion as the other samples, but without wiping.
- Record sample location, workers' names, surface area, work description, type of operation, PPE, and any other necessary information, along with any potential interferences on the OIS sampling worksheet.
- Submit the samples to the SLTC together with the OIS sampling worksheets as soon as possible after sampling. Ship any bulk samples separate from the surface samples. Note: Wipe samples taken in chromium plating and welding operations should be shipped to the SLTC within 24 hours after sampling by overnight delivery.

Appendix D
Combustible Dust Bulk Sampling

Combustible dust sampling is conducted where the potential for rapid burning (deflagration) or violent burning with rapid release of pressure (explosion) is suspected due to the presence of accumulations of settled dust. **Non-ferrous metals are especially hazardous and must be collected according to regional CSHO safety and health program policies and procedures.** In general, a thickness greater than 1/32 of an inch is cause for concern when the surface area covered by settled dust exceeds 5% of the floor area in a given room. The 5% factor should not be used if the floor area exceeds 20,000 square feet (ft^2), in which case a 1,000 ft^2 layer of dust is the upper limit. Accumulations on overhead beams, joists, ducts, the tops of equipment, and other surfaces, including vertical surfaces, should be included when determining the dust coverage area. Note that the available surface area of bar joists is approximately five percent of the floor area and the equivalent surface area for steel beams can be as high as 10%. Further detail is included in the compliance directive for the Combustible Dust National Emphasis Program (CPL 03-00-008).

Examples of combustible dust include but are not limited to:

- Metal dust such as aluminum and magnesium
- Wood dust
- Coal and other carbon dusts
- Plastic dust and additives
- Biosolids
- Other organic dust such as sugar, flour, paper, soap, and dried blood
- Certain textile materials

Examples of industries that handle combustible dusts: agriculture, food products, chemicals, textiles, forest and furniture products, wastewater treatment, metal processing, tire and rubber manufacturing plants, paper products, pharmaceuticals, wastewater treatment, recycling operations (metal, paper, and plastic), and coal handling and processing facilities.

***Examples of OSHA standards applicable to combustible dust hazards*:**

- 29 CFR 1910.22, Walking-Working Surfaces
- 29 CFR 1910.176(c), Materials Handling and Storage
- 29 CFR 1910.272, Grain Handling Facilities
- 29 CFR 1910.307, Electrical, Hazardous (Classified) Locations
- 29 CFR 1910.269 (v)(11)(xii), Electric Power Generation, Transmission, Distribution
- 29 CFR 1910.1200, Hazard Communication Standard
- Section 5(a)(1) of the Occupational Safety and Health Act, the General Duty Clause, may used to cite deflagration, other fire, or explosion hazards where combustible dust hazards exist within dust control systems or other containers.

Personal Protective Equipment (PPE): To conduct combustible dust sampling, CSHOs shall wear non-spark producing clothing such as natural fiber (e.g., cotton). CSHOs should also be equipped with flame-resistant (FR) clothing as appropriate. Other PPE for the reduction of static electric discharge includes conductive gloves and electrostatic dissipative (ESD) footwear without metal eyelets. Note: CSHOs should not rely on ESD footwear as being effective in all environments. Accumulation of debris, wax, and other high resistivity materials will compromise the conductivity of any floor. Conductive footwear should not be used where the potential for electric shock by line voltage exists.

Cameras: In areas classified as requiring intrinsically safe equipment, use only cameras that are intrinsically safe. If not available, either portray the scene with a sketch or use the zoom lens to take photos from a safe location. In areas that are not classified, the low energy levels produced by use of a regular camera will not normally present a hazard when dust concentrations in the air are below an OSHA PEL. If the dust levels in the air necessitate the use of a respirator, DO NOT USE YOUR CAMERA.

Safe Practices:

- If CSHOs find that there are potential combustible dust hazards, dust samples must be safely collected. Written statements should be taken from workers and employers regarding the properties of the combustible metals and any hazardous conditions present, such as but not limited to:
- Any history of fires/explosions/deflagrations involving combustible metals of concern (e.g. aluminum, magnesium, titanium, tantalum, niobium, zirconium, others). *If a fire, explosion, or deflagration has previously occurred at the establishment related to the handling of a combustible metal, document the occurrence and circumstances involved through the interview process. If a material has shown to be combustible at the establishment, there may not be a need for obtaining a bulk sample.*
- The experienced consistency/size fraction of the combustible metals of concern. *Interview the workers charged with emptying the collection bins beneath the dust collection devices. Document their experience regarding the particle size of the metal being collected. Common materials and their size are:*

- *White granulated sugar: 450 to 600 microns*
- *Table salt: 100 microns*
- *Flour: 1 to 100 microns*
- *Sand: 50 plus microns*
- *Talcum powder: 10 microns*

- The results of any previous combustible metals sampling conducted or commissioned by the employer*. If the employer has previously conducted combustibility testing, obtain the results for the file.*
- Material Safety Data Sheet (MSDS) or Safety Data Sheet (SDS) identification of metal material(s), SDS warnings or other instructions. *Obtain MSDSs or SDSs for the materials being utilized at the establishment for the file.*
- Do not collect a sample from an area unless a safe means of access is available.
- Take all precautions necessary to avoid the generation of a dust cloud while collecting a sample.
- Use conductive nonsparking tools when collecting samples. If possible, bond and ground the tools.
- Do not use plastic bags, as they cannot be sealed tightly enough to avoid sample leakage or moisture loss, and may cause a bellows effect resulting in airborne exposure during sample handling.

***Sample Collection Equipment may include*:**

- Natural bristle hand brushes for collecting settled dust.
- Non-sparking conductive dust pans (aluminum) for collecting settled dust.
- Non-spark producing sample container (1-Liter nonconductive plastic bottle, obtained locally or from the SLTC).
- Non-spark producing funnel for filling sample containers.
- Non-spark producing scoops for removing dust from cyclone containers or other ventilation equipment.

Sampling locations:

- Observe and document areas where the dust layer exceeds 1/32 inch in thickness, approximately the thickness of a small paper clip.
- Collect separate samples from:
- Equipment and floors where dust has accumulated. Note that samples collected at floor level present a significantly reduced potential for dust cloud generation.
- "High spaces" such as roof beams, open web beams, and other ceiling supports; tops of pipes, railings, ductwork, conduit, electrical boxes/panels and other horizontal surfaces located as high in the overhead as possible. Samples collected from elevated surfaces present a significantly greater potential for dust cloud generation from the inadvertent falling of material. High spaces are the preferred location for collecting samples, so long as there is a means of safe access.
- The interior (i.e., bins and/or bags) of a dust collector.
- Within ductwork.
- Avoid taking samples in close proximity of recognized ignition sources such as open flames, motors, electrical equipment, equipment bearings, etc.

Procedures:

- Use the correct equipment for collecting dust samples (see sample collection equipment above).
- Avoid contaminating the sample with other substances (some contaminants lead to underreporting of the explosiveness of the dust sampled).
- Collect at least 1 Liter of dust per sample.
- One sample of each type dust is sufficient.
- Each type dust must be collected as separate sample.
- Dust from several locations can be pooled into one sample container IF it is all the same type of dust.
- Several tests are conducted from the same bulk sample.

- If possible, collect the sample from the highest elevated horizontal surfaces in the plant. Finer particles more easily ignite and tend to collect on elevated surfaces.
- Determine if there is a hybrid mixture of combustible dust with a flammable gas or vapor.
- If it is grain dust, send an additional sample for percent (%) combustible analysis.
- Affix an OSHA-21 sample identification seal to the container. To seal the bottle, apply one end of the seal to the center of the lid, and run the seal down the edge of the lid and as far down the side of the bottle as it will reach.
- Document where, when, and how dust is used and/or generated. Document the description of the operation and the requested tests on the OIS sampling worksheet as follows:
- When requesting analyses for fire or explosion hazards that may result from housekeeping, 5(a)(1), or 29 CFR 1910.37 (Means of Egress) violations, write Kst.
- Where 29 CFR 1910.307 (Hazardous Locations) violations are a concern, write "Potential Class II Dust." This test must be done to support a citation for Class II hazardous (classified) locations. Note: This test only applies to electrical ignition sources in Class II locations. When in doubt, contact the SLTC.
- The Area Director must review the sampling plan and the number of samples being submitted. A concurrence letter is required due to the resource-intensive nature of these laboratory tests.
- Ship the sample with the paperwork (including the MSDS/SDS) in a box to SLTC. Note: No special DOT shipping requirements apply; however, when shipping metal dusts, especially dusts involving aluminum or magnesium, CSHOs should verify with the shipping company whether any special shipping requirements apply.

The hazard communication standard was revised in 2012. Safety Data Sheets (SDSs) will replace MSDSs. SDSs have a standardized 16-section format with specific information required in each section. Manufacturers and importers have until June 1, 2015 to replace MSDSs with SDSs, and until then a mixture of MSDSs and SDSs may be received by employers.

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